Integrated Science 13

Nima Rezaei *Editor*

Integrated Education and Learning

Springer

Integrated Science

Volume 13

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ISSN 2662-9461 ISSN 2662-947X (electronic)
Integrated Science
ISBN 978-3-031-15962-6 ISBN 978-3-031-15963-3 (eBook)
https://doi.org/10.1007/978-3-031-15963-3

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

This book series would not have been possible without the continuous encouragement of my family. I dedicate this book series to my daughters, Ariana and Arnika, hoping that integrated science could solve complex problems and make a brighter future for the next generation.

Preface

It has been a long practice since becoming a literate person was one's ultimate wish. With many efforts developed for the improvement of literacy rate by educational systems and policies, global literacy has noticeably risen–so, fewer than one in every seven of you reading this preface has a grandma who is illiterate and is always sweetly asking that you read her book of interest for her.

Movements and programs have frequently been local and community-based, with the goal of improving literacy in specific dimensions and for specific purposes, such as reducing disparities, discrimination, and crimes, employing kinesthetic intelligence to improve youth motor skills and engagement in physical activities and fitness, increasing teaching interest and developing effective teachers, or nurturing social and emotional intelligence and encouraging subjects to participate in group and teamwork activities, to name a few.

Today, becoming a scientifically literate person has become a challenge to educational systems. To read is good, but to read in science is different. To write is good, but to write for science is different. It would be simple to see these discrepancies while approaching the sea's surface, which has always been calm–under times of significant uncertainty, a crisis, for example, individuals cannot make efficient judgments. Such incompetent decision-making capacities are rooted in that the education once they had received was not suitable for their future, i.e., now. The main challenges to the twenty-first-century science education consist in a rigorous methodology of education that may be not suitable for all individuals, teacher/instructor-centered education that is often vulnerable to neglecting students' needs being related to the teacher or with their peers, and pure or formal science-focused education that students often fail to relate that with the society and their real-life and thus feel alienated and are reluctant to learn it and in the worst case become deviated from that educational environment.

Integrated Education and Learning deals with the problem by promoting creative and critical thinking skills. For this purpose, it provides an environment where the nature of science is not treated in a top-down relationship with that of art, but science is an art to acquire knowledge, and art is a science to transfer knowledge.

Tehran, Iran
April 2022

Nima Rezaei M.D., Ph.D.

Acknowledgments I would like to express my gratitude to the Editorial Assistant of this book series, Dr. Amene Saghazadeh. Without a doubt, the book would not have been completed without her contribution.

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1 Introduction to Integrated Education and Learning

Nima Rezaei and Amene Saghazadeh

We do not need Departments of Commerce, Labor, and Education; we need a single Department of Skills that will promote an integrated approach to global competitiveness.

Lou Gerstner

Summary

An introduction to the content of *Integrated Education and Learning* is presented in this Chapter, mainly including methods (transdisciplinary, linking, and networking), important topics for consideration (early childhood education, environment, play, native language and local culture, emotions and emotion regulation, and art experiences), challenges (gender and racial differences), teaching requirements, and other factors that enhance success in *Integrated Education and Learning*.

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N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_1

Graphical Abstract/Art Performance

Integrated education and learning.

(Adapted with permission from the Health and Art (HEART), Universal Scientific Education and Research Network (USERN); Painting by Mahdis Pouya).

Keywords

Education · Integrated education and learning · Learning

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

An integrated education and learning program promises to cultivate the 21st-century-demanding skills and knowledge and to provide integrated instruction and curriculum [1]. It should also prepare all teachers working to care about all students. As summarized in Table 1, "education" and "learning" occur together in more than 80% of uses, either in scientific research or for general purposes. However, they remain far from being integrated effectively with each other in educational settings and learning environments and systems.

Table 1 Number of search results using the keywords "education", "learning", and their combination recorded on March 26, 2022

Engine	Keyword(s)	Results
Google Scholar	"Education"	6,700,000
	"Learning"	7,070,000
	"Education" "Learning"	5,600,000
Google	"Education"	6,270,000,000
	"Learning"	7,180,000,000
	"Education" "Learning"	5,960,000,000

1.1 The Train is on Its Way

"Changing" is a fundamental element that develops the personality and sustains it over the times and spaces that are otherwise difficult to manage. The more one's life dimensions are affected and the larger the scale they welcome changes, the higher the likelihood their owner will succeed to manage and lead herself/himself on the horizon of the perfect, where others are reflected in and constitute her/his identity. From feeling a push to change to deciding to change is a distance, so is from doing a change to practicing more and more changes–i.e., from a novice who is afraid of changing to becoming an expert who likes change. These distances are similar in that they share a need to learn "changing".

To think "changing", learning is, therefore, required, and to learn "thinking" and "changing", education is required to be relevant and continuous. Suppose a medical doctor who has visited patients in person for years, and amid the COVID pandemic, she/he had to do the job virtually–i.e., telemedicine. This example clearly calls for continuing medical education (CME), which has long been characterized as an emerging need in the "ever-changing" world [2]. Not only to become a competent healthcare professional, continuing "education" is as important as initiating "education" to develop competencies in all professions. This is a warning for adults who are so obsessive about their children to become educated professionals, as we also emphasize that childhood is a critical period of learning and education later in this Chapter; they, however, need to remain stricter to learn themselves; they should not get off the train earlier!

1.2 No Excuse is Acceptable

"Education" is a direct path towards various forms of "learning", as summarized in Table 2, and continuing "education" is for lifelong learning—building a person who is knowledgeable in many respects, surprises others with her/his new interests along with her/his well-known interests, is passionate to expand her/his community, and makes interactions with others' community to help them deal with their problems, besides all of these she/he is successful at a job and her/his academic position [3]. Indeed, learning from this "world" and in this "world" is a process starting with the first breath and lasting until the last breath. Table 3 describes learning through four main ranges of age. Accordingly, each period of life is "golden" for a specific mode and style of learning; so education is endless; continuing education is quite possible if the background properly shows us what should be trained, who will be trained, and which are the trainee learning styles and modes and discontinuing education is nothing more than an excuse!

Table 2 Learning and education forms (*Prepared with data from* [3])

Learning form	*Context*	*Educational setting*	*Result*
Formal	Organized and structured	Formal education, in-company training	Formal recognition (certificate)
Non-formal	Planned activities	Work environments	Vocational skills
Informal	Daily life activities	Family, work, and leisure environments	Experiential (accidental) learning
Education form	*Goal*	*Educational setting*	*Rules*
Formal	Designed and planned education	School, workplace, or an organization	Determined
Non-formal	Training or professional development	Educational institutions and training organizations	Flexible according to needs
Informal	Knowledge acquisition and skills development	At home or work or in the society	None

Table 3 Learning periods (*Prepared with data from* [3])

Period	Major learning form	Sources of learning
0–5 years	Informal	Parents, peers and contexts
6–24 years	Both formal and informal	Educational, social, religious institutions, family environments, and mass media
25–60 years	Informal	Work environments, colleagues, touring, mass media, information technologies, and nature
Over 60 years	Informal	Art, music, sports, voluntary works, community organizations, clubs, and associations

1.3 On Our Journey

1.3.1 Form "Integrated Science" to "Thinking"

The first volume of the Integrated Science book series was entitled "Science without Borders", which came to mainly characterize all aspects of science as a true one nature and understand a pervasive relationship of all fields of science; for the purpose of which, scientists from different disciplines prestigiously contributed, artists who shared their viewpoints of thoughts along with their artworks made this contribution more and more desired to facilitate "Science without Borders" to become incorporated into science, art, and society. "Science without Borders" was the opening of the series [4]. The succeeding volumes aimed at integrating science for more specific purposes, i.e., to promote a healthy lifestyle [5], to enhance environmental education [6], to frame philosophy in chemistry [7], to review transdisciplinary approaches [8], and apply interdisciplinary and multidisciplinary approaches in health sciences [9]. Then, again, a volume was depicted to reflect our integrated view of thinking everything, science and art, self and others, formal and applied sciences, etc. [10]. It was named "Thinking" with the subtitle "Bioengineering of Science and Art".

1.4 On "Integrated Education and Learning"

1.4.1 From Cognitive Semiotics to Scientific Thinking

As a volume of the Integrated Science book series, the first part of *Integrated Education and Learning* also begins with an introduction to integrated science and its relation to thinking. Here, the introduction occurs from a cognitive semiotics perspective (Chap. 2). The meaning of "integrated" and "science" is presented there to understand what "integrated science" is meant, preparing the reader for a movement from classical semiotics to cognitive semiotics–that is, integrated semiotics and cognitive science-related domains, methods, and models. The discussion on cognitive semiotics is about the cognitive semiotics of pictures: ontogenesis, how children develop picture understanding; phylogenesis, the appearance of picture signs in evolution; and microgenesis, the perception of pictures. It ends with approaches to the epistemology of cognitive semiotics, including semiosis domains, three methods and three modes of access, and a sketch of epistemology for cognitive semiotics. In the end, cognitive semiotics is re-emphasized as an integrated field of all sciences that deal with experience and meaning, regardless of the methods they apply.

Moreover, coming after "Thinking: Bioengineering of Science and Art", scientific thinking is then introduced as employing cognitive processes that all have them fundamentally–implying that scientific thinking is a solution that both scientists and non-scientists can adopt. The history and definition of scientific thinking are reviewed. How such a type of thinking is powerful is addressed by referring to imaging and modeling and simulation studies. It concludes that everyday thinking will be greatly improved if it follows a scientific fashion, leading to the recommendation that scientific thinking is a mindset ready for productivity for everyone (Chap. 3).

2 Methods of Integrated Education and Learning

2.1 Transdisciplinarity

The second part of the volume is the first part specifically concerned with integrated education and learning. That the twenty-first century demands more creative individuals who can think deeper is highlighted throughout the part. These individuals can be developed in a context where learning and education are integrated. How an integrated pedagogy could help this development is addressed through a real-life journey (Chap. 4). In the words of the author–who has experience with both action research and educational settings–integrated education and learning is a means of humanizing the education–that has otherwise only one subject which students pass in, and it is nothing but teaching knowledge. Integrated education offers three teaching approaches: transmission, transaction, and transformation, being incorporated into the education, ensuring that three main purposes of education are fulfilled for our children to develop intellectually, to learn "learning", and to learn "living happily".

2.2 Linking

That the education and learning need to be integrated will be further supported by a detailed discussion of the concept of "linking". Linking is ubiquitous; theory and practice are linked [11], so values, knowledge, and behavior are [12], so problem and solution(s) are, so knowledge, management, and sense making are [13], etc.–and all these links are built due to a process that is "learning" — who can claim that learning about the subject (A) is not linked to the subject (B) in anyways? The more one thinks, the higher the number of links and the more the complexity of the links he/she can arrive at; however, all links are not necessary and even might be a cause of disordered thinking. Those links which are necessary and contribute to better thinking are: understanding, linking to develop learning; integration, linking to combine learning; schematizing, linking to organize learning; abstraction, linking to distill learning; inference, linking to extend learning; and transfer, linking to export learning. And to facilitate such linking, there are different ways: linking subject disciplines, linking locations and purposes of learning, questioning and verbal linking, visual linking, and linking people. So, for students to learn linking in thinking, teachers need to educate linking, and education is to be essentially linking. As a result, integrated learning and education is mandatory because it links what people learn to how they view learning, and this linking promotes knowledge transfer and the development of thinking competencies that are the need in this unpredictable world (Chap. 5).

2.3 Networking

Today's idea is to foster connectivity, blur the barriers, transfer and share ideas and knowledge, and enhance innovation and creativity for the destination larger and larger than our home–the globe [14, 15]. With technologies available to us, integrating education and learning is not impossible, but it is a necessity and can be simply expanded to society through means of communication. From an architectural point of view, reality can be figured based on self-similarity, and stereo reality implies that we are here, there, and everywhere. Linking to the concept of "knowledge society", the contemporary world is characterized as liquid and fractal. Accordingly, how would be the future scenario of knowledge and the degree to which it is complex and uncertain. In a world of globalized information, everyone is capital of knowledge, and education will be formulated in relationships. Learning to "connect" and "relate" would transform complexity–that is, a function of relationships between variables involved–from a difficulty to a beauty–an art!

3 Important Topics for Consideration in Integrated Education and Learning

The third part provides different views of factors to be considered when thinking about integrated education and learning.

3.1 Early Childhood Education

Early childhood is the period crucially important for the development of both brain and body functions. Of our interests are intellectual growth and development. Young children can be taught about and have shown the ability to learn how to conceptualize the nature of science (NOS) [16] and develop critical and creative thinking and problem-solving skills. Notably, in Vygotsky's words, early childhood is a period when experiencing fantasy, and its combination with thinking instills a power of imagination that can evolve throughout life and reflect in novel ideas, creativity, and innovation (Chap. 7).

3.2 Environment

In early childhood, children's learning occurs through transformation–that is, receiving information from others and acquiring knowledge–an experience-based phenomenon. For this, children need to be grown in suitable environments (Chap. 7) that promote scientific thinking in parallel with social skills development through small group discussions (Chap. 8). Children need to be challenged, being prepared for the globally increasing competition but not overwhelmingly, so they become afraid [17]. Dealing with and overcoming environmental challenges, the brain networks are activated and strengthened to make further connections [18]. Though online learning has been successfully implemented [19], the role of outdoor learning and nature remains much more important [20] in providing peer interaction.

3.3 Play

The child is not expected to do any job other than playing and if the parent, teacher, instructor, or educator wants the child to learn, then playing is the best opportunity to invest in resources. When doing "playful activities", the child does experiments, though informal, through which different cognitive processes are intertwined, e.g., exploring, conceptualizing, and re-conceptualizing, so high-quality learning in different contexts occurs effectively [21, 22].

3.4 Native Language

According to content and language integrated learning (CLIL), a model of learning for enhancing both teachers' and students' motivation, communication, content, cognition, and culture are the four pillars of learning [23]. Native language and local culture affect the student–teacher relationship, so education developers need to incorporate them into curriculum development and classroom practice ensuring that the education is constructivist and the purpose of education that is better thinking enhancement is achieved (Chaps. 9–11).

3.5 Emotion Regulation

Emotions constitute a pillar of learning [24]. Emotional learning occurs in association with social learning, and a variety of social-emotional learning approaches are available for achieving this two-objective learning [25]. Emotion regulation is another skill that develops early in children and is expected to be considered under an integrated education curriculum (Chap. 12).

3.6 Art Experiences

Encountering visual arts [26] and music learning [27] have been shown to facilitate critical and creative thinking. Stimulating expressions of curiosity and surprise and story-telling can be a path to art experiences as well (Chaps. 13 and 14), contributing, therefore, to this facilitation.

4 Challenges in Integrated Education and Learning

The fourth part views the challenges that learning and education face and proposes an approach to deal with the issue. Gender-based, ethnic, and racial stratification has long been a problem in educational settings since 60 years ago [28, 29]. The literature shows differences in academic achievement between male and female and between white and black children [30]. Gender and race differences are significant factors so to act against the influence social determinants can positively have on health [31]. Gender and racial differences and related social problems are among the main important challenges that need to be considered when teaching scientific thinking and social thinking (Chaps. 15 and 16).

5 Teaching Requirements for Effective Integrated Education and Learning

The fifth part occurs in educational settings. A bioeducational approach taking individual differences and adaptive variability into account promises an integrated education research framework (Chap. 17). To follow integrated education and learning, strategies and approaches are required to promote transdisciplinarity thinking and critical thinking in teachers, enabling them to design more thoughtful learning activities for students (Chaps. 18 and 19). Teachers need to give students opportunities to cultivate thinking skills, particularly by using concept maps and encouraging them to participate in multiple intelligences and case-based learning activities (Chaps. 20 and 21). In the end, teaching is completed when assessments are done (Chap. 22).

6 Mathematics, Arts, and Entrepreneurship that Promote Success in Integrated Education and Learning Settings

The sixth part highlights how the inclusion of computational thinking (Chap. 23) in an integrated education and learning environment is important. It critically appraises that current educational settings largely ignore this importance. Moreover, the positive role arts play in paving the way towards sustainability is pronounced as being discussed under the umbrella of STEAM (science, technology, engineering, and mathematics). Similarly, incorporating entrepreneurship in STEM (science, technology, engineering, and mathematics) education takes the learners a step closer to being prepared for future times of uncertainty (Chap. 25), for example, a global epidemic like COVID-19 we have lived with since 2020.

7 Experience Before Us

Searching the literature, there have been numerous efforts termed integrated education by the related developers.

7.1 An Integrated Classroom for Children with Disabilities and Normal Children

Teachers display prejudiced attitudes with regard to children with special needs against inclusive education [32]. A form of integrated education aims to engage children with disabilities in regular primary schools. Generally, teachers have expressed positive thoughts about the integration; however, the observations could not support that the needs of normal children and children with disabilities in an integrated classroom could be satisfied effectively and simultaneously [33]. This highlights the need to reform the educational system, so all children are included, all individual differences are considered, and all needs are met [32]. When education is inclusive, we can expect society to become inclusive [34].

7.2 Integrated Technology, Education, and Learning

Technology can be used to integrate learning in education by making technology-integrated lessons. Teachers who apply technology have shown that they are more likely to be constructivist in terms of the pedagogy they can make and lead a dynamic classroom that is student-centered [35]. The main challenge with this integration is that teachers need to have adequate professional knowledge; veteran teachers have expressed more interest and possessed the abilities/skills to promote a technology-based pedagogy than pre-service and novice teachers [36]. Other issues include, for example, that material preparation is time-consuming, resources are not accessible, and teachers are not comfortable with using technology-integrated lessons [37]. This calls for a need to prepare teachers for technology integration into education [38].

7.3 Integrated Psychology, Education, and Learning

As earlier mentioned, learning styles are different; so are teaching/lecturer styles. An integrated education and learning outline can be expected to have positive outcomes if both teachers' and students' styles are taken into account [39]—known as educational psychology.

7.4 Project-Based Learning in Integrated Education and Learning

Project-based learning (PBL) is a means of integration commonly used in STEM education. It has been shown to positively contribute to motivation and learning, creating a sense of community through collaboration, building a student-centered classroom, and providing versatile spaces for encouraging students' participation [40]. However, the implementation of a PBL-based program is faced with challenges that need to be addressed.

7.5 Integrated Different Knowledge Types, Education, and Learning

To integrate education with learning, there is a need to incorporate different knowledge types into education, importantly pedagogical content knowledge

(PCK) and general psychological knowledge (PPK). The integration of these types of knowledge has been shown to increase their joint applicability; however, it increases instruction time [41].

7.6 Integrated Differentiation, Education, and Learning

Differentiation is a teaching strategy where the teacher decides to modify the content, language, or process. In the context of CLIL, the differentiation in content and language might be adopted by the teacher to meet the diverse students' needs. The main challenge with this lying in an inappropriate teacher's understanding of the differentiation is that the differentiation is not implemented properly in practice [42]. The differentiation methods and purposes need to be defined for teachers.

7.7 Integrated Arts, Education, Learning

For an integrated learning program, teachers and artists can collaborate to ensure students acquire knowledge from different areas. CoTA, for example, is a collaboration between teachers and artists. Through such a program, both teachers and artists actively participate in evaluating students' needs, designing needs- and standards-based learning projects, and weekly updating these projects [43]. It is expected to facilitate learning through understanding the arts.

8 Conclusion

Integrated Education and Learning arose in response to the problem that in a world where competitiveness is ever increasing, a man can live with happiness if and only if he thinks of “changing”. To think “changing”, learning is, therefore, required, and to learn “thinking” and “changing”, education is required to be relevant and continuous. Despite this fact and that “education” and “learning” occur together in more than 80% of uses, either in scientific research or for general purposes, they remain far from being integrated effectively with each other in educational settings and learning environments and systems. This Chapter presented an introduction to the content of *Integrated Education and Learning*, mainly including methods (transdisciplinary, linking, and networking), important topics for consideration (early childhood education, environment, play, native language and local culture, emotions and emotion regulation, and art experiences), challenges (gender and racial differences), teaching requirements, and other factors that enhance success in integrated education and learning.

Welcome to *Integrated Education and Learning*.

Core Messages

- In a world where competitiveness is ever increasing, a man can live with happiness if and only if he thinks of “changing”.
- To learn “thinking” and “changing”, education must be relevant and continuous.
- Integrated education and learning methods mainly include transdisciplinarity, linking, and networking.
- Early childhood education is crucial for integrated education, along with the environment, play, and local culture.
- Emotion regulation and art experiences can help implement integrated education and learning.

References

1. Hardman ML (2009) Redesigning the preparation of all teachers within the framework of an integrated program model. Teach Teach Educ 25(4):583–587. https://doi.org/10.1016/j.tate.2009.02.005
2. Fox RD, Bennett NL (1998) Continuing medical education: learning and change: implications for continuing medical education. BMJ 316(7129):466
3. Laal M, Laal A, Aliramaei A (2014) Continuing education; lifelong learning. Procedia Soc Behav Sci 116:4052–4056. https://doi.org/10.1016/j.sbspro.2014.01.889
4. Rezaei N (2021) Integrated science. Springer
5. Kelishadi R Healthy Lifestyle
6. Vasconcelos C, Calheiros CS (2022) Enhancing environmental education through nature-based solutions: an introduction. In: Enhancing environmental education through nature-based solutions. Springer, pp 1–6
7. Vančik H (2021) Philosophy of chemistry. Springer
8. Rezaei N (2022) Transdisciplinarity. Springer
9. Rezaei N (2022) Multidisciplinarity and interdisciplinarity in health. Springer, Integrated science
10. Rezaei N, Saghazadeh A (2022) Thinking. Springer, Integrated science
11. Merriam SB, Bierema LL (2013) Adult learning: linking theory and practice. Wiley
12. Sinkula JM, Baker WE, Noordewier T (1997) A framework for market-based organizational learning: linking values, knowledge, and behavior. J Acad Mark Sci 25(4):305–318
13. Thomas JB, Sussman SW, Henderson JC (2001) Understanding “strategic learning”: linking organizational learning, knowledge management, and sensemaking. Organ Sci 12(3):331–345
14. Paulin D, Suneson K (2015) Knowledge transfer, knowledge sharing and knowledge barriers–three blurry terms in KM. Lead Issues Knowl Manage 2(2):73
15. Andersson U, Dasí Á, Mudambi R, Pedersen T (2016) Technology, innovation and knowledge: the importance of ideas and international connectivity. J World Bus 51(1):153–162
16. Akerson VL, Buck GA, Donnelly LA, Nargund-Joshi V, Weiland IS (2011) The importance of teaching and learning nature of science in the early childhood years. J Sci Educ Technol 20(5):537–549

17. Rushton S, Larkin E (2001) Shaping the learning environment: connecting developmentally appropriate practices to brain research. Early Childhood Educ J 29(1):25–33
18. Rushton S, Juola-Rushton A, Larkin E (2010) Neuroscience, play and early childhood education: connections, implications and assessment. Early Childd Educ J 37(5):351–361
19. Heirdsfield A, Davis J, Lennox S, Walker S, Zhang W (2007) Online learning environments: what early childhood teacher education students say. J Early Child Teach Educ 28(2): 115–126
20. Cooper A (2015) Nature and the outdoor learning environment: the forgotten resource in early childhood education. Int J Early Child Environ Educ 3(1):85–97
21. van Oers B (2003) Learning resources in the context of play. Promoting effective learning in early childhood. Eur Early Child Educ Res J 11(1):7–26
22. Ebbeck M, Waniganayake M (2017) Play in early childhood education: learning in diverse contexts. Oxford University Press, ERIC
23. Coyle D (2006) Content and language integrated learning: motivating learners and teachers. Scott Lang Rev 13(5):1–18
24. Denham SA, Liverette KH (2019) The emotional basis of learning and development in early childhood education. In: Handbook of research on the education of young children. Routledge, pp 43–64
25. Blewitt C, Fuller-Tyszkiewicz M, Nolan A, Bergmeier H, Vicary D, Huang T, McCabe P, McKay T, Skouteris H (2018) Social and emotional learning associated with universal curriculum-based interventions in early childhood education and care centers: a systematic review and meta-analysis. JAMA Netw Open 1(8):e185727–e185727
26. Eckhoff A (2008) The importance of art viewing experiences in early childhood visual arts: the exploration of a master art teacher's strategies for meaningful early arts experiences. Early Childhood Educ J 35(5):463–472
27. Young S (2016) Early childhood music education research: an overview. Res Stud Music Educ 38(1):9–21
28. Ogbu J (1994) Racial stratification and education in the United States: why inequality persists. Teach Coll Rec 96(2):264–298
29. Alterman T, Steege AL, Li J, Petersen MR, Muntaner C (2008) Ethnic, racial, and gender variations in health among farm operators in the United States. Ann Epidemiol 18(3):179–186
30. Kremer KP, Flower A, Huang J, Vaughn MG (2016) Behavior problems and children's academic achievement: a test of growth-curve models with gender and racial differences. Child Youth Serv Rev 67:95–104. https://doi.org/10.1016/j.childyouth.2016.06.003
31. Assari S, Nikahd A, Malekahmadi MR, Lankarani MM, Zamanian H (2017) Race by gender group differences in the protective effects of socioeconomic factors against sustained health problems across five domains. J Racial Ethn Health Disparities 4(5):884–894. https://doi.org/10.1007/s40615-016-0291-3
32. Unianu EM (2012) Teachers' attitudes towards inclusive education. Procedia Soc Behav Sci 33:900–904
33. Arbeiter S, Hartley S (2002) Teachers' and pupils' experiences of integrated education in Uganda. Int J Disabil Dev Educ 49(1):61–78
34. Maria UE (2013) Teachers' perception, knowledge and behaviour in inclusive education. Procedia Soc Behav Sci 84:1237–1241. https://doi.org/10.1016/j.sbspro.2013.06.736
35. Judson E (2006) How teachers integrate technology and their beliefs about learning: is there a connection? J Technol Teach Educ 14(3):581–597
36. Hughes J (2005) The role of teacher knowledge and learning experiences in forming technology-integrated pedagogy. J Technol Teach Educ 13(2):277–302
37. Alenezi A (2017) Obstacles for teachers to integrate technology with instruction. Educ Inf Technol 22(4):1797–1816. https://doi.org/10.1007/s10639-016-9518-5
38. Duhaney DC (2001) Teacher education: preparing teachers to integrate technology. Int J Instr Media 28(1):23–23

39. Entwistle NJ (2013) Styles of learning and teaching: an integrated outline of educational psychology for students, teachers and lecturers. David Fulton Publishers
40. Aksela M, Haatainen O (2019) Project-based learning (PBL) in practise: active teachers' views of its' advantages and challenges. In: Integrated education for the real world: 5th international stem in education conference post-conference proceedings. Queensland University of Technology, pp 9–16
41. Harr N, Eichler A, Renkl A (2015) Integrated learning: ways of fostering the applicability of teachers' pedagogical and psychological knowledge. Front Psychol 6:738
42. Roiha AS (2014) Teachers' views on differentiation in content and language integrated learning (CLIL): perceptions, practices and challenges. Lang Educ 28(1):1–18
43. Doyle D, Hofstetter CH, Kendig J, Strick B (2014) Rethinking curriculum and instruction: lessons from an integrated learning program and its impact on students and teachers. J Learn Arts 10(1):n1

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2 The Cognitive Semiotics of Pictorial Evolution and Development

Göran Sonesson

But if there is one thing I know now, it is that anyone looking for order ought to steer free of psychology altogether. Go for physiology or theology instead, where at least you will have solid backing – either in matter or in spirit – instead of psychology's slippery terrain. The psyche is quite a tenuous object of study.

Olga Tokarczuk [1]

Summary

The study of meaningful artifacts, such as pictures, has traditionally been caught between the humanities, which only take an interest in a selection of individual pictures, and psychology, which attends more to the majority reaction to pictures than to the nature of the pictures themselves. Some parts of semiotics, and, more, in particular, cognitive semiotics, endeavor to make use of all possible methods, including experiments, in order to make sense of pictures as meaningful artifacts. In this sense, cognitive semiotics is an instance of integrated science (in the sense in which science refers to all ways of creating knowledge about phenomena in the world). To throw some light on this claim, we will, in the present paper, first discuss the meaning of integrating the sciences and, then, after offering a sketch of the emergence of cognitive semiotics out of classical semiotics, we will account for what has been done so far, using different methods and approaches, within pictorial semiotics, and we will end with some considerations on the epistemology of cognitive semiotics.

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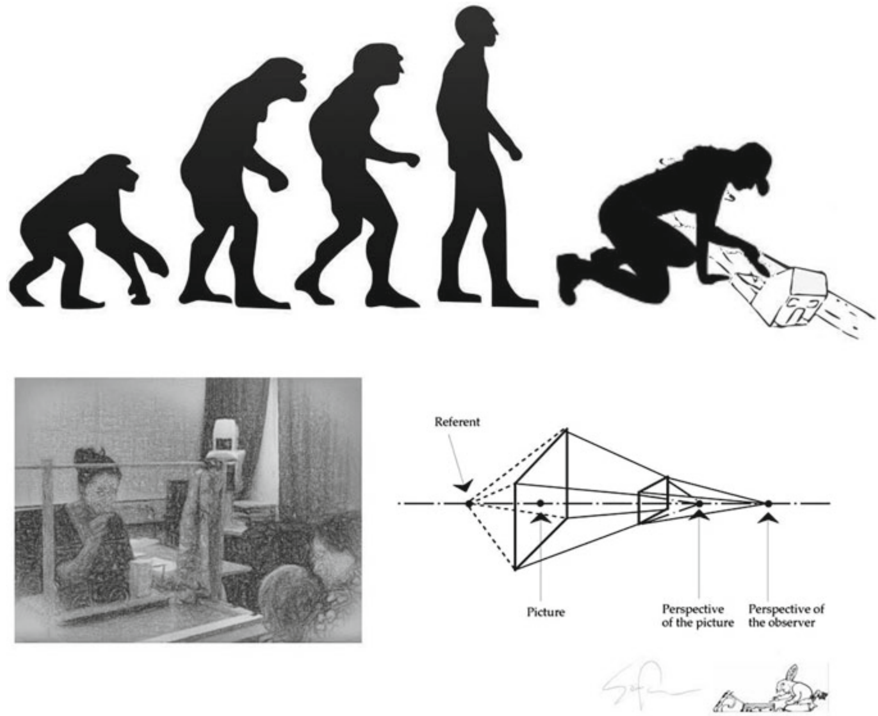
N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_2

Graphical Abstract/Art Perfomrance



A graphic description (in both senses of the term) of the author's contribution to the study of pictures within the framework of cognitive semiotics.

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Keywords

Epistemology · Experiment · Humanities · Integral science · Language · Meaning · Natural science · Phenomenology · Pictures · Social science

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

In this paper, we will be interested in cognitive semiotics, in particular as applied to the evolutionary origin of pictorial understanding and the corresponding development of such understanding in the child, as well as regarding the everyday act of perceiving pictures. Cognitive semiotics was invented two or three decades ago in an effort to bring together the two domineering paradigms of the last half-century, which both had the purpose of integrating the human and the social sciences, not without some contribution from the natural sciences. While cognitive science was, from the start, an attempt at the wedding of several domains of study, which, according to most listings, include psychology, linguistics, philosophy, computer science, and neuroscience, semiotics started as a domain of philosophy, with the ambition to redefine the social sciences and the humanities, and which, more recently, has tried to go into empirical mode. Retrospectively, cognitive science may be defined as the study of consciousness (in spite of the fact that many early exponents of the domain aimed to reduce consciousness to the workings of a computer), while semiotics is concerned to understand the different ways in which meanings were produced, conveyed, and experienced in real human societies. There is an obvious overlap between the domains of study of cognitive science and semiotics. At the same time, their methods, models, and epistemology have tended to be different. Cognitive semiotics aims to capitalize on both the convergences and the divergences of these two approaches [2–5]. Thus, cognitive semiotics is an eminent case of integrated science.

2 An Excursus on Integrated Science

Before discussing the sense to attach to the integration of the sciences, we have to determine what is meant in the following with the very term "science". In English, the term is normally taken to be a shorthand for the natural sciences (and the life sciences, if that is understood as something separate). Adding a specification, it is quite possible to talk about "the social sciences", but less naturally of "the human sciences". In German and French, as well as in many other European languages, on the other hand, it makes perfect sense to talk about the human or cultural sciences ("sciences humaines", "Kulturwissenschaften"). In this paper, the term should be taken in this wide sense to stand for the systematic study of any domain of knowledge, which uses specific methods and models and characterizes an epistemology. Cognitive semiotics was born out of an endeavor to remedy the lack of systematicity of the traditional humanities, including some traditions within semiotics. That said, it cannot be forgotten that "integrated science is a notion normally applied to the natural sciences, and among its antecedents is no doubt found the idea of "unified science" as defined by the logical positivists at the beginning of the last century. While we would like to go beyond this narrow understanding of integration, we will by no means leave out the natural sciences, and, in particular, not the life sciences.

Before entering our main subject matter, we should also consider the other term of the compound: the notion of integration, not in general, because this would take us too far, but as applied to different domains of knowledge. I was induced to consider the meaning of integration recently when I was challenged to write about the notion of "integral linguistics" as conceived by the prominent linguist Eugenio Coseriu [6]. From the inception of the twentieth century, starting with the posthumous edition of the *Cours de linguistique générale* attributed to Ferdinand de Saussure, and pursued within the frames of the generative grammar of Noam Chomsky as first presented in 50ies of that century, linguistics was supposed to study language as an isolated phenomenon, without taking into account social and psychological dimensions, nor, at least in the latter case, the meaning conveyed by language. No doubt this approach was useful for a time from a methodological point of view, but the end result could only be an increasing depletion and barrenness of the object of study, which, in turn, not only set obstacles to further scientific discoveries but also cut the link to ordinary human experience. Rather curiously, parallel to generative grammar, specialties such as psycholinguistics, sociolinguistics, gesture studies, pragmatics, and the like were beginning to emerge, but they were kept separate from linguistics proper. Also, in the 60ies, with the rebirth of semiotics, understood as a wider domain of study which includes linguistics but a lot more besides, the then-fashionable idea of a barebone approach was adopted by most scholars concerned. In short, the dominating fad in the humanities was quite the opposite of scientific integration.

A year after presenting my doctoral dissertation in general linguistics in 1978, I summarized its epistemological challenge at the 5th Conference of Scandinavian Linguistics in a lecture entitled, “A plea for integral linguistics”. Although I got acquainted with and learned to appreciate the work of the linguist Eugenio Coseriu only a few years later when I taught semantics at the School of Anthropology in Mexico City, I did not know, until very recently that, in the same year as the acts of that linguistic congress were published, in 1981, Coseriu had declared in a lecture to another regional linguistic congress, this time in Argentina, that henceforth the term “integral linguistics” was going to be the label for the kind of approach to language which he had preconized all his scholarly life. Obviously, there is a big difference between a declaration made by a doctoral student just received and that of an old scholar who has given weighty contributions to his domain of study all his life. Still, given the background of the history of linguistics in the twentieth century, I wanted to investigate whether we were prompted to call for integration for the same reasons.

Nevertheless, I realized that before such an investigation could be made, it was necessary to specify what was meant by the term integration: in other terms, what was the object which was going to be integrated with what object? In the particular case, with which I was concerned in this early paper of mine, and which preoccupied Coseriu, we might inquire whether the idea was that linguistics should be integrated into semiotics, into the humanities, or into some kind of unified science approach–or, whether it was merely the case of integrating different views of language into linguistics. After a close study of Coseriu’s paper, in particular where he refers to the notion of “integral linguistics” (of which there are few instances), I concluded that, to him, integrating linguistics meant to adopt three different perspectives on the same object, language, while still maintaining language as such as the sole object of study, but allowing the different perspective to interpenetrate to some extent. In other words, to Coseriu, integration is something that applies to a single domain of study, linguistics, by putting into correspondence different ways of looking at the object of study, language. Still, whether or not Coseriu was clearly aware of this fact, such a shift of perspective can hardly supervene without taking in more or less of the environment of language, that is, among other things, society, consciousness, and meaning.

My own take on integral linguistics, at the time, was more global: I wanted language to be treated on par with other domains of meaning, which included not only gesture and pictures but also direct perception. In spite of my juvenile presumption, the two lemmas that I formulated, taken together, show a certain insight into the fact that not everything can be studied at the same time:

i. the context is just another text;
ii. the world (of our experience) is inextricably contextual.

That is, whether going beyond language (or any other object of study) or not, it is impossible to take in the whole world of experience at a time, but you can create a thematic hierarchy of concerns, which includes the whole, though situated at different levels of adumbration. This is best understood as "an operation applied to the field of consciousness, in the sense of the phenomenologist Gurwitsch" [7], which was more recently imported into psychology by Arvidson [8], using the term, "the sphere of attention". It involves a modification of the theme which is the object of attention within consciousness, which, in turn, leads to a restructuring of the thematic field of which the theme is a part, and possibly also of that which appears at the margin of the thematic field, which is co-experienced with the thematic field, without having a meaningful relation to the theme, contrary to what is the case with the thematic field. In the case of scientific exploration of a thematic field, it is required for the facts of experience to widen the thematic field so that the original field only appears as a part of the field of study. This is what should happen when we go from linguistics to semiotics and from classical semiotics to cognitive semiotics.

3 From Classical Semiotics to Cognitive Semiotics

For the purpose of this paper, semiotics and cognitive science will be considered to be two distinct research traditions, each of which forms a temporal sequence made up of problems formulated from a particular perspective, solutions proposed to these problems, as well as new issues resulting from these solutions, and so on indeterminately. The perspective defining semiotics is the preoccupation with the nature of meaning, broadly conceived, which may involve how meaning is produced and conserved by means of different vehicles, how it develops in children, and in the evolution of human beings and other animals. The perspective of cognitive science is best described as being the nature of consciousness, although, as is well known, many of its exponents hoped to get rid of this pesky notion, substituting something easier to apprehend, such as the computer or the brain. Cognitive science is also often interested in the uses to which consciousness (or whatever stands in for it) is put in the real world, as well as its history of evolution and development.

As a research tradition, semiotics is very old, at least going back to Greek Antiquity, having reached the second apogee in Medieval Scholastics, and a third one during the Enlightenment, both periods of which abound in "treatises of signs", before Peirce and Saussure toiled with it, in their separate ways, during the penultimate turn of the century, and the French structuralists made it fashionable during a short time span about 70 years ago. Cognitive science is much younger, but it is made up of disciplines, some of which, as research traditions, have rich pedigrees, which is true of psychology, philosophy, biology, linguistics, and anthropology, and some which are very recent, such as artificial intelligence and neuroscience. Even more recent is cognitive semiotics that incorporates both semiotics and cognitive science perspectives and resolves their separate, but (according to this view) connected, problems by adding up their solutions and pooling their resources.

The first use of the term "cognitive semiotics may well be due to Juan Magariños de Morentin in order to describe the Peircean take on semiotics. Per Aage Brandt used the term to describe his own approach, which combined French semiotics with cognitive linguistics. In the sense that the term is used nowadays, however, as an encounter between semiotics and cognitive science, Thomas Daddesio (1995) would seem to have been the real pioneer. Taking his cue from French structuralism and ignoring other traditions within semiotics, Daddesio argues that semiotics tends to restrict its attention to static structures, whereas cognitive science is involved with the way structures are processed by consciousness. Though this may seem rather reductive as a historical description, Daddesio correctly pinpointed "the correlation of intersubjective structures (language as Saussurean langue) and subjective access (language as "competence", not in the sense of Chomsky but in that that of psycholinguistics). If meaning and cognition (in the very general sense of cognitive science) are connected, then semiotics and cognitive science, as we suggested above, may simply be different emphases attributed to the same field of study" [2, 4, 5, 9–11].

Quite independently of any of these attempts, another approach to cognitive semiotics, which was initiated at Lund University, emerged from the convergence of the lifetime work of two scholars, who only begun to collaborate at the turn of the last century: this author, who, after his linguistics studies in Lund, spent ten years working in France and Mexico, after which he returned to Sweden to establish semiotics as a subject of doctorate studies; and Jordan Zlatev, who, after studies in cognitive science and linguistics, was employed at the Department of Linguistics in Lund. Zlatev and Sonesson initiated their collaboration with a faculty-internal project concerned with language, gesture, and pictures in a developmental and evolutionary perspective, then proceeded to form the Swedish part in the EU project SEDSU. After that, they together led a six-year-long program, entitled "Centre for cognitive semiotics", involving around 30 scholars (not counting the students), many from linguistics, but also several other human sciences. From these experiences emerged an idea of cognitive semiotics as a specific way of merging semiotics and cognitive science, which will be the main focus of this paper.

4 The Cognitive Semiotics of Pictures

Space is lacking here to present pictorial semiotics, let alone the cognitive semiotics of pictures. The cognitive semiotics of pictures is interested in the way children learn to understand pictures as well as how pictures first came to be created and used during human evolution. In this respect, it is analogous to psycholinguistics and to the study of language evolution. But it is also involved with the way pictures are presently used (and, to the extent that this is different, how they were used at earlier historical periods) to convey meaning. In this sense, it is comparable to linguistic theory (and potentially to historical linguistics). Although they have not asked the questions precisely relevant to semiotics, psychologists have independently studied children's understanding of pictures, and anthropologists, archaeologists, and other students of evolution have now and then voiced their ideas about the place of the picture in human evolution. Even though some philosophers and psychologists have contributed important insights, the study of how the picture conveys meaning was basically pioneered by semiotics.

4.1 Ontogenesis: How Children Develop Picture Understanding

The study of the emergence of children's ability to make sense of pictures is the part of this task that can most straightforwardly be realized. Interpretational skills are most relevant here, for unlike the case of language, most human beings are not producing, but certainly interpreting pictures. Psychologists such as DeLoache [12] and Tomasello et al. 1997 [13] have given important contributions to this study, showing, in the first case, that children only can make sense of pictures (at least given the task of finding a hidden object shown in a picture in another room) at two years and a half, and, in the second case, that older children are better able than both younger children and apes to take hints for solving certain tasks from a number of different displays, such as pointing gestures, markers, and models. We replicated both these research paradigms, making several modifications, but those of most transcendence in the present context involve embedding the experiments in semiotic theory.

In the former case, the semiotically informed repetition of DeLoache's study in Sara Lenninger's doctoral dissertation [14], which introduced a familiar testing ground, the pre-school, and eliminated the task of finding a hidden object, nevertheless confirmed DeLoache's general conclusions. On the other hand, Lenninger concluded that "the children who were unable to find the object in the other room, even when carrying the photograph with them, could still identify the object from one picture to another. Thus, it appears that the similarities between one picture and another are of easier access than those between a picture and the world" [15].

In the latter case, our semiotic reworking of the paradigm amounted to the addition of a fourth category of displays, pictures, as well as implementing a theoretical framework in which there were two kinds of indexical signs, i.e., signs based on contiguity, one of which was, in addition, directional, the pointer, and another which was not, the marker; and two kinds of iconic, i.e., similarity-based, signs, pictures, and models. We demonstrated that, while apes could only make sense of indexical signs, children could also use iconic signs, and younger children grasped the meaning of pictures earlier than models [16]. At least one possible interpretation goes against Peircean semiotics, which postulates that iconic signs are more elementary than indexical ones.

Another experimental study which we realized within the framework of cognitive semiotics was inspired by a controversial issue in classical semiotics, according to which mirror images are not signs, like pictures, but should really be identified with direct perception (as claimed by Eco [17]). In a study involving two-year-old children discovering a hidden object either after being shown the act of hiding in reality, in a directly transmitted video clip, in a pre-recorded video, and in a mirror, we were able to demonstrate that the level of difficulty of the mirror image was more or less the same as that of the pre-recorded video, while the two other cases offered less difficulty [18, 19]. At least in the specific situation created by the experiment, the mirror image turns out to be just as difficult as pre-recorded video, which is more difficult to understand for small children than direct perception and directly conveyed video.

In another study, we showed that an ape, having been trained to perform certain actions from seeing them in reality, following the "do-as-I-do"-paradigm, was just as able to imitate these actions when shown the final or pre-final phase of the action in a still photograph as when shown the whole video sequence [10, 20]. This could be taken to show that some qualification is needed on the age-old saying, epitomized by an eighteenth-century book by the aesthetician Gotthold Ephraim Lessing, according to which pictures cannot render events while being good at rendering things, whereas the opposite is true of language. Taken together, this all goes to show that the way pictures convey meaning is rather different from that of language, and that we so far know fairly little about the former [10, 15, 21].

4.2 Phylogenesis: The Appearance of the Picture Sign in Evolution

The next task of cognitive semiotics is to establish when the picture became available as a semiotic resource for human beings. According to Merlin Donald's scenario [22] describing the differentiation of the human species from other hominids, this evolution went through four phases:

i. *Episodic memory,* "the memory for single situated happenings, is something that human beings share with many other animals" [23];
ii. *Mimetic memory,* which involves using the body to record behavior, and happens to human beings and, in one or other form, other hominids;
iii. *Mythic memory,* which corresponds to language, so designated because, according to Donald, "it involves the construction of narratives, no doubt initially used to recount myths, and thought by Donald to be at least one of the reasons why language evolved" [23]; and
iv. *Theoretic memory,* manifested by pictures, writing, and theories.

In later texts, Donald [24] has used the term "exograms" to pinpoint the specificity of the last stage, which consists in making memory available outside, and relatively independently, of human beings, both as to their body (unlike mimetic memory) and as to their consciousness (unlike mythic memory).

The central question in this context is what it takes to establish such a scenario. Some indications may be found in the experimental studies mentioned above, which allow us to discover the relative abilities to resolve certain issues in apes compared to human children at different ages. In ethology, many other observations of animal behavior have been made that are relevant to such a scenario. Although Donald is by profession a neuroscientist, it does not seem that neuroscience, at its present stage, is of much help here. A fundamental contributor is certainly archaeological exploration. Among the artifacts discovered at archaeological excavations, pictures, notably, have only been found at rather late historical levels (although there have been some controversial contrary claims). Still, as a whole, Donald's scenario is only possible as a product of the direct human interpretation of human achievements. It is part of Donald's personal experience that human beings are capable of language, which, in many respects, does not have an equivalent outside of the human species (although some apes can learn aspects of it when prompted by human beings). The same insight may, of course, be gained from taking cognizance of all the writings, from stone inscriptions to web pages, handed down to Donald and us throughout history. The same thing can be said about writing and theory.

Still, the case of pictures being necessarily exograms is problematic, even though such an idea naturally presents itself, given our present-day experience of pictures. There is no obvious reason to suppose that the advent of picture production had to await the surgency of the capacity to preserve memory outside of human bodies and minds. If pictures were created earlier in history, they may have employed more perishable media, such as sand or human skin, which means that the earliest pictures could not have been preserved in the archaeological record [25]. In fact, there are historically and ethnographically testified examples of drawings customarily being made on the ground and then rapidly wiped out (for a recent example, see [26]). This would mean that pictures may constitute a transient record in a way similar to (spoken) language and gestures. It follows that we have no clear evidence for their earliest emergence in the evolutionary history of human beings [27].

4.3 Microgenesis: The Perception of Pictures

The third task set for cognitive semiotics of pictures concerns the way pictures are understood. This could be identified with the act of perception, but, just as in the case of language, perception must then be conceived as an intricate and long-winded process. Art history, also when it has been renamed science of art, visual studies, image studies, or anything of the kind, has contributed very little to the understanding of picture interpretation since it remains exclusively preoccupied with particular pictures, not pictures as a particular way of conveying meaning. Most psychologists, such as the Gestalt psychologists and the constructivists interested in perceptual illusions, have used pictures as examples but have generalized their results to perception in general. A very small number of psychologists, notably James Gibson, John Kennedy, and Julien Hochberg, have attended to the specificity of the perceptual task presented by pictures as different from direct perception. Still, in so doing, they have very rarely used experiments but rather employed their own insights as perceivers. In that respect, their work is comparable to that of classical semioticians, such as Jean-Marie Floch, Felix Thürlemann, and Groupe μ, who have conceived models for the way the pictorial surface is organized, and philosophers, such as Edmund Husserl and Richard Wollheim, who have tried to grasp the peculiarity of the process in which objects are "seen into" the pictorial surface [10, 21, 28, 29].

In contrast to ontogenesis and psychogenesis, this kind of study could be said to concern microgenesis, so termed by Heinz Werner, but first studied, using the term "Aktualgenese," by the Gestalt psychologist Friedrich Sander [28, 30]. The term microgenesis designates the dynamic unfolding and differentiation "on a brief present-time scale of a percept, a thought, an object of imagination, or an expression". Most studies have, from the beginning, involved perception, but there is no reason to limit the notion to this domain of experience. Although Sander's and Werner's original studies were experimental, microgenesis also lends itself easily to a phenomenological approach, as testified by the pioneering work of Gurwitsch [7], which largely overlaps with earlier Gestalt psychology. *Mutatis mutandis* is also the kind of approach employed in work accomplished by the psychologists, philosophers, and semioticians mentioned above. The latter method seems to have been the most successful so far.

5 Approaches to the Epistemology of Cognitive Semiotics

As we have argued above, cognitive semiotics is a way of integrating the sciences; we have to spell out how such integration occurs in epistemological terms, which means, at least, both attending to the domains of study and the methods being used. As we have seen, cognitive science is itself an integrative approach, and semiotics may, at present, be understood in the same way. Cognitive semiotics thus aims to attain an even higher level of scientific integration. Nevertheless, the question remains to what extent it can be integrated into the sciences, where the latter is understood to comprehend all kinds of world study, including that realized by the natural sciences. As we have already seen, and as will become apparent below, cognitive semiotics is interested in part in domains that are usually belabored by the natural sciences. It uses, among others, methods that are practiced by the former. But that only makes more urgent the question of whether the worldview of the traditional natural sciences can be reconciled with that of cognitive semiotics.

5.1 The Domains of Semiosis

According to an original suggestion by Zlatev (2009) [31], the domain of study covered by cognitive semiotics can be divided into several levels, each with its corresponding subjects, worlds, and significations. Meaning, in the broader sense of the term (going well beyond the notion of sign), is referred to as the relation linking a subject and his/her environment which is determined by a value. We will present

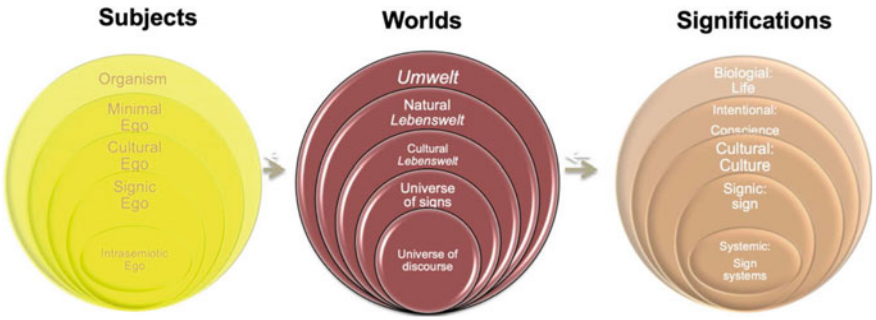

Fig. 1 Five types of selves, worlds, and significations (inspired in [29]), with the added distinction between the cultural Lifeworld and the universe of signs and the corresponding significations [30] and a generalization of "linguistic Ego" to all kinds of specific semiotic resources

the model here with some modifications suggested by Sonesson [32], which amounts to the introduction of a distinction between the level of culture and the level of the sign, in the narrow sense of Sonesson [28]: a unit of two items which are differentiated from each other, one of which is directly present but not in focus, while the other is in focus, but not directly experienced; and to the generalization of the case of language, being the innermost circle in Zlatev's original proposal, to all specific systems of meaning, including pictures (Fig. 1).

On a biological level, the value is life, more specifically the maintenance and reproduction of life, and the subject is the *organism*. This is what was described by Jakob von Uexküll as the functional cycle and, more recently, by Francisco Varela and Humberto Maturana, as (the original) autopoiesis. The next level, the *natural Lifeworld* (in the sense of what pertains to nature), has as its subject the minimal ego and is governed by the value of sentience. Since Zlatev identified this latter value with intentionality, in the sense of phenomenology, as it originally appears in perception, it can be understood as consciousness, in the broadest sense of the word. Above the level of the minimal ego is situated the cultural ego, the subject of the *cultural Lifeworld*, which is determined by a value that we will call culture. What is new at this stage is life in a community, also known as sociability, which gives rise to norms and other rules. A specific case of the cultural Lifeworld is the *universe of signs*. The fifth level consists, for Zlatev, of language, but we will here generalize it to include all kinds of semiotic resources which are in any way systemic, whether they depend mostly on rules of substitution, which is the case of language and formalized gesture systems, or on rules of transformation, as is the case with pictures and some kinds of gestures. This is the *universe of discourse*.

All these levels may be accessed, more or less adequately, from the point of view of experience (phenomenology in the wide sense). This also applies to von Uexküll's functional circle if we trust the definition. In actual fact, we have no way of knowing how it feels to be a tick, and von Uexküll notes, somewhat contradictory, that he is really relying on the anatomical organs of the animal, which is tantamount to depending on the experience of human beings in some kind of controlled format.

Ticks do not use pictures, but human beings, who do, have no problem telling us how it feels to be (that particular) human being experiencing pictures. Thus, we either have to ask many human beings about the same piece of experience, which would amount to some kind of experiment (in a wide sense) or trust the distinction between introspection and phenomenology (in the technical sense; See the following section!).

5.2 Three Methods and Three Modes of Access

From the start of my work on the semiotics of pictures, I have listed different approaches to its study, including the analysis of pictorial corpora, the recourse to users' intuitions, and experiments [28]. In more recent papers, I have used the phrase "the dialectics of phenomenology and semiotics" to describe how phenomenological experience is first called upon to construct an experimental situation in such a way that it is relevant to the behavior of real people and then is required to relate the results of the experiment to the corresponding situation in the experienced Life-world, all of which forms a helix the turns of which may be repeated many times over. More broadly, Zlatev [11] describes "methodological triangulation" as a characteristic of cognitive semiotics, which involves integrating what he calls the first-, the second-, and the third-person methods as applied to any domain, where, however, first- and second-person methods have epistemological priority. Here the types of methods should, of course, be understood in analogy to the three persons of the personal pronouns in Indo-European languages, also construed by Zlatev as being, respectively, subjective, intersubjective, and objective. To avoid confusion, the terms ipseity, dialogicity, and neutrality will be used in the following (Table 1).

Linguistics had long operated on the basis of the user's intuitions, well before this usage was institutionalized by Chomskyan linguistics. Suppose we generalize this notion to any kind of user's experience (which is unavoidable in any scientific domain of study, but rarely accounted for). In that case, we need to distinguish between the user's knowledge about the individual features of his/her experience

Table 1 The distinction of ipseity, dialogicity, and neutrality in the phenomena accessed and the modes of access, inspired in [11], as modified in [5]

Phenomena accessed				
		Ipseity (First person)	Dialogicity (Second person)	Neutrality (Third person)
Modes of access	Ipseity (First person)	Introspection	Empathy	Phenomenology
	Dialogicity (Second person)	Participant observation	Dialogue	Interactive description
	Neutrality (Third person)	Behaviouristic description ("heterophenomenology")	Interview	Experimentation

and those parts of his/her experience that may expose some invariants of any experience of the kind. To account for this distinction, and many others, we have to separate the modes of access employed and the phenomena on which they operate, both of which may pertain to the first-, second-, and third-person (Table 1 and [5]).

We can have third-person reports of introspection, which is what Dennett [33], confusingly, calls "heterophenomenology", but a more fruitful third-person approach that pertains to the third-person domain is experimentation. Both phenomenology and experimentation aim to attain neutral phenomena, but experimental approaches choose a neutral mode of access, while phenomenology uses an access method pertaining to ipseity. In part, experimentation and phenomenology may not attain the same neutral structures. In part, however, they do, but then phenomenology uses an iconic approach (in the sense of the next section), while experimentation is reduced to an indexical *modus operandi*. Since both methods have intrinsic problems, it is worth employing both approaches.

5.3 A Sketch of Epistemology for Cognitive Semiotics

At least since the nineteenth century, there has been a kind of consensus according to which the domains of study and the modes of access to knowledge characterizing the natural sciences and the humanities are different (See [2, 3], and references given there). While 19th-century scholars did no doubt focus on this distinction in order to defend the humanities from the onslaught caused by the rising prestige of the natural sciences, the result, in the twentieth century, was for the former to be seen as forming the poor relations among the sciences. Changing their methods somewhat, parts of the humanities tried to get out of this opprobrium, not without some success, through calling themselves "the social sciences". In our time, cognitive semiotics may be seen as an attempt to acquire the social sciences ' advantages without losing those of the humanities.

In the process of establishing an epistemology for cognitive semiotics, we should not neglect the eighteenth-century contribution of Vico [34], who, in opposing the contemporary fad of Cartesianism, observed that, in our capacity of human beings, we could grasp the meaning of what other human beings have created, which clearly comprehends the general traits of (human) culture, but, by implication, also the different historically and socially situated instances of this culture, whereas knowledge of other things, such as nature, can only be more indirectly, and laboriously, gained. More recently, this idea was endorsed by the eminent linguist Coseriu [35]. Without referring to Vico, the semiotician Prieto [36] has suggested that we should inverse the common epistemological view, according to which the human and social sciences, which he terms the semiotic sciences, are subjective and the natural sciences are objective. In his view, since the semiotic sciences are concerned with things created by human beings, we can directly understand them, that is, being objective. In contrast, the natural sciences can only bridge the gap between human knowledge and nature by fashioning hypothetical models, which are thus necessarily subjective. Prieto observes that "the sound, as a material object, may have innumerable properties, but the phoneme, which is defined by its functional relations to the other plane of the sign, has a limited number of clearly defined features. The latter, but not the former, can be grasped by human consciousness" [37]. The obvious objection to this claim is that our knowledge of what we ourselves have created, in particular, if "we" stands for all of humanity, may, in the end, turn out to be somewhat obscure. More importantly, however, whatever knowledge we can gain in that way is never sufficient, even in linguistics, because we have to go below the level of what we, as language users, are ordinarily aware of, beyond the phoneme to the phonological features, and so on [6, 28]. Put in the traditional terms of hermeneutics, "we may say that, after coinciding with the user in his or her *understanding* of the phoneme, the semiotician goes on to explain the conditions of possibility of this understanding on the level of distinctive features. In this case, semiotics contains the knowledge of the user and *something more*" [25].

There are basically two procedures for going beyond what is directly given to human beings as meaning users. One of these procedures, which can be characterized as an iconic operation, may largely be the case for semiotic sciences, as Vico and Prieto think. The second one, which can be described as indexical, is fundamentally the same as that employed by the natural sciences.[1] Along the lines of what will henceforth be called the *Vichean-Prietean supermaxim*, it may be supposed that, since there is no way we, human beings, can make to get direct knowledge of nature, there can be no knowledge without indexical operations. In contrast, for the semiotic sciences, however paradoxical that may seem, iconic operations can be used to get more appearances while also needing, in specific cases, to have recourse to indexical operations. The first procedure is only possible because of the *sedimentation* of acts in the stream of consciousness, as described by Husserl [39]. According to Husserl, all our acts of consciousness (including but not limited to those accompanied with external manifestations) can only have a meaning which is funded on the "passive synthesis" of prior experiences, which is the result of acts of consciousness, which either occurred earlier in our own life (*genetic* sedimentation) or which is the outcome of acts of consciousness experienced by earlier generations of human beings (*generative* sedimentation). In their passive state, these sedimentations already form the basis of the assumptions permitting us to realize present acts of consciousness. But the procedures of phenomenology are designed to allow us to reactivate these sediments, clarifying their contribution to present meanings. As is clearly seen from Husserl's own manuscripts, this is a laborious and highly fallible procedure. Combining Husserlean and Peircean phenomenology, we could say that this is a way of delving deeper into iconicity.

There are two very different reasons why indexical procedures are also needed in the human sciences, including cognitive semiotics. In the first case, some facts are

[1] An aside for those who are familiar with semiotics: These terms are not used here to describe different kinds of signs, and not even, in the first case, a kind of ground. According to my meta-analysis of Peirce's different phenomenological characterizations of grounds [38], iconicity basically corresponds to the idea of "something being there", that is, it concerns direct perceptual experience. According to the same meta-analysis, indexicality involves something being added to such a direct experience, that is, some more indirect procedure.

simply not accessible to the human mind, and we are reduced to proposing relatively arbitrary hypotheses, which can be more or less well-founded, to the extent that they serve to connect a greater or lesser extent of nodes of observations, whether these observations are made with the naked eye, with some, relatively speaking, simple extensions of the eye such as microscopes and telescopes, or using positron emission tomography (PET)-scanning, functional magnetic resonance imaging (fMRI), and the like. In any case, these are probes into a matter which remains inaccessible to us, which is not to deny that the history of the (natural) sciences of the last 500 years has been the story of the extension of our ability to delve deeper into this black matter.

The second case is different, but it leads to a similar conundrum. In spite of our efforts to reanimate the sedimented layers of our consciousness, whether they were laid down genetically or generatively, our access to their meaning is often blocked. Using a term which has a history, since, after being coined by Ludwig Feuerbach, it was adopted and adapted by Karl Marx, and thus by all his followers, we might say that some kinds of sedimentations resist reanimation because they have become *reified*. This is why some approaches to the study of humans, particularly to social life, have adopted the indexical procedures characteristic of the natural sciences. A case in point is economics, which is certainly opaque to human consciousness, although it is clearly a human creation.

Charles Sanders Peirce, on the other hand, suggests in numerous passages [40] (e.g., CP 1.121, 1.81, 6.307, 6.315), that (natural) science is possible because we can start from presumptions about the connection between things (his "abductions"), which are more often right than wrong, due to some kind of affinity between the human mind and the laws of nature. This Peircean supermaxim could be understood as an extension of that of Vico and Prieto, but I have more difficulty in espousing it. It seems that, in the history of the natural sciences, human beings have often been wrong before being half right.

The lively 17th-century discussion between Newton's disciples, who claimed that light was made up of particles, and the followers of Huygens, who thought the light was composed of waves, has by now subsided, resulting in the consensus according to which light consists of something characterized as a wave-particle duality. Since human beings have no experience of anything which is both a wave and a particle, this can only be a metaphorical way of saying that some of the properties which are familiar to us from our experience of waves as well as some of those involving our experience of bodies can be shown to pertain to light, using the indirect procedures employed. That is, it does not tell us anything about what light is, only how it can be observed in different experimental situations. Such divergences between human understanding and physical models, the problematic nature of which Husserl [39] anticipated, have been exacerbated by the physics of quarks. This goes beyond the classical problem of explaining the results of scientific inquiry to the layman. It simply does not make sense to human beings, so we are reduced to using contradictory metaphors. Physics, it follows, is fundamentally based on indexical procedures.

But the difference between the natural sciences and the human and social sciences is not as clear-cut as this may suggest. The domain of study of medicine is the human body, yet we have direct, "iconic" access to it: you can perceive the inner organs with the naked eye, if first you take care to discard those parts of the body which form obstacles to your view. Indeed, it was not so long ago that physicians investigated the patient's urine sample by tasting it [41]. Nowadays, medicine disposes of many advanced indirect methods, such as fMRI, colonoscopy, ultrasound scans, and so on. Without there being any immediate relation between the change of methods and medical theories, it must also be said that medicine has had to liberate itself from a lot of theoretical baggage inherited, notably, from Hippocrates and Galen, which proves that, at least in medicine, assumptions are sometimes more wrong than right.

We have seen that many of the most important advances of psychology, which terms itself a social science and even of evolutionary theory, have been founded, wholly or predominantly, on iconic procedures. This is even true of evolutionary biology, which, as Gould [42] observes, is largely concerned with singular facts. To what extent this is also true of the "really hard" sciences, I must leave for others to decide. As compared to the classical humanities and even most of classical semiotics, cognitive semiotics makes much more use of indexical procedures. But it continues to maintain that iconic procedures are indispensable, and the access to them is a privilege which it holds on to since it is not given to all kinds of inquiries into knowledge.

6 Conclusion

In a way, this whole paper may be seen as a way of preparing to go beyond the experience of the hero of the novel by the Nobel prize winner Olga Tokarczuk [1] quoted at the beginning. Although it has no relation to theology, and most of the time not much relation to physiology, cognitive semiotics is an approach to a vast domain of knowledge, which can be characterized by the value "life", which coincides, in the general sense, with meaning: meaning-making, meaning-transference, and meaning-reception. It is concerned with these three modalities in which meaning is encountered at the level of ontogenesis, phylogenesis, and microgenesis. As for methods, cognitive semiotics employs all resources which can bring new facts to our knowledge, including, to a large extent, experimental design, and field studies. Still, it abides resolutely by the *Vichean-Prietean supermaxim*, according to which the surest access to meaning, however laborious, remains that of ipseity, or the first person. Since all endeavor for knowledge is fallible, all methods are called upon to bring their part, but in the field of consciousness pertaining to methodology, phenomenology is always thematic. In the case of language, this ideal has been realized, at least in part, by several pre-Saussurean and pre-Chomskyan scholars, as well as, more recently, by many scholars taking up the task after the epistemological night of the Chomskyan half-century. In the study of pictures, it is only recently that we have been able to make a start.

Core Messages

- Integrated science must start by analyzing the meaning of the terms, “science” and “integration”.
- Cognitive semiotics integrates semiotics and cognitive science’s domains, methods, and models, including neuroscience.
- We study pictures as percepts, and as a skill developed by children, as in psychology, but with a focus on meaning.
- We study the specific human ability for picture perception, as in archaeology and zoology, focusing on meaning.
- Cognitive semiotics integrates the sciences based on experience, i.e., meaning, whatever method is used.

References

1. Tokarczuk O (2017) Flights. Fitzcarraldo Editions, London
2. Sonesson G (2016) Epistemological prolegomena to the cognitive semiotics of evolution and development. Lang Semiot Stud 4:46–99
3. Sonesson G (2017) Beyond the “tragedy of culture”: in-between epistemology and communication. Am J Semiot 33(3–4):141–180
4. Sonesson G (2019) La sémiotique cognitive: le même et l'autre de la sémiotique structurale. In: Bigliari A (ed) La sémiotique et son autre. Editions Kimé Paris, pp 147–60
5. Sonesson G (2021) Nothing human is foreign to me — except some of it: from the semiotic tradition to cognitive semiotic by the way of phenomenology. Degrés 186–187:b1–b23
6. Sonesson G (2021) Considerations on the subtle art of integrating linguistics (and/or semiotics). In: Willems K, Munteanu C (eds) Eugenio coseriu: past present and future, pp 151–164
7. Gurwitsch A (1964) The field of consciousness. Duquesne University Press, Pittsburgh
8. Arvidson PS (2006) The sphere of attention: context and margin, vol 54. Springer Science & Business Media
9. Sonesson G (2011) Semiotics inside-out and/or outside-in. How to understand everything and (with luck) influence people. Signata Annales des sémiotiques/Ann Semiot 2:315–348
10. Sonesson G (2014) The cognitive semiotics of the picture sign. In: Machin D (ed) Visual communication. De Gruyter Mouton, pp 23–50
11. Zlatev J (2015) Cognitive semiotics. In: Trifonas P (ed) International handbook of semiotics. Springer, pp 1043–1067
12. DeLoache JS (2004) Becoming symbol-minded. Trends Cogn Sci 8(2):66–70
13. Tomasello M, Call J, Gluckman A (1997) Comprehension of novel communicative signs by apes and human children. Child Dev 68(6):1067–1080
14. Lenninger SM (2012) When similarity qualifies as a sign: a study in picture understanding and semiotic development in young children. Doctoral dissertation, Lund University
15. Sonesson G (2013) The picture between mirror and mind: from phenomenology to empirical studies in pictorial semiotics. In: Sachs-Hombach K, Jörg S (eds) Origins of pictures: anthropological discourses in image science, Acts of the conference in Chemnitz, March 30–April 1, 2011. Halem Verlag, pp 270–310

16. Zlatev J, Madsen EA, Lenninger S, Persson T, Sayehli S, Sonesson G et al (2013) Understanding communicative intentions and semiotic vehicles by children and chimpanzees. Cogn Dev 28(3):312–329
17. Eco U (2000) Kant and the platypus: essays on language and cognition. Harcourt Brace & Co., New York
18. Sonesson G, Lenninger S (2015) The psychological development of semiotic competence: from the window to the movie by way of the mirror. Cogn Dev 36:191–201
19. Lenninger S, Persson T, van de Weijer J, Sonesson G (2020) Mirror, peephole and video-the role of contiguity in children's perception of reference in iconic signs. Front Psychol 11:1622
20. Hribar A, Sonesson G, Call J (2014) From sign to action: studies in chimpanzee pictorial competence. Semiotica 2014(198):205–240
21. Sonesson G (2019) The Psammetichus syndrome and beyond: five experimental approaches to meaning-making. Am J Semiot 35(1–2):11–32
22. Donald M (1991) Origins of the modern mind: three stages in the evolution of culture and cognition. Harvard University Press
23. Sonesson G (2017) Greimasean phenomenology and beyond: from isotopy to time consciousness. Semiotica 2017(219):93–113
24. Donald M (2010) The flexographic revolution: neuropsychological sequelae. In: Malafouris L, Renfrew C (eds) The cognitive life of things: recasting the boundaries of the mind. Cambridge, McDonald Institute for Archaeological Research, pp s71–79
25. Sonesson G (2008) From the meaning of embodiment to the embodiment of meaning: a study in phenomenological semiotics. In: Ziemke T, Zlatev J, Frank R (eds) Body, language and mind, vol 1, Embodiment. De Gruyter Mouton, pp 85–128
26. Green J (2014) Drawn from the ground: sound, sign and inscription in central Australian sand stories. Cambridge University Press
27. Dunér D, Sonesson G (2016) Human lifeworlds: the cognitive semiotics of cultural evolution. Peter Lang Publishing Group
28. Sonesson G (1989) Pictorial concepts: inquiries into the semiotic heritage and its relevance to the interpretation of the visual world. Lund University Press, Sweden
29. Sonesson G (2010) Pictorial semiotics. In: Sebeok TA, Danesi M (eds) Encyclopedic dictionary of semiotics
30. Rosenthal V (2004) Microgenesis, immediate experience and visual processes in reading. In: Carsetti A (eds) Seeing, thinking and knowing. Springer, pp 221–243
31. Zlatev J (2009) The semiotic hierarchy: life, consciousness, signs and language. Cogn Semiot 4(Supplement):169–200
32. Sonesson G (2015) Le jeu de la valeur et du sens. In: Biglari A (ed) Valeur. Aux fondements de la sémiotique. L'Harmattan, Paris, pp 85–100
33. Dennett D (2003) Who's on first? Heterophenomenology explained. J Conscious Stud 10(9–10):19–30
34. Vico G (1988) On the most ancient wisdom of the Italians: unearthed from the origins of the Latin language: Including the disputation with the Giornale de'letterati d'Italia. Cornell University Press
35. Coseriu E (2003) Geschichte der Sprachphilosophie von der Antike bis zur Gegenwart 1. Von den Anfüngen bis Rousseau. A. Stuttgart: Francke
36. Prieto L (1975) Essai de linguistique et sémiologie générale. Droz, Genève
37. Sonesson G (2001) The pencils of nature and culture: new light on and in the lifeworld. Semiotica 136:27–53
38. Sonesson G (2013) The natural history of branching: approaches to the phenomenology of firstness, secondness, and thirdness. Signs Soc 1(2):297–325
39. Husserl E (1954) Hua 6: Die Krisis der europäischen Wissenschaften und die transzendentale Phänomenologie: eine Einleitung in die phänomenologische Philosophie. Nijhoff, The Hague
40. Peirce CS (1998) CS 1931–1958. Collected papers, I–VIII. Harvard University Press, Cambridge

41. Johannisson K (2004) Tecknen: läkaren och konsten att läsa kroppar. Norstedts Förlag, Stockholm
42. Gould SJ (1999) Rocks of ages: science and religion in the fullness of life. Ballantine, New York
43. Sonesson G (2005) Semiotiska perspektiv på perspektiv. In: Hellberg S, Rossholm G (eds) Att anlägga perspektiv. Stehag, Stockholm

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3 Scientific Thinking: A Mindset for Everyone

Osman Yaşar

Only he who, himself enlightened, is not afraid of shadows.

Immanuel Kant

Summary

It is difficult to instill beginners with experts' habits of mind. Young children, for example, frequently lack the content knowledge and practice skills required to engage in scientific thinking (ST) processes. Furthermore, the cost of supplying them with a laboratory to undertake scientific research could be prohibitive. Linking ST to basic cognitive processes could be a solution, allowing us to narrow down ST skillsets to more fundamental competencies that can be taught to students. By merging relevant concepts from the literature with decades of empirical data on science education, this chapter attempts to present a theoretical framework to link scientific thinking to everyday thinking. The chapter proposes a call for action to emphasize ST education for both the students and the general public. While non-scientists employ ST processes the same way as scientists do, not everyone uses them as iteratively, regularly, or methodologically as scientists. With the myths around scientific thinking cleared away, we should feel confident and empowered to tackle unfounded assumptions and taboos that have haunted us for generations.

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N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_3

Graphical Abstract/Art Performance

Scientific thinking: a mindset for everyone.
The calligraphy of a poem by Rumi 1207–1273.
It includes a distich:
Say not all are fighting; what use is my lone call for peace?
You're not one, but thousands; light your beacon.
It expresses how a mindset can be powerful in thinking.
(Adapted with permission from the Association of Science and Art (ASA), Universal Scientific Education and Research Network (USERN); Made by Reihaneh Khalilianfard).

Keywords

Computational thinking · Conceptual change · Inductive and deductive reasoning · Modeling and simulation · Scientific thinking

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

There are two major myths about science education. One is that scientific thinking (ST) is a linear process, which has been perpetuated to this day by textbooks and instructional resources. This linear process starts with making observations, building a hypothesis, making predictions, and conducting experiments to test the validity of the hypothesis [1]. The other myth is that scientific thinking is a special state of mind that only scientists get to have, use, and enjoy. However special the scientific mindset might be, understanding the mind of a scientist is key to science education because learning theories claim that students would learn science better if they did it in a way to emulate how scientists think and work. Such understanding could even have implications beyond science education because many believe that the ST skillset may be narrowed down to fundamental cognitive competencies that are no different from those of ordinary thinking. If that is true, then we can teach scientific thinking to everyone.

Even though learning theories and educational frameworks recommend that we teach kids essential scientific thinking skills [2], constructivist science activities have yet to be fully integrated into the relevant grade-level curriculum. It is difficult to instill beginners with experts' mental habits. Young children, for example, frequently lack the content knowledge and practice skills required to engage in scientific thinking processes. Furthermore, the cost of supplying them with a laboratory to undertake scientific research could be prohibitive. Therefore, linking scientific thinking to basic cognitive processes could be a remedy, allowing us to narrow down its skillset to more fundamental competencies that can be taught to novices [3–5].

This chapter attempts to link ST to fundamental cognitive processes by using a computational model of the mind that is in line with the latest findings in several disciplines. This model is based on the premise that a computational device may generate cognition from information processing. It also assumes that the universal characteristics of information may dictate how a computational device, be it electronic or biological, processes the incoming information. For example, as articulated by Yaşar [6], a duality in distributive/associative characteristics of quantifiable information, addition/subtraction modes of fundamental computation, and scatter/gather aspect of information storage/retrieval by a distributed network of neurons in the brain appear to lead to an inductive/deductive duality in fundamental cognitive processing. Furthermore, theoretical considerations and empirical studies from epistemology, neuroscience, educational psychology, and computing and cognitive sciences indicate that these cognitive processes' iterative and cyclical dynamics are the essence of thinking and conceptual change. We all use them, but not with the same consistency, frequency, or methodological rigor as scientists. The following sections will introduce a brief history of scientific thinking, along with a discussion of its cognitive essence and a way to promote it in science education.

2 Brief Definition and History

The thought process in a scientist's experimental, theoretical, and computational study is now referred to as scientific thinking (ST), which was previously known as the scientific method. A scientist's skills during an investigation encompass a set of processes that pervade the field of science as well as the content of sciences. Problem-solving, development and testing of hypotheses, concepts, and models, conceptual transformation, and a collection of reasoning skills (deductive, inductive, abductive, causal, and analogical) are among the ST skills identified in the present literature and briefly listed in Table 1 [3].

While scientists like Galileo and others laid the groundwork for scientific knowledge through observations and experiments, philosophers debated for two more centuries whether a scientist's subjective perspective of the universe could be deemed objective and real knowledge [7, 8]. Some of these thinkers (mostly the empiricists) stated that the mind is a blank slate that learns through perceptions and experiences as well as generalizations and conclusions derived from these experiences in an associative (bottom-up) manner through inductive reasoning. Other

Table 1 Cognitive processes involved in scientific thinking [3]

1. Problem-solving	6. Reasoning	6a. Deductive Reasoning
2. Design and modeling		6b. Inductive Reasoning
3. Hypothesis testing		6c. Abductive Reasoning
4. Concept formation		6d. Causal Reasoning
5. Conceptual change		6e. Analogical Reasoning

philosophers (such as the rationalists) thought that knowledge is first gained through innate concepts, which then serve as a source of more information derived from them in a distributive (top-down) manner through deductive reasoning. Figure 1 represents a simple illustration of associative and distributive ways of information processing.

Kant merged these competing views to suggest the scientific method's cognitive essence as a two-way process of *inductive reasoning* (synthesis) and *deductive reasoning* (analysis) [7]. It has been through an iterative and cyclical process of synthesis and analysis that science has progressed over the years at both the societal and individual levels [4, 8]. The way science is done should shape how new generations are educated, yet unfortunately, the scientific method is still being taught as a one-way linear process of synthesis for many reasons. First and foremost, the way it is being taught ignores the top-down process, shown in Fig. 1, by which theories get re-examined, broken down to smaller elements, and changed over time. We dislike change on a cultural and psychological level because it threatens our mental stability. Also, because of limited resources and the attention needed to answer new questions, revisiting previously addressed inquiries or theories has been a low-priority and slow process often spanning decades. Growing resources and new technologies, however, have recently accelerated scientific progress by encouraging us to revisit previously established conclusions at a much faster rate. As such, we should then teach students not only the synthesis and analysis parts of the scientific process but also their non-linear occurrence. Many students have a tendency to cling to their preconceptions and misconceptions. Teaching them deductive thinking (analytical) skills is as important as facts-and-data driven inductive thinking (synthesis) skills. Furthermore, teaching students (as well as teachers) a cognitive understanding of scientific thinking and how such expert thinking relates to the everyday thinking of a non-scientist could help eliminate the myths and stigma surrounding science education.

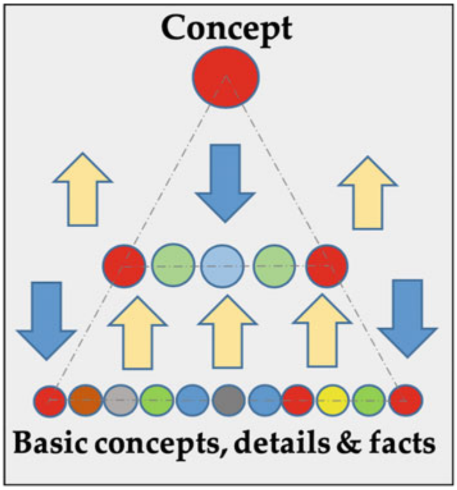


Fig. 1 Distributive and associative way of information storage and retrieval (Adapted from [6], copyright held by the author)

While the scientific methodology was introduced several centuries ago [7], our understanding of its cognitive essence has only been possible recently through the use of new imaging technologies and computational modeling techniques. Cognitive psychologists increasingly use imaging techniques to investigate how we all see, remember, and think. They also explore what brain areas are involved in crucial perceptual and cognitive processes during scientific inquiry and problem solving by monitoring scientists' brain functioning. At the same time, new techniques are being used by neuroscientists to better understand the brain systems that are activated throughout the learning process. Development and education psychologists use all these findings to construct human development theories and how they might be applied to education. Other theoreticians, such as cognitive scientists, also create mental models to investigate how the brain may be generating cognition through information processing and computation [9].

Since the inner workings of our brains appear to resemble, to some extent, those of the electronic computers, having such tools in the hands of scientists in the past several decades has generated some evidence as to how a scientist's own thinking resonates with certain uses of such tools. One of the insightful uses of electronic computers in scientific research and engineering design has obviously been modeling and simulation [10]. Electronic computers have recently proven to be particularly useful since they speed up the model construction and testing of many scenarios, allowing researchers and engineers to enhance their initial models quickly. Computational modeling and simulation technology (CMST) has been very effective in scientific and industrial research. In high-stakes scenarios, CMST's forecasts of natural phenomena (e.g., weather, storms) and product performance and safety (e.g., engines, planes) accurately match the behaviors of real-life physical models. When a study is impractical to conduct experimentally because of its size (too large such as the cosmos, or too small such as subatomic systems), ambient conditions (too hot or dangerous), or expense, CMST appears to be all we have as a methodology to tackle the problem at hand. The bottom line is that computation is indeed a major pillar of scientific study, besides theory and experiment [10]. Having used computational modeling and simulations to solve challenging science and engineering problems at a national laboratory for many years [11] and also having worked as a computational science educator later in higher education and K-12 for more than two decades [5, 6, 12–17], I here present a view on cognitive essence of scientific thinking as a follow up to earlier work [6] on cognitive processes involved in everyday use of information storage, retrieval, and processing by our brains.

3 The Essence of Scientific Thinking

While imaging techniques help neuroscientists and cognitive psychologists locate the brain parts where cognitive functions are occurring [3, 4, 18], understanding how cognition is generated from the electrical activities of neurons is still limited due to the complexities of the brain and the lack of direct access to it. As a remedy, we use models of the mind to relate cognition to information processing, storage, and retrieval. Thanks to Alan Turing [19], his electronic imitation of the brain has grown to display many structural and operational similarities with the brain in a way to help us form a relationship between computation and cognition. Thanks also to Donald Hebb [20], a neuropsychologist, we now know that the brain, just like today's electronic computers, uses distributed hardware (i.e., neurons) for information storage, retrieval, and analysis. That is, information is retained in memory as a distributed pattern and pathways of neurons, with retrieval requiring an associative reassembly of the original pattern. This reassembly is regarded by some neuroscientists as an act of re-imagination, which either adds some holes or extra bits to the original pattern. In many ways, storing and retrieving information appear to be similar to the act of thinking [21].

A consolidated view of information storage/retrieval and thinking supports an argument that the associative and distributive nature of quantifiable information, as shown in Fig. 1, determine how information would be handled optimally by any device that operates on it [6, 12]. As such, our brain's current structural and operational state may just be an evolutionary response to thousands of years of optimizing how better to handle distributive and associative operations of sensory information. We have seen a similar evolution with electronic computing devices since their first design by Alan Turing eighty years ago. For example, not only data and instruction are now being handled the same way, but also centralized hardware designs of the old days have evolved into distributed structures to optimize storage, retrieval, and processing of information.

Even so, we stop short of equating mental representations with information processing since it ignores the significance of mental experiences [9]. Furthermore, the efficiency with which the human mind operates is still unrivaled. We appear to have two competing brains: one that tries to simplify things, while another that wants to dig deeper—a dual operation that mirrors the natural flow of information processing in Fig. 1. Neuropsychologists and evolutionary biologists believe the main cause is a structural tendency by an autopilot limbic system to bypass, simplify, or minimize more complex cognitive tasks of a developed neocortex [22]. Cognitive scientists such as Montague [9] rather point to some non-structural tendencies (e.g., concern for efficiency/survival) which drive the mind to attach value, cost, and goals to our thoughts via computations, modeling, and simulations of various scenarios.

Montague claims that the human brain employs modeling and simulation (M&S) not just to represent external objects mentally but also to wrap up and compare its own computations before making a decision. Then, those who use electronic devices in the same fashion should greatly enhance their cognitive functions. Rightly so, empirical evidence supports the effectiveness of M&S in scientific inquiry by experts [10, 11] and in learning by novices [14–16, 23]. One of the benefits of modeling is that it simplifies reality by removing details and directing the focus on what is being studied/learned. Before delving into the underlying specifics, modeling allows the researcher/learner to comprehend significant facts surrounding a topic. As such, the process of modeling and simulation mirrors the scientific method described by Kant [14–16]. That is, a prior concept/theory (a model) is first deductively analyzed and broken down into its sub-models for testing and analysis. The sub-models are then updated, if necessary, and put back together inductively (i.e., synthesis) to create a new or a modified version of the previous model/theory.

Table 2 illustrates a commonly used terminology that describes various cognitive processes involved in scientific thinking. Words in each column have the same connotation, while words in each row describe poles of a dichotomy. At the core of our simplistic ST framework (Fig. 2) lies the root cause for such dichotomy: associative and distributive ways of information storage, retrieval, and processing [5, 6]. While we are all capable of computationally generating cognition from the two fundamental modes of information storage, retrieval, and processing [4, 9], not everyone utilizes them in the same way that scientists and engineers do–i.e., iteratively, cyclically, consistently, regularly, and methodologically. For example, while people casually form an idea, a concept, a model, or a design in their lives as a form of associative (inductive) processing, when such a thing is methodologically formed and examined by scientists, it is known to have led to major theories, including the discovery of a specific bacterium as the cause of many ulcers and the discovery of planet orbits as the representation of astronomical observations [4]. Furthermore, when associative processing of information is automated beyond the capacity of scientists, it then is known, in the form of inductive algorithms in data mining, to have generated in a few days what research programs took decades [4, 24].

We all use inductive and abductive reasoning in our everyday lives. This type of associative information processing is utilized to filter out details and concentrate on the larger patterns, assigning priority and relevance to freshly acquired data. It aids our brain by reducing, categorizing, and registering crucial facts and knowledge for faster retrieval and processing, especially in its early phases. It is astonishing how

Table 2 A common terminology to describe ST dichotomy

Actions	Addition	Subtraction
	Associative processing	Distributive processing
	Synthesis	Analysis
	Inductive/abductive reasoning	Deductive reasoning
	Packing	Unpacking
	Abstraction	Decomposition
	Uniting	Breaking down
	Gather	Scatter
Outcomes	Whole	Parts
	Model	Submodels
	Generalized information	Details
	Hypothesis	Observations/facts
	Concept	Observations/facts

Fig. 2 The essence of scientific thinking in terms of our typical cognitive processes (Adapted from [6], copyright held by the author)

humans use these reasoning skills to build powerful generalizations from confusing and scarce facts. Abductive reasoning is a watered-down version of inductive reasoning, especially when there is not sufficient data to draw concrete conclusions [3]. Scientists use abductive reasoning to make estimates or generate assumptions until further data is available to turn the data into a hypothesis. Engineers use it more heavily because incomplete data set and uncertainty motivate them to find an optimum solution from limited and feasible options [25].

Inductive/abductive thinking, also known as abstraction, can be thought of as the wrapping (modeling) of objects. If so, then unwrapping, examining, and updating the contents of such a model or construct against changed conditions at a later time is needed for its evolution. As a result, it is just as vital to decompose (analyze) a concept, a package, or a model in a distributive manner as it is to construct it in an associative manner. Decomposition (a form of deductive reasoning) goes hand in hand with abstraction. Where there is an abstraction, there is decomposition before or after it because a breakdown often follows the unification of quantifiable things.

Deductive reasoning analyzes previously established theories and concepts to discover new situations that these theories might be tested on. Re-examination of theories under changing conditions and observations is part of how science advances [8]. Deductive reasoning uses distributive processing and is similar to dismantling or separating a generalization (a whole) into its constituents (parts) for further investigation. In our daily lives, we all use deductive reasoning. It aids in analyzing complex circumstances by breaking them down into smaller, more manageable chunks (scatter). Then, we attack each item one by one until we arrive at a total solution (gather). The famous "divide and conquer" statement, attributed to Napoleon, demonstrates how important such thinking is to the general public. Deductive reasoning is utilized more frequently in engineering than inductive and abductive reasoning. It looks at how well-known scientific concepts and engineering designs can be applied to various situations and issues [25].

As illustrated in Fig. 1, iterative and cyclical use of inductive and deductive reasoning becomes the fundamental essence of conceptual change that we all use for learning [26]. Conceptual change is the process of iteratively forming, testing, and modifying a theory, design, or model in science and engineering. The process of modeling and simulation is an important mechanism by which conceptual change occurs, both electronically and biologically, though more expeditiously with electronic computers than with the human mind.

Prior to synthesizing new concepts or analyzing existing ones for additional testing under new circumstances, it is important to connect all relevant pieces of information via searching and sorting. Both causal reasoning (to build cause and effect relationships) and analogical reasoning (the formation of analogies between different variables) are intertwined with and dependent on searching, sorting, and other aspects of scientific thought that we have examined thus far [3]. For example, causal reasoning is crucial in connecting unexpected or accidentally discovered findings. Many scientific discoveries have actually been of an unexpected nature, thereby requiring scientists to utilize causal model-building, analogical reasoning, and problem-solving to identify and prove the relationships [4]. Engineers use analogical reasoning very often, as they tend to defend their choices of optimal design solutions by citing precedents, or they start with a design that has already been employed in another application [25].

In the literature, problem-solving is defined as a search within two connected spaces: hypothesis (conceptual) and experiment (empirical). Each space contains all of the potential states of its kind, as well as all of the procedures a problem solver can use to move from one state to the next. Researchers Klahr and Dunbar [18] found that each space-constrained search in the other during problem-solving, and participants moved between hypothesis and experiment spaces, similar again to the dynamics in Fig. 1.

According to Paul Thagard [4], scientific thought processes are no different from those used by non-scientists in everyday life. What he meant is that their essence is the same and that the difference comes from how they are used. The utilization of information processing, storage, and retrieval would vary for each person. While the underlying brain hardware and the quality and quantity of sensory input we each receive from our environment determine how each of us utilizes our brain's computational capacity, we are all naturally inclined to employ both associative- and distributive-aspects of information processing and the inductive/deductive reasoning that they support. However, not all of us are equally aware of the value and significance of these reasoning skills, nor do we all completely exercise and utilize them. By judging from success stories of scientists or scientific discoveries in the past [3], we expect an ideal scientist to be a person who uses the mind's capacity for associative/distributive processing of information in an iterative, cyclical, consistent, and methodological way in order to acquire a habit of conceptual change. Of course, in reality not all scientists think and work the same way. All in all, how these processes are used distinguishes scientific thinking from ordinary thinking. The good news is that, with training, knowledge, and experience, such capacity can be developed beyond what is inherited. And, this is what often motivates educators like us to demonstrate that there exist some tools, such as modeling and simulation, to facilitate scientific thinking.

4 Conclusion

There are a lot of similarities between electronic and biological computing devices as to how they store, retrieve, and process information. This is arguably due to an invariant (associative and distributive) nature of information that optimally resonates with any computing device which handles it in such a manner. The root of associative and distributive nature of information is no different than that of the granular matter itself. They both involve ontological constructs that behave computationally–either by uniting associatively to form larger constructs or by breaking down distributively to form smaller constructs. And, the entire dynamics of all quantifiable objects has been shaped by an iterative and cyclical process of this behavior [13]. It has certainly been employed by the universe in its evolution for billions of years. We humans also use it because we have a computational mind which operates on quantifiable information. Any mind that uses it consistently, frequently, and methodologically–like that of scientists and engineers–should evolve to become smarter, more knowledgeable, and freer of misconceptions and preconceptions.

Many core elements of ordinary (and expert) thinking can then be viewed as forms of associative and distributive processing, scatter and gather way of information storage and retrieval, as well as searching and sorting in conceptual and empirical spaces; all of which are prompted by sensory input or result from inter-neuron communication. Such a simple cognitive framework could help us narrow down scientific thinking skills to more basic competence that even novices can learn. The good news is that such skills can be improved, through education and experience, beyond what we inherit. Slow or fast, our minds will one day gain a more universal awareness that would free us of unfounded assumptions that have haunted us for generations. Yet, we can set the pace of this progress to save time and to minimize loss.

The history of science education suggests that the way science is done impacts how new generations are educated. Science done computationally in the past several decades has been well recognized and even received several Nobel prizes. The cognitive benefits of a cyclical/iterative deductive and inductive approach to the scientific method and the use of electronic devices to expedite such an approach via modeling and simulation are well recognized now. Its impact on education has been the introduction of many undergraduate and graduate courses and degree programs in computational science and teacher education [14–17]. The author has been at the forefront of this computational revolution from the beginning through his efforts of establishing the first undergraduate degree and teacher education programs in computational science and of his advocacy of such programs through his testimonies before the U.S. Congress and funding agencies. Thanks to funding and encouragement from the U.S. National Science Foundation, relevant professional societies, and the State governments, computational thinking is now being taught in a growing number of K-12 schools. The computational thinking reform has now taken on a worldwide global character as many other countries are starting similar initiatives. The author believes that scientific thinking education also needs to ramp up its own efforts as the time has come now to expand the ongoing computational reform to pre-college education of our students as well as general education of the public itself. After all, scientific thinking is a mindset for everyone, not just the scientists.

Core Messages

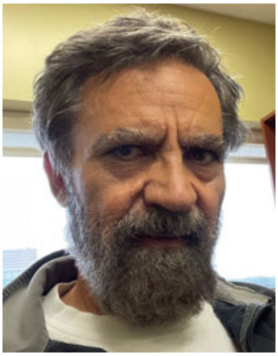
- We can teach everyone how to think like a scientist.
- The two core elements of scientific thinking are deductive thinking (analysis) and inductive thinking (synthesis).
- The scientific method that is currently being taught in schools does not reflect how science is done these days.

Acknowledgements The author acknowledges support from the U.S. National Science Foundation. His views are not necessarily those of his employer or the U.S. federal government.

References

1. Bauer HH (1992) Scientific literacy and the myth of the scientific method. University of Illinois Press, Chicago, IL
2. National research council report (2012) A framework for K-12 science education: practices, crosscutting concepts, and core ideas. National Academies Press, Washington, DC
3. Dunbar KN, Klahr D (2012) Scientific thinking and reasoning. In: Holyoak KJ, Morrison RG (eds) The oxford handbook of thinking and reasoning. Oxford University Press, London, pp 701–718

4. Thagard P (2012) The cognitive science of science. The MIT Press, Cambridge, MA
5. Yaşar O, Maliekal J, Veronesi P, Little L (2017) The essence of scientific and engineering thinking and tools to promote it. In: Proceedings of the American society for engineering education annual conference. Paper ID: 18172
6. Yaşar O (2018) A new perspective on computational thinking. Comm ACM 61(7):31–37
7. Kant I (1787) The critique of pure reason. (Meiklejohn JMD, Translated). eBook@Adelaide. The University of Adelaide Library, Australia
8. Kuhn T (1962) The structure of scientific revolutions. The University of Chicago Press, Chicago, IL
9. Montague R (2006) How we make decisions. Plume Books, New York, NY
10. National Science Foundation (NSF) Report (2006) Simulation-based engineering science: revolutionizing engineering science through simulation. Washington, DC
11. Yaşar O (2001) A new ignition model for spark-ignited engine simulations. Parallel Comput 27(1):179–200
12. Yaşar O (2017) The essence of computational thinking. Comp Sci Eng 19(4):74–82
13. Yaşar O (2017) Modeling and simulation: how everything seems to form and grow. Comp Sci Eng 19(1):74–77
14. Yaşar O (2016) Cognitive aspects of computational modeling and simulation. J Comput Sci Educ 7(1):2–14
15. Yaşar O, Maliekal J, Veronesi P, Little L, Vattana S (2015) Computational pedagogical content knowledge. In: Liu L, Gibson DC (eds) Research highlights in technology and teacher education. Association for the advancement of computing in education, pp 79–87, ISBN: 978–1–939797–19–3
16. Yaşar O, Maliekal J (2014) Computational pedagogy. Comp Sci Eng 16(3):78–88
17. Yaşar O, Landau R (2003) Elements of computational science and engineering education. SIAM Rev 45(4):787–805
18. Klahr D, Dunbar K (1988) Dual space search during scientific reasoning. Cogn Sci 12(1):1–48
19. Turing AM (1936) On computable numbers, with an application to the entscheidungs-problem. In: Proceedings of the London mathematical society, series 2, vol 42, pp 230–265
20. Hebb D (1949) The organization of behavior. Wiley, New York
21. Brown PC, Roediger HL, McDaniel MA (2014) Make it stick. The Belknap Press of Harvard University Press, Cambridge, MA
22. Evans J, Frankish K (2009) In two minds: dual processes and beyond. Oxford University Press, Oxford
23. Smetana LK, Bell RL (2012) Computer simulations to support science instruction and learning: a critical review of the literature. Int J Sci Edu 34(9):1337–1370
24. King RD (2011) Rise of the robo scientists. Sci Am 54(1):73–77
25. Lucas B, Hanson J, Claxton G (2014) Thinking like an engineer. A report for the royal academy of engineering. ISBN: 978-1-909327-09-2
26. Carey S (1985) Conceptual change in childhood, 1st edn. MIT Press, Cambridge, MA



Osman Yaşar has a broad education background (Ph.D. and BS in engineering physics and MS degrees in computer science, nuclear engineering, and physics) and has been at the forefront of the computational revolution in industrial research, academia, and public schools. He developed massively parallel codes to solve grand challenge problems in science and engineering at Oak Ridge National Laboratory, established the world's first undergraduate degree program (and department) in computational science at the State University of New York (SUNY), and taught computational thinking to more than 1,200 school teachers in Upstate New York. He has been a Principal Investigator on many projects supported by the U.S. National Science Foundation, recognized as a national icon in his native country, and he has testified before the U.S. Congress on the virtues of a computational approach to science, technology, engineering, and mathematics (STEM) education and research. He currently holds a SUNY Empire Innovation professorship at the College at Brockport.

4 Integrated Education

Brian Lighthill

...the happiness of mankind comes from education, which is about learning how to develop mental facilities, how to express opinions and how to develop dialectic reasoning.

Aristotle

Summary

In this chapter, I will argue that based on my action research and based on a decade of peripatetic work in schools and other further education settings, pedagogic practice as is does not achieve the results needed by the 21st-century learner–that of becoming an independent, flexible, creative, problem-solving thinker. By the transdisciplinary exploration of selected Shakespearean stories from the literature curriculum in parallel with the personal and social development syllabus, this chapter will champion the benefits–for both students and teachers alike–of integrated education. I discovered that in an age of readily available information, the teacher's role is less as a provider of knowledge in subject-specific silos and more as an impartial facilitator who stimulates learners of all ages to develop their mental faculties, encourages them to vocalize their ideas and, though the Socratic method, become receptive to investigating and discussing the truth of other opinions.

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N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_4

Graphical Abstract/Art Performance

Integrated education.

(Adapted with permission from the *Health* and Art (HEART), Universal Scientific Education and Research Network (USERN); Painting by Polina Abramova).

Keywords

Impartial facilitator · Integrated education · Personal and social development (PSD) · Shakespeare · Socratic method · Transformational teaching

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction to the Chapter Title–Unpacked

I have a dream. And my dream can be described in one sentence:

> I dream that the primary aim for all education is to develop the ability of learners to think for themselves.

This would be a humanistic way of thinking about an educational system that aims to empower students rather than treat them like empty vessels into which facts are poured [20].

The education system in the UK is what Apple (2004) [1] calls a de-humanistic process: "cultural transmission" which "processes" both knowledge and people (pp. 32–33) in "factories of order" (Gardner et al., 2000, cited in [15], p. 12)–better known as a "school". What my research has shown me is that instead of teaching knowledge in silos–one subject in isolation to all other subjects–a deeper epistemology would be transdisciplinary study–or "integrated education".

Recognition of three extant approaches to pedagogic delivery brings clarity to this debate:

i. *first*, there is "transmission teaching", which is the traditional one-way transfer of knowledge, skills, and values from teacher to the learner;
ii. *second*, "transaction teaching", which emphasizes problem-solving through a process of pupil/teacher interaction; and
iii. *third*, "transformation teaching", which is holistic and non-compartmentalized and factors in cognitive, moral, spiritual, and socializing needs [9].

The dominant methodology is transmission teaching, where students learn to accept that knowledge has been logically organized for their benefit [9]. However, Reid and Scott's (2005) [47] analyses indicate that education should not just be about acquiring subject knowledge–training the learner for the workforce–but acquiring the skill to transfer knowledge–learning for life. Buzan and Dixon's (1978) [8] research concluded that the mind does not generally think according to a "collection code" ([6], p. 231) but in images, keywords, and linked patterns using an "integrated" system (Ibid.) and that there was an enormous improvement in the performance of learners who substitute mind patterns for the more traditional method of approaching and organizing information.

When allowed to, students grab pieces of information that have many hooks attached to them. This act encourages enquiring minds and self-motivated higher-order cognition as tangential ideas and a holistic picture of the curriculum (Ibid.) comes into focus. But, as Paechter (1995) [41] wrote, are Buzan and Dixon's ideas realistic in an education system that struggles to think "outside the boxes of subject specificity/particularity" (p. 99)?

Three quotes bring me to the foundations on which the conceptual framework of my research was built:

i. *first,* that "the purpose of education is to lead children towards intellectual development" ([48], p. 4);
ii. s*econd*, that the aim of education is "learning to learn" ([43], p. 30); and
iii. *third*, which synthesizes the first two that the happiness of humankind comes from education for life, which is about learning how to develop mental facilities, how to express opinions, and how to develop dialectic reasoning [2] or, as Nelson (1965) [39] wrote, "making philosophers of the students" (p. 1).

Finley (2005) [12] advocates that the aim and objective of pedagogy are for children to embrace their understandings of themselves and society and, in so doing,

> encourage them to imagine all that they can do and be in their lives (Ibid., p. 690).

Finley (2005) [12] writes that the teacher's task is to provide tools for constructing new autobiographical images by taking students back to the past to contextualize their present inheritance of a previous society's discoveries and then point learners towards exploring their own *possible* futures [16]. This is a humanistic way of thinking about an educational system that aims to empower students rather than treat them as empty vessels into which facts are poured [20].

The 1988 "Education Reform Act" (cited by [37]) laid out a national curriculum for the UK. It noted three core and ten foundation subjects that could benefit from various types of integrated curricular provisions–skills such as communication, problem-solving, and study skills could be taught cross-curricular; as could economic and industrial understanding; environmental education; health education; individual, family and community awareness; and national, European, international legal and political dimensions. Further development on integrated education thinking came as a result of the Dearing Report (1994), which advocated a reduction of curriculum content by “working towards the greater integration of school subjects” (cited in [41], p. 102)—but, as Fullan (1999) [14] noted, such blue-sky thinking was based on idealism, rather than executive *or* teacher consensus.

Whitty et al. (1994) [58] defined integrated education as organic planning and horizontal learning, which arises from the real-life context in a complex world. However, until there is clarity on the benefits of a well-planned integrated curriculum as a way of dealing with a crowded timetable, as a way of saving students time, and as a way of allowing them to carry out longer, more open, and more substantial tasks [41], teachers will struggle to embrace interdisciplinary pedagogy and support the claim that knowledge could be interrelated [26]. It can be argued that only when the relationship between learning-in-school and learning-for-life is recognized will there be a move towards an integrated timetable.

Because of my journey through life (which I will explore in more detail in Sect. 2), I have three primary interests which I want to share with learners of all ages. The first is my love of William Shakespeare’s work; the second and third are the two ‘social science studies’ on the curriculum, which are clumsily known as: “personal, social, health and finance education” or PSHFE and “citizenship” or Citz–which, for the sake of brevity and clarity I conflate into: personal and social development (PSD).

PSD are the learning for life skills that will continue to be relevant to the students as they journey along their road toward their “good life” ([21], p. 191). Long after subjects which were taught in silos–geography, maths, history, physics, art, languages, etc.–have been forgotten by young students, their development of personal and social issues will continue to inform their life choices and enable learners to cope with those “slings and arrows of outrageous fortune” (*Hamlet*, III.I. 72) which life throws at us all.

So, I hypothesize that, by Integrating social science studies with the literature curricula, we move to learn away from pedagogy based on knowledge transfer (students as empty vessels into which facts are poured) and towards transformational knowledge (which will give them the tools they need to make good choices on their journey through life).

2 My Influences–Described

I am all too aware that my life journey will influence my research–both past and current–and that said life journey is both an asset and a limitation. I brought to my doctoral research my life-long learning, but that life-long learning could also have affected the objectivity and reliability of my investigation.

There was a need to be mindful that my enthusiasms, my appreciation of the wider pedagogic value of drama, my love of Shakespeare’s plays, and my desire to stimulate personal and social development in learners, did not influence the case study dissemination and subsequently lack that determining credo which underpins the researcher's work–the holy trinity of "validity, reliability and objectivity" ([53], p. 59). I am aware that I should not make great claims for my work; there is a need to remain the "impartial facilitator" (Gearon, 2006, cited in [17], p. 125) in practice and the impartial researcher in evaluation.

Harwood (1998) describes the "impartial facilitator" (cited in [17], p. 125) as in charge but as passive as possible. And though being "impartial" is an unattainable state of mind, as Freud's body of work illustrates, the facilitator can aspire to be as non-judgemental as possible [13] and [my parentheses are mine],

> not to convey a new truth to them (the students) in the manner of an instructor but only to point out the path along which it might be found ([39], p. 5).

After leaving school–with very few qualifications–I trained and qualified as an accountant. This was a part of my life that is best marginalized.

I then went to Drama school, where my heart lay, and then started as a professional actor in 1968. My second contract (1969) was at the "Theatre Centre", London, under the artistic director Brian Way–one of the doyens of the theatre *for* education movement. Way believed in participative drama where the actors and audience jointly explored a story. For example, very young primary school students shook shakers to create magic music to take Balloon (and us) to the moon, and secondary school students became kinaesthetically involved in a dance drama that explored the plight of Caliban in *The Tempest*.

Way's philosophy on theatre for educational purposes can be encapsulated by this quote from his seminal work, *Development through Drama* (1967):

> …the question might be 'What is a blind person?' The reply could be 'a blind person is a person who cannot see'. Alternatively, the reply could be 'Close your eyes and, keeping them closed all the time, try to find your way out of this room.' The first answer contains concise and accurate information; the mind is satisfied. But the second answer leads the inquirer to moments of direct experience, transcending mere knowledge, enriching the imagination, possibly touching the heart and soul as well as the mind. This, in over-simplified terms, is the precise function of drama ([57], p. 1).

Way, with typical modesty, considered the above example an "oversimplification", but I would argue that this example goes to the very heart of the function of drama for education because dramatic exploration, whether cognitive or kinaesthetic–through English or Drama classes–allows pupils to speak from the illusion of having had a first-hand experience. Somers (1994) wrote that:

> The relationship that exists between the imagined and the real is the key to the learning process unique to drama. Augusto Boal calls this state 'metaxis'. […] Whilst engaging with the situation in the shoes of another, the student views what happens to the character from the reality of self ([52], p 11).

…with a resultant "doubling of the self"–looking in and looking out at the same time–which can lead to the "'I-now' perceiving 'I-before' and having a presentment of, the anticipation of, a "possible-I", a "future-I" ([7], p. 28). And as Heathcote (1972), a contemporary of Way, noted:

…then who knows what success we may have in educating children to become sensitive, aware, mature citizens, able not only to see the world from their own viewpoint, but through the eyes of others ([22], p. 161).

Over the next three years, I worked with Way on scripted and improvised plays–discovering the power of participative drama to stimulate Socratic dialogue [39]. In 1974 I joined the BBC, and from that date through to 1999, I worked my way through the BBC in-house training system to become a director and producer of television and radio dramas. I subsequently worked on one-off plays, series, and serials for major UK television and radio production companies.

My love of storytelling (2.9)–for that is what I regard drama to be–has never waned. And on reflection, throughout my directing and producing career, I have continued to appreciate the pedagogic benefits of exploration through drama. As Miller (1998) wrote in the Secondary Heads Association report, *drama sets you FREE*,

"Drama contributes far beyond its own curriculum area in most schools. Personal and social education, assemblies, and other subjects using role play, benefit most. All schools identified confidence, communication skills, team work and understanding as the four most important benefits. Drama clearly contributes comprehensively to personal and social development" ([33], p. 22).

Drama has been central to my work-life. And if the contribution of my work-life needed factoring into my research project, so too must the interests in my out-of-work-life. I worked extensively with disaffected teenagers in London's high-rise estates and have been privy to the challenges they face. And over the years, I heard adolescents speak of the increasing pressure placed on them to stay out of trouble, grow up, and act responsibly, but as Madge (2006) notes.

Many measures to encourage social order among young people focus on the individual but may well be more effective were they to urge community responsibility ([31], pp. 142–3).

In the past decade, I would argue that the need for a renewal of the idea of the community has become both a political ideal–and a social necessity. From 1998, when the United States Embassy was bombed in Tanzania, the 9/11 attacks on the Twin Towers in New York (2001), the train bombings in Spain (2004), the London bus and tube attacks (2005), and the daily suicidal "martyrdom" in Iraq, Afghanistan, India, Paris, and Pakistan–the citizen who feels disenfranchised has become aggressively visible.

There was a national gasp of incredulity, reflected in the popular UK press, as the bombers in London were discovered to be British-born and bred. But I would argue that the young men responsible for those bombings were citizens who felt disengaged from both their country of birth and their community. Moschonas (2002) [36] argued that there is a direct correlation between the identities of social democracy being weakened over the last decade with the repression of the political classes into an amorphous classlessness and that a resultant *zone of quasi-non-representation* (p. 322) has been created where citizens find it increasingly difficult to be heard. The italics introduced to the following extract from the suicide video left by British-born Mohammad Sidique Khan corroborates Moschonas' thinking as Khan illustrates his sense of being the "Other" [25] in his birth country [italics are mine]:

> *Your* democratically elected governments continuously perpetuate atrocities against *my* people and *your* support of them makes *you* directly responsible […] "Until *we* feel security, *you* will be our target. Until *you* stop the bombing, gassing, imprisonment and torture of *my* people, *we* will not stop this fight [10].

In 2000 I retired from directing and producing television and radio dramas and decided to study English literature at university. Over the next six years, I gained a B.A. and M.A. in the English faculty at the University of Warwick, UK. I enjoyed those journeys–particularly the research for my M.A. dissertation, which explored my case for the continued inclusion of statutory Shakespeare studies on the secondary school curriculum. I started that exploration with the desire to promote Shakespeare's study because I thought that Shakespeare might become "an endangered species" ([29], p. 36). In short, my MA dissertation explored how to contemporize Shakespeare's work and make the plays more accessible for young learners.

When I decided to take my M.A. research forward, I began to appreciate that I had to approach my objective of making Shakespeare's study accessible via a different route. And this subconscious conceptual discovery inspired my move from the English faculty to the Institute of Education to focus on the epistemology behind the evolving pedagogy. The theoretical emphasis now developed from exploring the relevance of Shakespeare's plays head-on through the English curriculum to using three selected stories–written by me and closely based on Shakespeare's texts–as pedagogic tools with which to stimulate Socratic discussions [39] on personal and social topics, as students start to navigate the "second decade" ([3], p. 11) of their lives.

So, over the four years of observations and action research, the focus of the research question became: "Can the ideas, themes, and issues [45] embedded in selected Shakespearean stories stimulate exploration by the learners into what it means to be both an empathetic member of, and an active contributor in, the parochial (school) and wider (country/global) communities?".

I think that Shakespeare's plays have lasted because the "ideas, themes, and issues" (Ibid.) that the characters negotiate are as relevant today as four hundred years ago. The stories are recognizably "peopled with fathers, mothers, sons, daughters, wives, husbands, brothers, and sisters" ([19], p. 2) and the emotions they express, "love, hate, awe, tenderness, anger, despair, jealousy, contempt, fear, courage, wonder" (Ibid., p. 3) are all familiar to the learners I was working with and are a stimulus for personal development. And Shakespeare's stories also can stimulate social awareness by offering students an "inexhaustible resource of alternatives of what it is to be human, and what societies are or might be" ([18], p. 141).

And because Shakespeare's stories are grounded in an education system which was based on the Classical idea that "truth is not singular" ([4], p. 327), these stories reflect a model of a balanced social contract [46] — for every Hermia, there is a

Helena (*A Midsummer Night's Dream*), for every Macbeth there is a Banquo (*Macbeth*), and for every Romeo, there is a Tybalt (*Romeo and Juliet*). Bate (1997) [4] argues that Shakespeare's stories are an ambidextrous pedagogic tool for personal and social development. Wittgenstein's (cited in [4], p. 328) encapsulated the idea of the "aspectuality of truth" when he wrote on the famous Gestalt drawing ([23]; Fig. 1), which depicts both a duck and a rabbit.

> This is a drawing of a duck. This is a drawing of a rabbit. Now you see a duck; now you see a rabbit (Ibid., p. 328).

How frustrating, how exciting, and how stimulating that is. Neither the duck nor the rabbit can be seen simultaneously, yet both realities are true. Shakespeare's plays exemplify that truth is not singular–a concept that learners, steeped in receiving "right knowledge" and "teaching to the test" ([32], p. 48), find difficult to comprehend.

3 The Action Research–Explored

As an "impartial facilitator", I worked with two student intakes over four years (2006–10). There were approximately 90 students in each intake, and I followed their development between the ages of 11–16. In the first group (2006–9), I was the "observer"–watching closely existing teaching practices as PSHFE, citizenship, and Shakespeare was 'transmission taught'. The second cohort (2007–10) was my "action research" group with whom I developed "30 lesson plans for teachers" [28], which deliver both the PSD and English (Shakespeare) curricula.

With the first cohort, the "observation" group, a "research randomizer" [56], selected seven students who were interviewed three times a year by me, in their homes, to ascertain what they thought those mentioned above "taught" lessons "did

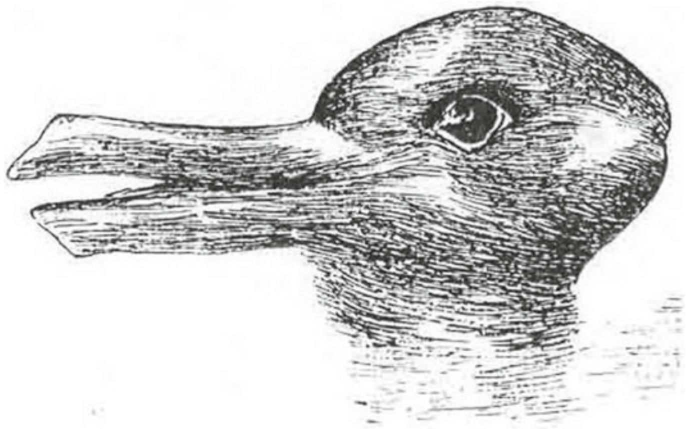

Fig. 1 The mind's eye: duck-rabbit ambiguous image [23] Anonymous Illustrator, 1892

for them"? I also explored how the students thought the lessons could be "improved" and what was the "point" and "impact" of these lessons on their life-world? These interviews were triangulated by parallel interviews with parents and teachers–and all interviews were transcribed for future analysis. With the "action research" cohort of students, I also looked for any development in the randomly selected students' maturation through time which could have been influenced by my integrated approach to use Shakespeare's stories as a portal through which personal and social development might take place.

After observing the first cohort, I discovered that one of the challenges in "teaching" emotional literacy and social awareness is that teacher pontificating, however well informed and sensitive it might be, will not stimulate deeper learning than peer-on-peer teaching. And however disappointing this might be to teachers, research suggests that [parantheses are mine].

> as they (the students) get older, children and young people turn increasingly to friends and media channels for information ([31], p. 62).

I discovered that by becoming an impartial facilitator, who is "steering" the PSD sessions, I made a greater contribution to personal and social development and the relevance of Shakespeare's work than by using traditional transmission pedagogy.

Nelson (1965) [39] challenged the idea of "dogmatic teaching" (p. 25)–the teacher as expert, the student as a blank slate, the classroom in fixed rows, and the best way to learn is alone [11] — and introduced the idea of communally learning, peer-on-peer learning in order to develop the skill of philosophizing ([39], p. 11; 4.4). One of the primary aims of the Socratic method is for students to discover that they do not know of all certain knowledge. Learners need to become aware of the "perplexities and uncertainties" in life (Plato, *Epistles* cited in [39], p. 14). Nelson argued that such an approach is not negative but productive because it enables the possibility of "regressive inference" ([51], p. 131) or "metaxis" ([7] cited in [38], p. 10) to take place: metaxis–learner discovery, re-discovery, and the possibility of change–goes to the very heart of personal and social development because it helps learners to look at issues from many angles and develop the empathetic skill of being flexible–of seeing others' points of view.

So, as the impartial facilitator in PSD lessons, I would set a conundrum–inspired by an issue being aired in one of Shakespeare's stories–for the students to discuss in small groups and then present their conclusions to the whole year. Conundrums like: "What makes a good community?", "Who is to blame for all the murders in the *Macbeth* story?"; "Is there such a thing as love at first sight?" were deeply discussed, philosophized over, challenged, and counter-challenged by the students. My research led me to understand that through exploration of the character's journey in the stories and through peer-on-peer Socratic discussion on the decisions made by those characters, students could explore the various courses of action that *the characters could have taken*–and vicariously the course of action they, the student, *might* have taken if faced with a similar conundrum. And through listening to other points of view, students develop the skill of understanding that "truth is not singular" ([4], p. 327).

If cooperative learning is a process of bringing about agreement amongst students based on a validity claim that speaker and receiver can mutually recognize, then such an approach nudges the ego towards the common good. This is not an inherent skill but one that needs developing. If deep-learning and conceptual understanding are enhanced; if social awareness and acceptance of "the other" developed; if peer acknowledgment of personal contributions raises self-esteem and prepares students to become positively involved in the wider community–then cooperative learning, through speech acts, would be a productive way forward for both educational and citizenry development [42].

Over the four years of observation and action research, I developed an integrated exploration of PSD and Shakespeare studies. I started each academic year with interactive storytelling of a Shakespearean story. Let me explain this idea further…

Everyone loves having a story told to them. But story-listening can be a very passive exercise. So, to reinforce the relevant themes and issues in the chosen Shakespearean story, I devised an interactive storytelling method I call the Shakespeare "whoosh"–for reasons that will become clear…

My version of the Shakespeare "whoosh" originated from Winston and Tandy's (1998) [59] "story stick" idea for primary school students. It was further developed by the Learning Department at the Royal Shakespeare Company. My "woosh"–the hub of "making Shakespeare *relevant*" [28]—morphed into a 35–40-min storytelling experience where the whole story of a Shakespearean play can be enjoyed in an interactive, immersive, all-inclusive way. Freed from the complexity of Shakespeare's language, my contemporary written "whoosh" is accessible to all ages and all abilities. If pure storytelling is "two-dimensional", then my "whoosh" is "three-dimensional"–with the students as the pop-up characters. My Shakespeare "whoosh" creates moving pictures that illustrate and clarify the characters' journey in the story. But the "whoosh" is *not* a drama lesson–it is merely "controlled play", as one 11-year-old (2007) said to me,

> The story was cut down to the main points; Brilliant, everyone involved; I liked the lessons because we got to interact and had fun.

The Shakespeare "whoosh" described…The Story Teller (S.T.) sits with the students in a circle and, with a storybook (folder) in hand, *reads* a synopsis (for an example, see below) of a Shakespearean play. At times the students passively listen to the story. At other times randomly selected students are invited into the circle (ACT) in order to make a moving picture of the action as the story unfolds, e.g., in *Romeo and Juliet,* Samson biting his thumb at the Montague servants *or* Abraham and Samson moving together to fight. And when the story is being "acted out" by the students, the (S.T.) can either remain sitting in the circle–or can move amongst the characters as either the storyteller *or* (in the role) as one of the characters.

And at the end of a section of the story–a scene changes in the text–the (S.T.) says "WHOOSH", and all the students in the circle sit down, and new volunteers are drawn in as the story develops. This means that many students can get involved in the storytelling as they listen and react to the actions being described. It also means that many different students can play at being Romeo, Juliet, Capulet, the Nurse, etc.

So, the opening of the *Romeo and Juliet* “whoosh” goes like this: All students are sitting on the floor in a circle, as shown in Box 1.

Box 1 Students at the opening of the Romeo and Juliet “whoosh”

(S.T.) A long, long time ago - in a beautiful city in Italy - Verona was its name - two families (*indicate half the seated circle*) the MONTAGUES and (*the other half of the circle*) the CAPULETS lived in hatred of each other. Their hatred went back such a long time no one living could remember why they started the feud in the first place. But hate each other, they did. Even the ruling PRINCE **(S.T. in the role)** found controlling these families difficult, “and the Prince’s word is the law!”.

(ACT) One hot summer’s day, some of the SERVANTS (choose THREE servants) from the Montague family are hanging around in the Cathedral square spoiling for a fight with some of the SERVANTS from the Capulet family (choose THREE servants). SAMSON — a bit of a trouble maker - from the Capulet family, bites his thumb at the Montague servants (**S.T.** demonstrates, get a student to imitate this action). Now, this is a serious insult in Italy, and ABRAHAM, from the Montague’s, accepts the insult, and the two men get out their blades and approach each other to start a knife fight. (*freeze the students*).

Romeo’s friend BENVOLIO, a really nice lad, tries to make the men stop fighting by drawing his own knife. Then Juliet’s cousin, TYBALT - a lad with a serious ‘attitude’ - seeing Benvolio with his knife drawn, draws his own blade to join in the ‘fun’. (*freeze these two students*).

Finally — into the square comes Mr. CAPULET and Mr. MONTAGUE, the heads of the families, who get out their knives so that they *too* can fight. (*freeze).*

When the PRINCE arrives **(S.T. in the role),** he is furious! “In the past few months, three fights have broken out between the families, causing the street of Verona to become unsafe for other citizens. This behavior will not be allowed to continue!” He orders them all to return to their homes - “*Immediately*!!”.

WHOOSH! (…and all the students return to sit in the circle again.)

And so, the story progresses.

After the students experience the “whole” story, I, as the impartial facilitator, set relevant conundrums which will act as a portal through which they can explore one of the many issues which Shakespeare airs in the play; for example, issues about self-responsibility, blame, family control, relationships, society, children’s rights, bullying, gang fights, etc. The students then start to discuss these conundrums in small groups of, say, five students (these groups could be friendship groups, peers who do not normally work with; same-sex groups; or a deliberate mix of the sexes to widen the small group experience). However, all the small-group discussions end up with the students sharing their thoughts with the whole class to develop their oracy skills, their presentation and listening skills, and their ability to make their opinions visible.

As an impartial facilitator, I neither agree nor disagree with their thoughts. I give a neutral response: "Ah-ha" or a, "Mmmm…" And if a student disagrees with his/her peer, I encourage them to engage with their fellow student and debate *why* they disagree. Stimulated by Shakespeare's stories, these lessons are very much *their* time in which to explore *their* personal and social understandings. And to reinforce the importance of their philosophizing and to illustrate that their opinions do matter, I always write their key points on a whiteboard — nothing does more to validate and give gravitas to a student's thoughts than to see it written up on a whiteboard or on a flip chart. And on rare occasions, I acted as an "agent provocateur" to "force" philosophizing. By doing this, I sit on the shoulders of a mighty giant:

> One achievement is universally conceded to Socrates: that by his questioning he leads his pupils to confess their ignorance and thus cuts through the roots of their dogmatism. This result, which indeed cannot be *forced* in any other way, discloses the significance of the dialogue as an instrument of instruction. […] Only persistent pressure to speak one's mind, to meet every counterquestion, and to state the reasons for every assertion *forces* minds *to freedom* ([39], p. 15).

All of the sessions are held in large spaces, large enough to accommodate the whole year and large enough to help develop a sense of "community". However, I discovered that if this is totally impractical, if there is no suitable, quiet space for the whole year, then I recommend splitting the year in two. A large workshop builds a community. As one of the English teachers I worked with said (2010),

> I think they (the students) have a very conscious sense of 'community'. I do think they are more aware of it […] not many year groups have lessons together like that for three years, and I think it has given them as a year group a sense of cohesion which is always good - and that builds community in itself.

What I aimed to do was create a space where the students could learn to express their opinions safely. I want to create an atmosphere where philosophizing can take place on whatever cognitive level the students are at.

Finally, I want to share the second element in this integrated pedagogy briefly. After most sessions, I give the students a "home thinking" exercise. This was a way to give the students some quiet time at home to think about their own personal and social development *and* the relevance of the Shakespearean stories to their life-world. Sometimes this home thinking consisted of a moral conundrum; at other times, I asked them to evaluate what they had discovered in the session we had just had together. And because I wanted to differentiate "home thinking" from "home work", I initially made the "home thinking" voluntary–but, to be honest, that did not work.

"Home thinking" needs to be backed by the rigor of "home work"–but with a subtle emphasis on the fact that "though this work is not assessed it is important for your "good-life"", for *"your* development". If I said it once, I said it a hundred times to the students:

> 'Home Thinking' is a work-out for the brain. Don't forget - like physical exercise: 'use it or lose it!' Use your brain or lose your brain...the choice *is* yours.

Giedd coined the phrase "use it or lose it" (cited in [44], p. 866), observing that if adolescents–at this critical time in their physical and mental maturation–are involved in, for example, music, sports, or academics cognition, then those are the cells and connections that will be hardwired throughout the learner's life-world; the corollary being that if teenagers are lying on the couch watching television or playing video games, then *those* are the connections that are going to survive. So, developing thinking skills, especially with "high horsepower, low steering" ([40], p. 6) adolescents, is one of the facilitator's main challenges.

4 My Research Discoveries–Illustrated

From the start of my research, I understood that analysis of the transcripts of hours of interviews with the students from the first (2006–2009) and second (2007–2010) cohorts, with their parents and their teachers, would draw on my life's work as a storyteller. After all, text analysis is what I do. Further, analyzing those transcripts–which explore student development through time–would, primarily, be a *qualitative analysis* that would follow three rigorous "stages" (diagrammatically illustrated in Fig. 2).

If one of the cornerstones of the action research is that truth is not singular, then I argued (in defense of qualitative analysis) that research like mine should seek a less didactic method than quantitative analysis. I sought analysis that could point beyond truth to an in-between [27] way of thinking. Spencer et al. (2003) [53] argued that "what is important is the methods fit the question"–not that *a* method makes a superior claim to "quality" over another (pp. 47, 60). All researchers aspire to the "holy trinity" of "validity, reliability and objectivity" ([53], p. 59), but Mol (2002) [34] asks, can knowledge ever be certain when one is investigating the uncertain and complex lives of students in a world where there is no closure, where realities overlap and collide in a complex way [27]? Stake (1995) [54] also argued that truth can only be discovered by the individual reader and that researchers and readers alike can extrapolate concepts that will enable them to construct some kind of meaning of the world being researched. So, my job was not to present didactic "conclusions"–but to offer discoveries, claims, interpretations, theories in a credible and plausible way, based on "the material from the archive" ([27], p. 129). What I had to accept was that such discoveries I made were not *the* truth–merely *a* version of the truth. Were not "conclusions", merely "discoveries".

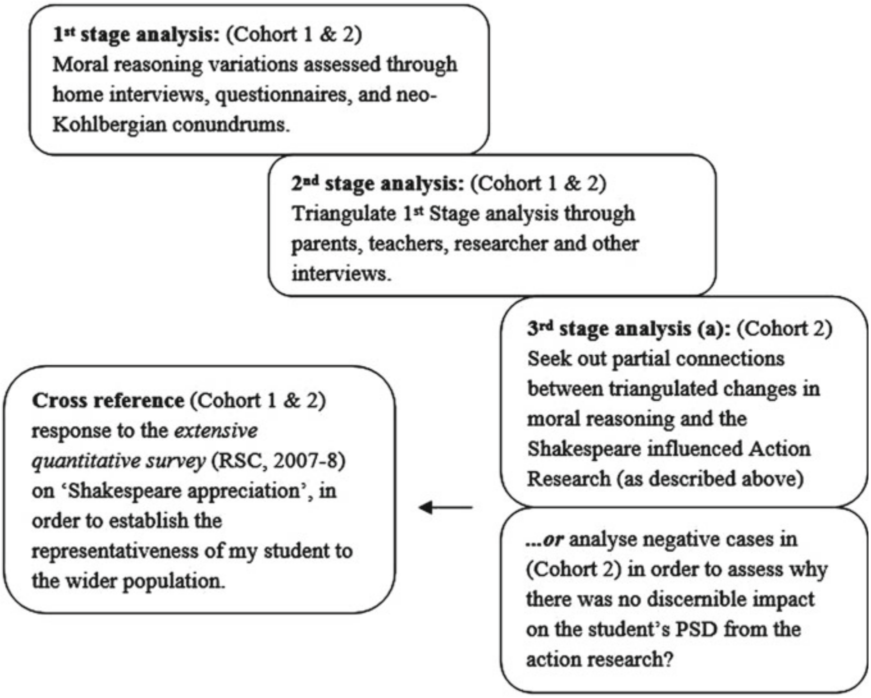

Fig. 2 Template for case study analysis inspired by [54, 24, 30]

After extensive casework analysis, I discovered that there *were* some "lightbulb" moments ([55], p. 103) amongst the interviewed students in the action research cohort which had long term effects on the students' life world and which could be traced to my/their Shakespeare inspired discussions.

The case study analyses of the second cohort of students (2007–2010) revealed two groupings:

i. one randomly selected student exhibited discernible connections between the use of the Shakespeare stories and the student's life-world *but*, on final analysis, these connections did not last beyond a "phase" ([50], p. 142) and therefore were not substantial changes; and
ii. for most students from the action research cohort, there was a discernible impact from the Shakespearean stories on their personal and social development. There was an increase in Shakespeare appreciation during this longitudinal study. For each of these students, the Shakespeare stories had had an impact in varying degrees.

Student S–who had started secondary school so quiet in class that S could hardly be heard during home interviews: I noted,

> it was necessary to repeat S's answers–there was concern that the recordings might not be audible.[1]

By the end of our time together, S had found S's voice and was able to challenge and debate with S's form teacher. Student S's dissection and reinterpretation of *Much Ado About Nothing* was full of subconscious references to the *PSD* topics explored, especially with respect to "the cause and effect" of one's actions:

> It's like stealing. Because you're, you're only really going to, get into trouble yourself, you're only cheating on yourself really if you're gonna steal…because what goes round comes around, usually[2]

Student H–despite being a special needs student, "I can only read odd little words"[3]—had felt empowered to read and write the *Macbeth* assessment unaided. "I could do that (*Macbeth* assignment)–because the "whoosh" made you think and that",[4] which was a positive response to a scheme of work based on developing Socratic thinking.

And in ***Student K's*** final home thinking exercise, in answer to the question, "did Shakespeare's stories make any difference to your understanding of any *PSD* topics?" student K wrote,

> I think the Shakespeare stories helped in our own lives because they are mostly to do with honesty in relationships and friendships and how to sort out our differences. One main thing realised is friends *always* come before a relationship, because your friends have always been there for you whereas, boyfriend/girlfriend you will not know as well, even if you think you do[5]

Throughout the three years of home interviews with K, I noted an understandable need for parental approbation–and fear of parental criticism was omnipresent. Throughout 2007–2008 and 2008–2009, K struggled to balance parental control with adolescent desire for greater autonomy yet, over time, K did start to find K's voice and find ways to negotiate with K's gatekeepers [my parentheses are mine]:

> …well I had a *special* friend, er, that they…I, I, I spoke to them (K's parents), and that was about two weeks ago, and I actually asked my mum first, I said, "can I go out with so and so", er, and my mum said, "Seeing as you've asked this time, I'll speak to your father about it". So, she spoke to my dad, and they both said, "Yes"![6]

In the summary of K's case study, I noted that a more appropriate research question could have been: "could this integrated methodology help the students find their own voice and help them to become their own person?".

Student J started the first year at secondary school very lively–J was sport mad, particularly cricket. But J was very immature regarding J's "thought process or problem-solving procedures" ([49], p. 102). However, by the end of our three years

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[1] Lighthill B., Research Diary, 2007.
[2] Lighthill B., Home Interview, December 2010.
[3] Lighthill B., Home Interview, December 2007.
[4] Lighthill B., Final interview, June 2010.
[5] Lighthill B., April 2010.
[6] Lighthill B., Home Interview, April 2009.

together, J was able to respond more clearly to various real-life conundrums discussed in the home interviews. After the "whoosh" of *Macbeth*, in answer to the question, "how relevant was the Macbeth story to your life?", J offered a spontaneous updated version of the *Macbeth* story set in a cricket changing room. J's interpretation eloquently synthesized two parts of J's life–cricket and the *PSD/Shakespeare* sessions in school. In this home interview, J and I had been discussing the idea of Macbeth "aiming high:"

> …it's like, in cricket, if you want to be the captain of your national team but there was somebody who already was captain, then erm, you wouldn't like say bad things in the dressing rooms and get him kicked off from being captain. But you *can* be captain - you sort of just take it slowly and let the selectors select you as captain in time[7]

All those "feedback loops" ([24], p. 26) indicated that the use of Shakespeare's stories as a pedagogic tool in *PSD* sessions had had an impact because Shakespeare had become "relevant" to the student's life-world. Student J noted, "I think I *have* been influenced by Shakespeare's plays and characters".[8] J was able to draw feedback loops between rows at home, advice given by peers, and the Witches interventions in the *Macbeth* story.

Is there a commonality across the case studies of the action research cohort above, which suggests that integrated education contributed to the development of the students' oracy skills and "raised the status"[9] of the school syllabus as is to a deeper, more meaningful learning for life experience [21, 46]? Did combining exploration of the issues in a Shakespearean story with the PSD topics on the syllabus deepen student understanding of the need for both more substantial, less superficial communal communication? I think the answer to both these two questions is "yes".

That in order to serve the need for deep learning, an integrated approach seems appropriate as it moves to learn away from pedagogy based on knowledge transfer [5] and towards transformational knowledge. I think that integrated education *is* the way forward–and my dream lives on.

5 Conclusion–My Research Discoveries–Revisited

If my work with Way (1967) [57] was the source of this study, then Nelson's (1965) [39] Socratic methods were the map of the journey towards day-to-day philosophizing and reflective self-examination. Nelson's challenge to learners was that when they can admit:

[7] Lighthill B., May 2010.
[8] Lighthill B., A Response to Case Study March, 2011.
[9] Lighthill B., Teacher A final interview, June 2010.

> to being unable to say what he (she) knows [...] professes his (her) ignorance (and) face the questions, puzzles, and problems' that arise (Morrison, 2011 cited in [35], p. 184. my brackets) the 'I-now' will be able to perceive the 'I-before' and have 'a presentment of a 'possible-I', a 'future-I' ([7], p. 28).

And this act of "doubling of the self" (Ibid.)–looking in and looking out at the same time–described my post-research journey as a "future-I" came into focus.

Over the last ten years, I have been lucky to work with unexpected people in unexpected places. When I finished my research, I thought I would continue as a peripatetic facilitator working with young secondary school students. And I did continue to work in various secondary schools around the UK, working with 10–18-year-old students in the inner city, country, and public boarding schools.

But I also was invited to facilitate workshops in Art Galleries (9–11-year-olds), in primary schools (8–11-year-olds), and at teacher training courses (19–21-year-olds). I have organized taster-days for 15–17-year-olds at Universities which, inspired by Shakespeare's story of *Romeo and Juliet*, involved a professor of chemistry (exploring the kind of drugs which might have been used by the Friar to put Juliet into suspended animation), a neuroscientist (exploring the development of the teenagers "high horsepower, low steering" brain ([40], p. 6)), and me–as a social scientist (exploring questions around "actions having consequences" and "gang warfare" as the Montague and Capulet families fought). And I have also worked with the homeless (30–60-year olds) in Birmingham, the UK exploring their life-world in parallel with Romeo and Juliet's.

Much to my delight, my research seems to have value for students of *all* ages–some who are in full-time education, and some who think life-long learning is just…fun. But I am all too aware that an integrated timetable can engender deep-rooted resistance from teachers. Integrated pedagogy can be perceived as a "corrective" to the dominance of one of the subjects. However, as the head of English in my host school said in her final interview with me[10]:

> There was no sense of 'reverence' about Shakespeare's plays…it was that Shakespeare is relevant to your lives and to *PSD*–so doing it in English or PSD lessons just wasn't an issue.

"By combining social science studies with the literature curricula, we move learning away from pedagogy based on knowledge transfer and towards transformational knowledge".

Brian Lighthill

[10] Lighthill B., July 2010.

Core Messages

- An integrated timetable is the glue between learning and deep educational knowledge.
- My research points me towards integrated education being less about knowledge transfer and more about student-discovery of transformational knowledge.
- That integrated pedagogy is mutually beneficial for both students and teachers who grow to "… know my students better after sitting in on your PSD/Shakespeare classes".[11]

References

1. Apple MW (2004) Ideology and curriculum, 3rd edn. RoutledgeFalmer, London
2. Aristotle (1992) Aristotle — The politics. Translated by Sinclair TA, Saunders TJ, 1992. Penguin Books, London
3. Bainbridge D (2009) Teenagers: a natural history. Portobello Books Ltd., London
4. Bate J (1997) The genius of shakespeare. Picador, London
5. Ben-Shahar T (2006) Make lemonade out of lemons — education guardian. http://education.guardian.co.uk/schools/story/0,,1760219,00.html. Accessed 8 March 2008
6. Bernstein B (1973) Class codes and control. Granada Publishing Ltd., St Albans
7. Boal A (1995) The rainbow of desires: the boal method of theatre and therapy. Translated by Jackson A, 1995. Routledge, London
8. Buzan T, Dixon T (1978) The evolving brain. David & Charles Ltd., London
9. Clark JDW, Neelands J, Goode T (1997) Lessons for the living. Mayfair Cornerstone Ltd., Ontario
10. Dodd V, Norton-Taylor R (2005) Video of 7/7 leader blames foreign policy - the Guardian. http://www.guardian.co.uk/attackonlondon/story/0,16132,1561383,00.html. Accessed 23 Sep 2005
11. Drake SM (1998) Creating integrated curriculum: proven ways to increase student learning. Corwin Press Inc, Thousand Oaks, CA
12. Finley S (2005) Arts-based inquiry: performing revolutionary pedagogy. In: Denzin NK, Lincoln Y The sage handbook of qualitative research, 3rd edn. Sage Publications, London
13. Fries JF (1914) System der Logik. In: Nelson L (1965) Socratic method and critical philosophy: selected essays. Translated by Brown III TK. Dover Publications Inc., New York
14. Fullan M (1999) Change forces: the sequel. Routledgefalmer, London
15. Gardner R, Cairns J, Lawton D (2000) Education for values: morals ethics and citizenship in contemporary teaching. Kogan Page Ltd., London
16. Garforth FW (ed) (1966) Editor's introduction. In: John Dewey: selected educational writings. Heinemann, London
17. Gearon L (ed) (2006) Learning to teach citizenship in the secondary school. RoutledgeFalmer, Abingdon
18. Gibson R (1994) Teaching Shakespeare in schools. Routledge in Association with the Open University, London
19. Gibson R (2005) Teaching Shakespeare. Cambridge University Press, Cambridge

[11] Lighthill B., Teacher C, April 2008.

20. Gove M (2011) Gove stresses 'facts' in school curriculum revamp - BBC NEWS education & family. http://www.bbc.co.uk/news/education-12227491. Accessed 27 April 2011
21. Habermas J (2000) The habermas reader. Polity Press, Cambridge
22. Heathcote D (1972) Drama as challenge. In: Hodgson J (ed) (2003) The use of drama. Eyre Methuen Ltd., London
23. Jastrow J (1899) The mind's eye. Popular Sci Mon 54:299–312
24. Kincheloe JL, Berry KS (2004) Rigour and complexity in educational research: conceptualizing the bricolage. OUP, Maidenhead
25. Lacan J (2004) Ecrits: a selection. Translated by Sheridan A, 1989. Routledge, London
26. Law B (2004) Citizenship: new subject; new type of 'subject.' Teaching Citizenship 8:38–45
27. Law J (2007) After method: mess in social science research. Routledge, Abingdon
28. Lighthill B (2017) Making Shakespeare Relevant — 30 lesson plans for teachers. Matador, Kibworth
29. Lighthill B (2011) Shakespeare — an endangered species? English in education. Special edition life made conscious; the drama of English. Spring pp 36–52
30. Macintyre C (2000) The art of action research in the classroom. David Fulton Publishers, London
31. Madge N (2006) Children these days. The Polity Press, Bristol
32. Mansell W (2007) Education by numbers: the tyranny of testing. Politico's Publishing Ltd., London
33. Miller P (1998) Drama sets you free: the position of drama in the curriculum of secondary schools. Secondary Heads Association, Leicester
34. Mol A (2002) The body multiple: ontology in medical practice. Duke University Press, Durham
35. Morrison DR (ed) (2011) The Cambridge companion to Socrates. Cambridge University Press, Cambridge
36. Moschonas G (2002) In the name of social democracy: the great transformation: 1945 to the present. Translated by Elliott G, 2002. Verso, London
37. NFER (1995) Education for life: the cross-curricular themes in primary and secondary schools. NFER, Slough
38. Neelands J (1997) Three theatres waiting: architectural spaces and performance traditions. http://www.eduref.org/plweb. Accessed 18 July 2011
39. Nelson L (1965) Socratic method and critical philosophy: selected essays. Translated by Brown III TK, 1965. Dover Publications Inc., New York
40. OECD/CERI (2007) Understanding the brain: the birth of a learning science — executive summary. http://www.oecd.org/dataoecd/42/33/38811529.pdf. Accessed 12 Dec 2007
41. Paechter C (1995) Crossing subject boundaries: the micropolitics of curriculum innovation. HMSO, London
42. Petty G (2006) Evidence-based teaching: a practical approach. Nelson Thornes, Cheltenham
43. Piaget J (1973) The child and reality. In: Egan K (1989) Teaching as storytelling. Translated by Rosin A. Routledge, London
44. Powell K (2006) How does the teenage brain work. Nat 442(7105):865–867
45. QCA (2008) 1.2.2 Overview of texts – GCSE English Literature Set Text List. http://www.qca.org.uk/download/kd/ocr_31049_kd_gcse_2010_spec.pdf. Accessed 20 Sep 2010
46. Rawls J (1971) A theory of justice. Belknap Press of Harvard University Press, Massachusetts, Cambridge
47. Reid A, Scott W (2005) Cross-curricularity in the national curriculum: reflections on metaphor and pedagogy in citizenship education through school geography. Pedagog Cult Soc 13(2):81–204
48. Renner JW (1997) Research, teaching, and learning with the Piaget model. http://chiron.valdosta.edu/whuitt/col.cogsys/piaget.html. Accessed 29 Jan 2008
49. Rowe D (2005) The development of political thinking in school students: an English perspective. Int J Citizsh Teach Educ 1(1):97–110

50. Saldana J (2003) Longitudinal qualitative research: analysing change through time. AltaMira Press, Oxford
51. Saran R, Neisser B (2004) Enquiring minds: socratic dialogue in education. Trentham Books, Stoke-on-Trent
52. Somers J (1994) Drama in the curriculum. Cassell Educational Ltd., London
53. Spencer L, Ritchie J, Lewis J, Dillon L (2003) Quality in qualitative evaluation: a framework for assessing research evidence. http://www.chsrf.ca/kte_docs/qqe_rep.pdf. Accessed 3 Sep 2008
54. Stake RE (1995) The art of case study. Sage Publications, London
55. Stringer ET (2007) Action research, 3rd edn. Sage Publications, London
56. Urbaniak GC, Plous S (1997–2008) Research randomizer. http://www.randomizer.org/form.htm. Accessed 26 Nov 2006
57. Way B (1967) Development through drama. Longman, London
58. Whitty G, Rowe G, Aggleton P (1994) Discourse in cross-curricular contexts: limits to empowerment. Int Stud Sociol Educ 4(1):25–42
59. Winston J, Tandy M (1998) Beginning drama 4–11. David Fulton Publishers, London

Brian Lighthill has worked as an actor, television and radio, drama producer/director for thirty-five years. In 1995 Lighthill won a BAFTA and in 1996 the Prix Jeunesse International for TV channel 4's "Coping with Grown-Ups". In 1998 Lighthill was nominated for Sony Award for a radio 4 drama, "The Sevenfold Crown". In 1999 he retired from the "world of the media" and worked his way through the university system at The University of Warwick (UK)–B.A., M.A., and finally Ph.D. research into "The Impact of selected Shakespeare's Stories on Personal and Social Development for 11–14-year-old learners". This study took four years of observations and action research in one Warwickshire secondary school, on behalf of Warwick University's 'Institute of Education'. Lighthill is now facilitating and lecturing around the UK to learners in both an academic setting and real-life world.

5 The Need to Cultivate More Linking in Learning to Promote More Effective Thinking

Emmanuel Manalo

Learning is connecting.

Edward Thorndike [1]

Summary

Linking is a fundamental requirement of learning. It is, however, rarely considered a key function of education, and much of formal education is delivered using a framework of discrete subject disciplines. The result is a general lack of connectivity in what people learn and how they view learning. This limits their ability to synthesize different kinds and fields of knowledge, which is necessary if they are to possess the thinking capabilities demanded of the largely unpredictable environments we now operate in modern as well as developing societies. In an effort to clarify this problem and contribute toward addressing it, this chapter first explains some of the kinds of linking necessary for the promotion of better thinking and the reasons for those. It then describes some methods employed to promote greater reliability in such linking. It concludes by highlighting the need for greater awareness about the importance of promoting better linking in learning and for more research and development of methods that can make such linking viable and sustainable.

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N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_5

Graphical Abstract/Art Performance

Student Learning. The artwork shows the importance of establishing internal and external links in learning. Celina is the author's daughter and, at the time of writing this chapter, she was undertaking a graphic design degree at university. (Made by Celina Watanabe).

Keywords

21st-century environments · Creativity · Deeper learning · Education · Innovation · Knowledge integration and synthesis · Learning strategies · Linking learning · Teaching strategies · Thinking competencies · Transfer

QR code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

Ninety years ago, the famous psychologist, Edward Thorndike, wrote that "learning is connecting" [1]. He meant that establishing connections, or linking, is necessary for learning to occur. For example, a baby needs to "link" crying with the attention it gets from its parents for it to learn that its action (crying) has consequences (attention). This principle applies to everything that we know of as "learning". To learn a new word, we need to link it to its meaning. To learn to solve a mathematical problem, we link the sequence of steps necessary to derive the required answer. We learn because we connect symbols to meaning, experiences to internal representations, actions to consequences, and so on. It seems fairly simple, but it is also absolutely essential because if we fail to link, we also fail to learn. Furthermore, in the past few decades, advances in technology and brain research have revealed that there is a biological basis to the idea that "learning is connecting". In very simple terms, new synapses (or connections) are formed between brain neurons when new learning occurs [2–4]. This means that the idea is not just notional or conceptual but firmly based on the physiological reality of what happens to us when we learn.

Since Thorndike's comment, linking as a fundamental learning requirement has generally been accepted without it being a specific focus of concern or attention. It has been assumed that linking will occur naturally, and we do not need to do anything in particular to promote it. Formal instruction is typically provided in discrete subject disciplines (e.g., math, science, history, English, German, etc.), with little or no attempt to establish links between each of those. As a school student, I may use math when solving some physics problems and may even have the same teacher for those subjects, but it would be unlikely for my teacher to explicitly refer to the value or relevance of what I have learned in math to what I may be learning in science–or vice versa. Generally, learning areas–or "subjects"–are artificially compartmentalized.

This compartmentalization of subject disciplines may have been suited for a time when schools were meant to prepare students for future work, which was specialized and more or less constant (i.e., it would not likely change in its requirements). You needed to learn knowledge and skills that matched your work, and those were the same as for others doing the same line of work as you, or they complemented the knowledge and skills of others doing different work. Work was fairly easy to categorize, and most everyone could be educated to secure his/her place in the structure of work in society. Unfortunately, despite the significantly changed work, social, and personal environments we now inhabit in the twenty-first century, education has by and large not adjusted and–among other things–the compartmentalization of subjects continues to persist in the majority of education systems around the world.

Andreas Schleicher, the OECD's (Organization for Economic Cooperation and Development) Director of Education and Skills, has emphasized the importance of being able to make "connections between ideas that previously seemed unrelated" [5]. He characterized this ability to synthesize different knowledge fields as essential to the progression of knowledge and value creation in modern societies. It facilitates imagination and creativity and develops the capacity to respond to the constantly changing and unpredictable environments we now operate in such societies. Schleicher rightly pointed out that today's students need to become prepared to effectively manage the demands of work environments that currently do not exist, and to solve problems that we currently cannot foresee. Fifty years ago, for example, many jobs that we now take for granted (e.g., data scientists, mobile app developers, artificial intelligence (AI) engineers) did not exist. And at the time of writing this chapter, we are facing an unprecedented global pandemic that has quickly been changing every facet of daily life–from the way we work and socialize to the way we dress (e.g., wearing face masks!) and provide education (e.g., "social distancing" physical arrangements in classrooms; online instead of face-to-face delivery of course lectures in many universities). These kinds of unforeseen changes require not a simple ability to draw from well-learned responses but to link and synthesize various strands of knowledge, skills, experiences, and new inputs to generate new ways of responding that can produce the most optimal outcomes given the new circumstances that are faced.

2 What Kinds of Linking Are Necessary–And Why?

This section provides a way of considering some kinds of linking necessary for promoting better thinking. The kinds given here are by no means exhaustive–doubtless, there would be others–but these provide a useful initial framework for considering this need. A simple diagrammatic representation is included with each kind of linking to visually clarify the nature of the linking being considered. The red circles with bolded outlines represent the learning in question, and the thicker/bolded lines represent the pertinent linking that needs to be made.

2.1 Linking to Develop Learning (Understanding)

The connection between the object of learning and its meaning would seem fundamental: it is hard and seemingly pointless to learn something we do not really understand, let alone think about it in any useful way. Yet learning without really understanding is a phenomenon that appears to be deeply integrated in the formal education systems of modern societies. Many students want to just find out what the expected or "correct" answer might be without necessarily understanding it so they can simply reproduce it in tests or other assessments, and ultimately get the credit and/or qualification that their education is supposed to provide them. From that perspective, the linking is fairly simple: it is just between the "stimulus" (e.g., the question, the kind of problem, the terminology) and the "required response" (e.g., the answer, the solution, the definition). For example, if I get asked about "photosynthesis", I must be able to answer that it is "the process by which plants use sunlight, water, and carbon dioxide to produce their own food and oxygen"–or whatever definition my teacher or textbook has given me. However, I may not even know what that definition really means, let alone how that process works–or why it matters to me. This kind of learning is shallow, and the likely ability to think about and use what has been "learned" would be fairly limited. It would be similar to Marton and Säljö's description of "surface-level processing", where students were focusing attention only on the sign (i.e., in their study, the given text itself) for the sake of later being able to reproduce it in some way [6]. The meaning–"what is signified"–is not considered. And as a consequence, the students were not even able to satisfactorily explain what was important in the text that they had "learned".

More substantial linking is necessary to adequately develop learning so that understanding is achieved beyond just the stimulus–response connection. At the very least, the new thing being learned needs to be linked to its meaning. That "meaning" can range from the basic (e.g., a simple definition or description of what it might be) to the more comprehensive (e.g., with elaborations, qualifications, and variations in those definitions and descriptions; associated mechanisms and/or processes that inform on how it works; the underlying and pertinent reasons)–depending on the number, kind, and quality of links that are made. More sophisticated and comprehensive links would lead to better-developed learning and understanding–and consequently, the ability to think.

Keeping to the example of learning about photosynthesis: initially, I may only have my teacher's and my textbook's definitions and explanations. Although I may feel that I understand what it means to some extent, I would nevertheless be fairly limited in what I can think about it. However, as I find out more (e.g., through reading, conducting an experiment that my teacher asks us to do, talking/asking questions about it, watching YouTube videos, etc.), I would, in effect, be adding more links to my concept of photosynthesis and building my knowledge about it. I might then be able to think more about it. For instance, instead of just "knowing about" photosynthesis, I might now also be able to contemplate how plants and trees are directly relevant to me as a human being and why deforestation is extremely bad for everyone on this planet.

One way we can usefully consider linking for developing learning is as building of foundational knowledge for thinking. It is additive and cumulative: we create more links as we find out more (Fig. 1). Obviously, in the absence of adequate information or knowledge, what I think–and hence the decisions I make and the actions I take–may be compromised. This is why education systems that are heavily test-oriented are problematic: they effectively undermine the development of students' abilities to think [7]. Because tests only require a limited amount of information to be learned for use in a very limited amount of time, by encouraging students to learn for the sake of tests (and other similar assessments), they instill a view that learning any more than what is required is simply optional and may not even be strategically beneficial. But learning should be for life rather than just to pass tests. Educators should be cultivating curiosity and a thirst for knowledge.

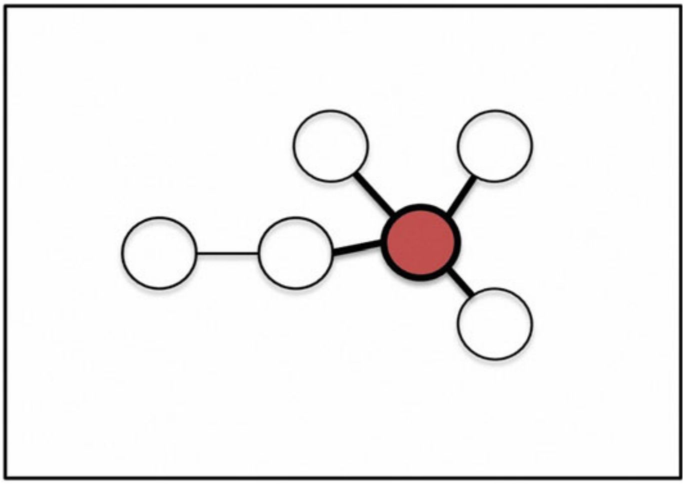


Fig. 1 Linking to develop learning (Understanding)

2.2 Linking to Combine Learning (Integration)

Beyond just developing our knowledge about individual units or items of what we learn, it is also important that we establish links between those units or items so that they make sense together where possible. In other words, we need to combine or integrate what we learn. Earlier, we referred to the problem of school subjects or learning areas being compartmentalized and how the necessary links are not developed, but this compartmentalization of learning extends beyond subjects and learning areas. For example, learning also tends to get compartmentalized according to locations or contexts. Hence, many students do not see important links between what they learn at school and what happens in their life outside of school [8, 9]. Likewise, many fail to see any connections at all between much of what they learn at home and in various social contexts, or the hobbies and interests that they spend their free time on and what they learn at school. And their teachers may provide little or no encouragement or guidance for such crucial integration (and to be fair, they probably received little or no training on how to provide such encouragement or guidance).

Linking to integrate different facets of what we learn is important at the micro and macro levels. At the micro level, we need to integrate different views, descriptions, explanations, and other facets of what we learn. For example, we might link different interpretations of a novel or play we are studying or the explanations of a concept like “free will” or “memory” from different theoretical perspectives. Such links may be obvious–albeit tedious if we are not interested in what we are supposed to be learning–as the links we need to make are about the same aspects (i.e., interpretations, explanations) of the same thing (i.e., novel or play, concept). However, sometimes what needs to be linked is not so obvious; for instance, what we might read about “racial discrimination and equality” in our textbook and on the internet, what we might see in the news about it, and what people that we know might say about it. As in this example, the components that should be linked may be separated not only in location but also in time (i.e., not happening or available to us around the same place and/or time). At the more macro level, the links may be even less obvious as they may lie on more abstract levels or different dimensions. For example, we may need to link what we know about the mechanisms of the human heart and our personal experiences of engaging in strenuous physical activities or establish connections between stress-induced psychological conditions we learn about in a university course and the actions taken by a protagonist in a novel we read for pleasure. By integrating these different strands of our learning, we are able to see a more complete and accurate version of the pertinent big picture.

Linking to integrate learning is important for thinking purposes because the big picture it creates for us is more informative than isolated units or items of learning. An integrated view can provide alternative perspectives and arguments and enable us to apprehend similarities, differences, and relationships, enriching our understanding. This kind of linking can therefore be considered a logical next step to “linking to *develop* learning (understanding)”, described in the previous subsection. The

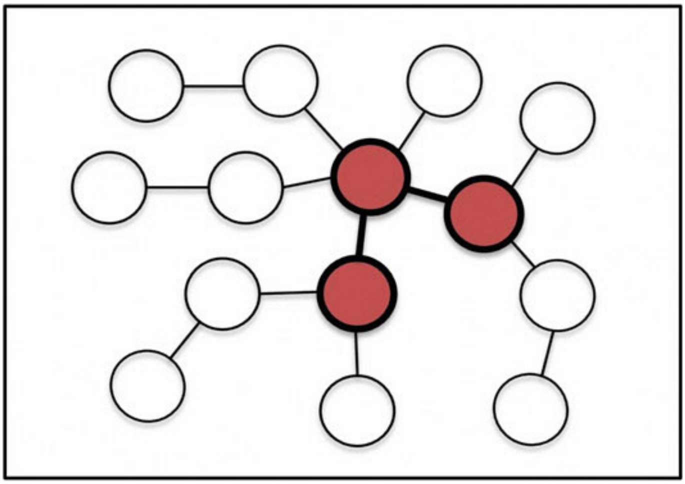


Fig. 2 Linking to combine learning (Integration)

difference is in the focus and purpose of linking. In linking to *develop* learning, the focus is on the single units or items we need to learn to understand those. For example, I find out a new word, concept, or idea and link various kinds of information to it (e.g., definitions, explanations, descriptions, examples) to understand what it is and what it means. In contrast, in "linking to *combine* learning (integration)", the linking is of those units/items I have understood so that I can construct a more comprehensive bigger picture that meaningfully connects them (Fig. 2). The bigger picture that integration of learning provides makes it easier to find meaning and value in what we learn. Such apprehension of meaning and value is crucial for motivation and self-regulation [10]. The multiple perspectives that integration brings together are also essential to critical thinking and avoiding bias [11].

2.3 Linking to Organize Learning (Schematizing)

One very important function that linking enables is the organization and reorganization of what has been learned. This kind of linking can be considered as a special case of "linking to combine learning (integration)", described in the preceding subsection, but we create a separate category for it here as there are important differences in the processes involved and the functions it serves. When we "integrate" learning, we combine different learning units to create a more comprehensive big picture. All components of each unit of learning included in the linking contribute to creating that big picture. In other words, it is a composite view that provides a variety of information from multiple sources and perspectives. In contrast, when we "schematize", although there is a combining process involved, there is also selection and reorganization. Not all components of the units of learning that contribute to a schema are retained, only those necessary to the purpose of the new organizational structure. More importantly, that new organizational structure, that is, the new schema that has been created, constitutes a new unit of learning in itself (Fig. 3). It provides a new way of understanding or perceiving something or a new guide to thinking or behaving, exactly as schemas are meant to do [12, 13].

Take, for example, the construction of a schema for solving math word problems. There are many units of learning we need to draw from and link together to construct such a schema (e.g., what we know of arithmetic procedures, examples of problem-solving that our teacher might have demonstrated in class, the use of heuristics like drawing diagrams or trying out known formulas, etc.). However, even though we might integrate those in constructing our schema, we only select and incorporate relevant components in that new schema. Hence, the schema may comprise a sequence of steps to take for solving such problems (e.g., reading carefully to understand the terms of the problem, identifying the kind of information required for the answer, determining what pertinent information is already provided in the problem description, re-representing pertinent information in a diagram that matches the requirements of the problem, etc.). Such a schema is a guide to behavior and helps us avoid a disorganized approach to solving the problem (e.g., relying solely on trial-and-error, reading and re-reading the problem in the hope of a clue materializing, etc.). It is derived from combining previous learning units but retains only those elements that are essential for its particular purpose. It is also organized in a new way and hence, a new learning unit, rather than just a composite or a big picture.

Schema creation that results from organizing and reorganizing learning is important for the efficiency and viability of more complex thinking. Schemas enable automatization of procedures (e.g., we no longer have to think from scratch

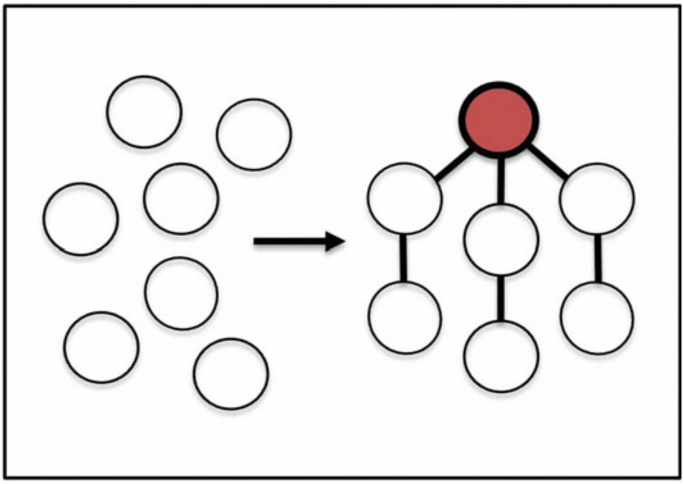


Fig. 3 Linking to organize learning (Schematizing)

about what to do each time we have to solve a math word problem) and reduce cognitive load (e.g., the problem to solve or issue to deal with becomes more mentally manageable). Also, schema construction and the resulting reduction in cognitive load lead to a freeing up of resources in working memory [14]; hence, we have more mental resources we can deploy to the thinking tasks we need to engage with.

2.4 Linking to Distill Learning (Abstraction)

Linking to distill learning can also be considered a special case of "linking to combine learning (integration)". However, its process and the functions it serves are different, so it warrants a category of its own here. Abstraction can follow integration; once the big picture is realized through linking pertinent learning, the overarching meaning or meta-understanding can be distilled (i.e., the conceptual interpretation or symbolic representation of the composite big picture can be apprehended; Fig. 4). Hence, the linking here is to a higher-level summarization or representation of what there is: it captures the important essence of the learning. This abstraction of meaning is more than just a general overview gained if we simply combine and integrate what we have learned.

An example would be reading a novel (e.g., Mary Shelley's *Frankenstein* or Anna Burns' *Milkman*) [15, 16]. Combining all that we find out in the novel about its characters and the events that occur would provide us an integrated big picture of the novel (e.g., *the novel is about …; in the novel, x and y happen because …;* etc.), but distilling what we think the novel's meaning or main message might be (e.g., *people need to have a sense of acceptance and belongingness; people need to find*

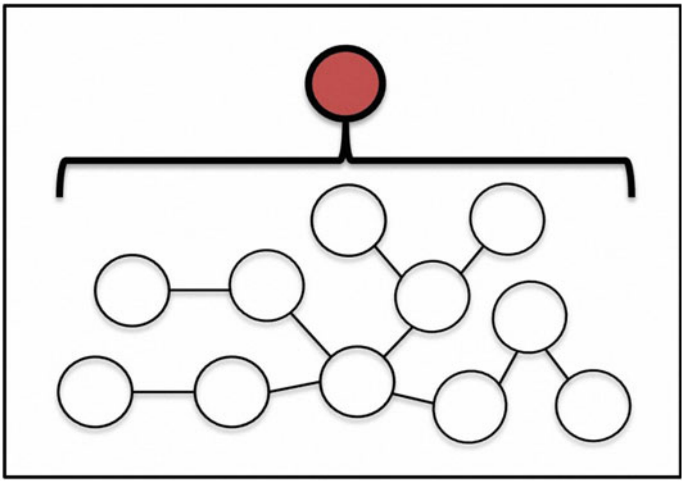


Fig. 4 Linking to distill learning (Abstraction)

ways of coping with difficulties that present when politics intrude on their lives) would provide us with a conceptual interpretation that is the abstraction of what we have learned. Abstraction is important to thinking as it enables us to apprehend the deeper meaning or main thrust of our learning. It provides an answer to what the main point is.

2.5 Linking to Extend Learning (Inference)

Linking to extend learning and draw inferences could be confused with "linking to distill learning (abstraction)" as they are both creating a link to something new based on what has been learned. However, while abstraction or drawing out a meta-understanding of what has been learned is firmly based on the contents of learning, inference goes beyond that. When we draw inferences, we extend what we learn to more than the information or data available [17]. For example, from reading various reports and case descriptions of student performance during the coronavirus (COVID-19) pandemic, I might infer that isolation is causing low motivation for learning in many undergraduate students. None of the reports or cases I read may explicitly state or indicate that, but I may draw links between low rates of coursework submission in courses that have been taught asynchronously and poorer performance (compared to previous semesters) from out-of-town students living on their own. The inference I draw (which, of course, may or may not be correct) is not just integration or conceptual interpretation of the information I have available: I actually make a deduction that constitutes "new learning". In effect, I extend my learning to more than the building blocks I started with (Fig. 5). Of course, before I can draw inferences, I need to integrate what I have learned and completely understand what it means. It is based on such understanding that I can extend my learning.

Linking to extend learning is important for more advanced thinking. Making inferences is at the core of the ability to draw conclusions from what has been learned. It also likely underpins sudden insight (i.e., the "aha!" moments) and creativity [18].

2.6 Linking to Export Learning (Transfer)

In very simple terms, transfer of learning refers to applying what has been learned (information, strategy, skill) to a new situation or context (Fig. 6). For example, if I learn about fractions in school and use that learning at home to determine how much of an ingredient I should use in my cooking just for myself instead of a family of four, that would constitute transfer. The ability to transfer is very important as it is the key indicator that *deeper learning* (i.e., profound understanding of knowledge) has occurred [19, 20].

A distinction can be made between *low-* and *high-road* transfer [21]. In low-road transfer, learning is applied to a new situation/context highly similar to the original

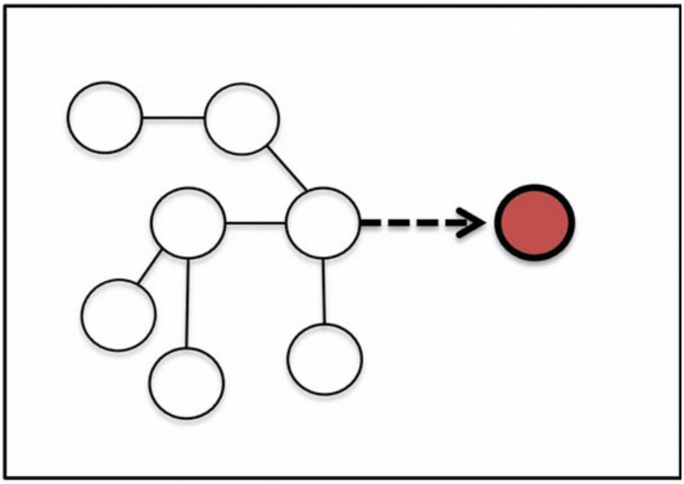


Fig. 5 Linking to extend learning (Inference)

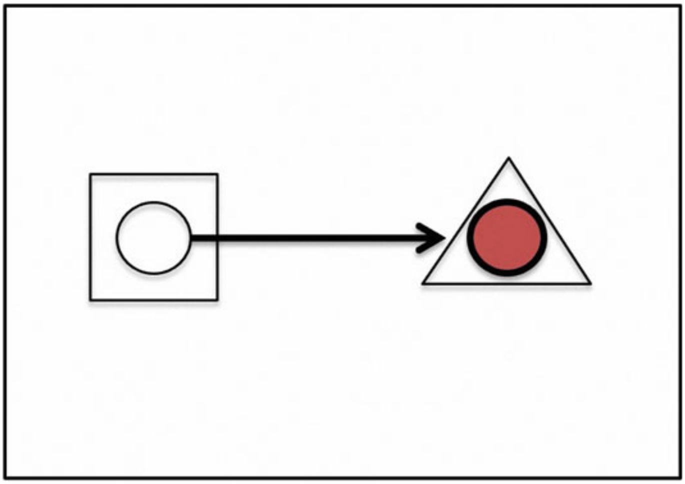


Fig. 6 Linking to export learning (Transfer)

learning situation/context. The learning has also been well-practiced, increasing the salience of its availability and the level of automaticity of its execution. Thus, the transfer of learning would involve a lower level of effort, and we would normally expect it to occur if learning was sufficiently successful. For example, if I learn strategies for solving math word problems during my regular math class and use those strategies in solving new problems I encounter in an entrance examination, that would be a case of low-road transfer. The strategies I have learned have been well-practiced, and I am quite familiar with what to do (i.e., I can execute the steps with some degree of automaticity). Furthermore, the problems I encounter in the exam–even though different in their cover story and numerical values–would be very similar in structure to the ones I have encountered in my regular math class.

In contrast, high-road transfer involves mindful abstraction of the elements that need to be transferred. The stimulus and situation/context bear lower levels of similarity to those during the original learning. In other words, in high-road transfer, I need to abstract important principles from what I have learned to apply those to new situations/contexts that may not be easy to recognize as similar. For example, I may have learned during my math class in school that constructing diagrams helps solve math word problems because the visual representation makes clear the connections between elements of the problem that need to be considered together. Some years later, at work, my boss assigns me the task of preparing an explanation of a complicated office procedure for staff, and I construct diagrams to supplement the explanation provided in text that I write. This would be a case of high-road transfer. Both the situations/contexts (school vs. work) and the task/stimulus are different (math problem solving vs. constructing an explanation). But in considering what I could do to make the procedures easier for other staff to understand, I draw from my experiences in school and abstract what I learned about the properties of diagrams (i.e., they can clarify relationships and flow in complicated information). Hence, I *transfer* what I have previously learned to this new situation. Linking to export learning, or transfer, is at the heart of making learning useful. It is therefore imperative that we consider effective ways of promoting it in student thinking processes.

3 How Can We Promote More Reliable Linking in Learning?

The problem of disconnection in learning described in this chapter has not gone unnoticed in the field of education, and there already exists a number of instructional approaches that have been proposed for overcoming various aspects and manifestations of this problem. In this section, we will outline some of those approaches, as well as some other teaching methods/strategies that appear promising in facilitating linking in learning.

3.1 Linking Subject Disciplines

The most salient manifestation of the disconnection-in-learning problem is the compartmentalization of subject disciplines. As noted earlier, in most regular classrooms worldwide, academic subjects are treated separately, and there is very limited effort to link learning between those subjects. It is therefore not surprising that movements for interdisciplinarity have gained recognition and, to some extent, acceptance. In simple terms, interdisciplinarity combines and integrates two or more subject disciplines into one activity to facilitate a more comprehensive understanding [22–24]. It is often compared and contrasted with multidisciplinarity, which is the study of a topic or issue from several disciplines simultaneously to gain multiple perspectives but without as much emphasis on disciplinary integration [24]. It is outside the scope of this chapter to consider the similarities and differences between these or other alternative terms used to describe this approach (e.g., transdisciplinarity, indisciplinarity) [25]. For the sake of simplicity, we will use interdisciplinarity here to describe this effort to overcome the constraints of learning within the boundaries of traditional subject disciplines.

When using the interdisciplinary approach to instruction, students are taught using themes, issues, or problems that are approached from a combination of subject disciplines (e.g., understanding and finding a solution to the pollution of waterways in a particular city might be approached from the perspectives of biology, chemistry, geography, health science, history, etc.). There are many different types and levels of interdisciplinary instruction [26, 27], but the important point is that students focus on understanding the issues, problems, or phenomena from multiple perspectives like they would in real life. Well-known approaches in interdisciplinary instruction include project-based learning (PBL) [28, 29] and phenomenon-based learning (PhenoBL) [30, 31]. In PBL, students work in teams for an extended time on a project to address real-world issues, problems, or challenges that have some relevance to them (e.g., understanding viral infections and pandemics and how we can deal with such problems on a day-to-day basis). They utilize various sources in their investigation, including interviews and consultations with experts in the field, and collect primary and secondary data to answer pertinent questions. PhenoBL (also known as "phenomenal education") is a similar approach that has been developed in Finland. In PhenoBL, both teaching and learning are focused on real-world phenomena (e.g., humans, energy, water, the European Union): these are studied holistically (i.e., across the boundaries of traditional school subjects) across different learning environments (e.g., regular classroom, laboratory, fieldwork, e-learning environments).

Interdisciplinary instruction promotes interdisciplinary thinking, which has been described as a complex cognitive skill that includes the ability to view issues from multiple perspectives and create crucial, meaningful connections across disciplines [32]. Interdisciplinarity is also considered effective for cultivating flexibility, criticality, and creativity in thinking, as well as communicative competencies [23].

3.2 Linking Locations and Purposes of Learning

There are also initiatives that focus particularly on strengthening the links between what students learn in different locations (e.g., school, home, the wider community) and learning for what may seem like different purposes (e.g., learning in school and for work). An example of the first kind is the "school, family, and community partnerships" program developed by Joyce Epstein [33, 34]. In this program, the main aim is for schools to better connect with families and relevant communities in reciprocal relationships to benefit not only the students but also parents, teachers, and others in those communities. While the program has broader goals that include learning itself (e.g., parental and community engagement in matters like decision-making and management of school-related activities), the linking of what students learn in school to the contexts in which they live, work, and play is crucial. For example, interactive homework can be designed and implemented so that there are regular opportunities for students to discuss what they are learning with their parents, and parents take greater responsibility in ensuring their children are provided support for the successful completion of homework and other learning tasks. Family math, science, and reading activities at school are organized so that teachers can discuss strategies with parents to continue and hence link what students are learning in their school subjects with everyday activities at home. For younger children, for instance, opportunities for counting items at home (and hence link what they learned in math at school) and playing games that require reading and word skills (e.g., *Scrabble*) are considered invaluable. For older children, helping with matters like weekly or monthly budgeting or building and fixing things around the home can likewise present useful opportunities for applying what they have learned at school in authentic, real-life tasks and challenges. Students can also be provided opportunities to engage with various community-based projects that require the use of what they have learned at school, such as recycling programs, community art projects, music, drama, and activities to support elderly community members. Through such involvement, the program promotes a greater sense of meaning and value for what students are learning at school: bi-directional links are established with what they do in real life outside of school (i.e., not only is school learning relevant to home and community but also home and community learning is relevant to school).

Initiatives for "linking learning and work" [35] aim to address the need to better link what students learn at school or university and what they have to do at work. Such initiatives encourage teachers/educators to consider how the classroom instruction they provide can cultivate not only discipline/content knowledge and skills but also the employability of their students. They can do this, for example, by incorporating the development of skills considered as essential or ideal in work contexts (e.g., creativity, complex problem-solving, communicative competencies, critical thinking, leadership) in what and how they teach their students. Teachers/educators can also collaborate with career guidance professionals in ensuring that work relevance is addressed in courses they teach and in developing possible links with potential employers and industry so that students gain first-hand experience of the work relevance of what they are learning (e.g., guest talks or visits). Linking academic and work relevance of what is being learned should help students better appreciate the meaning and value of that learning, think more flexibly, develop a tolerance for ambiguity, create work opportunities, and adapt to their environments. All of these matter when dealing with the uncertainties of the future, including the constantly changing nature of work.

3.3 Questioning and Verbal Linking

Questioning is a particularly powerful way to link and build knowledge and facilitate engagement in various aspects of thinking. Questioning can be used on its own as an instructional strategy [36–38], but it can also be used as an integral part of other teaching and learning methods, such as dialogic learning [39–42]. The process of generating questions and seeking answers to questions that have been asked necessitates the linking of information and thought processes. For instance, if a friend tells me about a new computer application she is now using, I learn something new: the existence of that application and perhaps its name. If I ask, “What does it enable you to do?” then I would be building a new link from just the existence of that application to its function, which would be elaborated on if my friend explains that to me. The information she provides could pique my interest, and I might then ask more questions (e.g., Is it free? Where can you get it? How easy is it to use? Does it work with [name of other application]?) in the process creating more links to what I now know about that application. As may be obvious from this simple example, questioning plays an extremely important role in our learning and thinking development. Through it, we can develop our understanding and our interest, engagement and enthusiasm about something, and identify gaps in what we know, alerting us to what more we need to know. Formulating a question in itself is helpful toward developing critical thought, metacognition, autonomy, and decision-making [38]. However, despite all this potential, questioning as a learning and teaching tool is very much underutilized in most education systems [37]. Students lack spontaneity in asking questions, even in situations when they should. Many are also poor at generating appropriate questions for addressing gaps in their knowledge. Without appropriate and adequate training, many teachers also lack skills in asking appropriate questions [43, 44], which may explain the reluctance that many of them have to use questioning as part of their regular teaching strategy.

Dialogic learning means learning through dialogue, while dialogic teaching means teaching through dialogue, including quality dialogue [40]. Ideally, in dialogic learning, the dialogue between participants is egalitarian, meaning that there is no hierarchy, and they can contribute to the dialogue equally. For this reason, dialogic learning is usually contrasted with monologic learning. In the latter, the learner aims to find out the “correct” knowledge or information from the other participant (usually the teacher), and there is little or no room for debate about the “correctness” of the knowledge or information conveyed. In monologic learning, which is the form that most regular classrooms take, the learner is *not* an active participant in the construction of knowledge: he/she is only a receiver of knowledge that is more-or-less fixed. This is the key difference because, in dialogic learning, the learner is an active contributor to constructing knowledge through the dialogue he/she engages in. This dialogue can take the form of interactions with teachers and other students (or other people) in one-to-one or group situations [42].

As noted earlier, questioning is central to dialogic learning, particularly because knowledge is viewed as continually being constructed and developed as the dialogue takes place. As we apprehend answers to questions asked, knowledge is created. Questions inevitably arise in the context of dialogue, with the provision of answers leading to more questions being asked. The knowledge, therefore, evolves as those new questions are asked.

In dialogic learning, knowledge is never fixed or final: the questioning and answering process continually creates new linking for knowledge building. This feature of the dialogic approach promotes flexible and adaptive thinking, creativity, and innovation. Furthermore, the participant's responsibilities in sharing/answering and finding out/questioning during the dialogue facilitate the development of learning skills [19].

3.4 Visual Linking

Apart from verbal linking of learning, another potentially powerful way to link learning is through visual representations, also known as diagrams. In this section, we will use the term *diagrams* to refer to the broad category of visual representations, which includes sketches, drawings, illustrations, tables and other arrays, charts, and graphs. We also count the portrayal of three or more words/phrases that are connected by lines or arrows–in effect creating a flow or organizational chart–as instances of diagrams.

By their very nature, diagrams establish links between pertinent elements of what is being learned or between pieces of information pertinent to the matter under consideration. It is for this reason that Larkin and Simon considered diagrammatic representation as more efficient than sentential representations [45]. They explained that diagrams group all pertinent information that needs to be used together in tasks such as problem-solving. That grouping clarifies connections and relationships, supporting people's ability to draw the necessary inferences from the information provided. For instance, in layout diagrams (e.g., diagrams that show the layout of buildings, people, furniture, equipment, etc. in a given area), the proximity of pertinent 'items' can more easily be apprehended, making it easier to consider or calculate matters like movement or travel time, directions, and various other space issues. In communication, diagrams make it easier to 'see' and understand the message being conveyed verbally (via text or speech). Diagrams link pertinent elements of the message to be conveyed, making them easier to apprehend. For example, flow charts can make the correct sequence of procedures easier to follow. Illustrations and sketches, on the other hand, can make it easier to perceive the connections between elements being described and what the composite or integrated 'big picture' might look like.

When students construct their own diagrams, the process of diagram construction necessitates–among other things–determination and representation of the links that exist between crucial elements of the information provided (or the issue under consideration). To construct those links, students need first to understand the meaning and significance of those elements. Once the diagram has been constructed, the elements and their connections become more evident, thus enabling many inferences to be made [46].

There is considerable research evidence showing that the generation and use of self-constructed diagrams in tasks like learning, problem-solving, communication, and critical thinking lead to better performance [47–54]. However, students do not reliably construct and use appropriate diagrams, and the majority lack spontaneity in using diagrams [55–57]. It is also unfortunate that instruction in graphicacy, especially to cultivate student competencies in constructing and using diagrams, is rarely provided in the current school education systems.

3.5 Linking People

A lot has been written about collaborative learning in the education research literature, including how it promotes various thinking skills [58, 59]. In this subsection, therefore, we will outline some of the important ways it promotes the linking of learning and how such linking can, in turn, promote various thinking competencies.

Like the saying that "two heads are better than one", collaborative learning essentially presents opportunities for two or more people to combine knowledge, skills, and wisdom they possess so that the combination amounts to more than what each person would possess if the collaborative learning did not occur. The linking of learning occurs at multiple levels, the most obvious of which is at the information sharing level. For instance, if I am working collaboratively on a learning task with another person, he/she could share some information relevant to the task which I might not previously know. Thus, I create a new link to combine my previous and new learning. At another level, though, the collaboration *process* facilitates the construction of new learning links: my collaborator and I learn new things due to how we interact and work together. This learning goes beyond the combination and/or synthesis of what we know and share with each other. It includes drawing inferences based on our experiences of collaboration. For example, suppose during collaboration, I struggle a bit with explaining something (e.g., my collaborator cannot understand what I am trying to explain). In that case, I might employ another strategy, such as drawing a diagram to supplement my verbal explanation, and this may prove successful. Thus, based on that collaboration experience, I might extend my learning by drawing the inference that visual aids can be helpful in the explanation process. This is not based on information my collaborator shares with me; instead, it arises from the process of experiencing collaboration itself. This kind of learning that collaboration promotes can also include more subtle forms, such as apprehending nonverbal forms of behavior that indicate various cognitive states of my collaborator (e.g., comprehending, misunderstanding, metal tiredness, etc.). These constitute inferential learning that can later be transferred (e.g., used in other collaborative learning situations or other interactions with other people).

Collaborative learning also facilitates the linking of learning that leads to more critical thinking. The collaboration process necessitates understanding of other people's perspectives, even in cases where we disagree. It also provides a checking mechanism so that our own perspectives can be scrutinized by others, which can help us expand (develop more linking) and improve those perspectives by utilizing the feedback, critical comments, and alternative ideas we receive.

4 Conclusion

The approaches and methods/strategies we considered here for promoting more reliable linking of learning are by no means exhaustive; no doubt, numerous others can be used. In fact, because most of these approaches and methods/strategies were not developed specifically for the purpose of promoting linking in learning, they require more work to serve that purpose better. For example, interdisciplinarity promotes the acquisition of knowledge about and awareness of multiple perspectives in understanding issues, problems, and phenomena. However, the idea of also being able to synthesize those perspectives–let alone abstract, draw appropriate inferences, and transfer the combined learning–does not always follow. Thus, further research is sorely needed in this area, particularly in developing these and other new approaches for the specific purpose of better linking learning.

There is also a related, serious need to ensure that teachers and education stakeholders are aware of the need for better and more reliable linking of learning in our education systems. To match this, we need to ensure teachers receive the training and/or professional development that would enable them to facilitate such linking in their students effectively. As noted earlier, for example, questioning is a powerful tool for promoting the linking of learning, but some findings show teachers themselves are not always able to ask the kinds of questions necessary for different learning purposes [37, 43, 44].

If we want to equip learners with the capability of connecting ideas that previously seemed unrelated, and hence to meet the creativity, flexibility, criticality, responsibility, and innovativeness in thinking that the environments of the current century demand, we need to ensure that linking of learning is recognized and implemented as a fundamental objective of education.

Core Messages

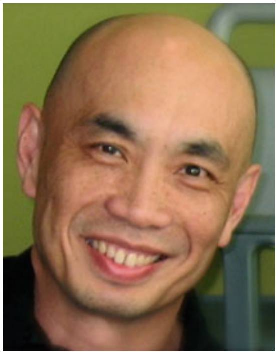
- Linking is necessary for learning, so we need to take concrete, deliberate measures to ensure that happens.
- We must find ways to overcome the disconnection in learning that is currently prevalent in formal education systems.
- Linking we need to promote include understanding, integration, schematization, abstraction, inference, and transfer.
- Successful linking of learning leads to better thinking capabilities.
- We need to improve instructional methods and implementation strategies to more effectively promote linking of learning.

References

1. Thorndike EL (1931) Human learning. Century, New York, p 122
2. Kandel ER (2001) The molecular biology of memory storage: a dialogue between genes and synapses. Science 292:1030–1038
3. Koizumi H (2004) The concept of 'developing the brain': a new natural science for learning and education. Brain Dev 26(7):434–441
4. National Research Council (2000) How people learn: brain, mind, experience, and school (expanded ed). National Academies Press, Washington, DC
5. Schleicher A (2018) World class: how to build a 21st-century school system. OECD, Paris, p 31
6. Marton F, Säljö R (1976) On qualitative differences in learning: I-outcome and process. Br J Educ Psychol 46:4–11
7. Harlen W, Crick RD (2003) Testing and motivation for learning. Assess Educ 10(2):169–207
8. Ito M, Gutiérrez K, Livingstone S et al (2013) Connected learning: an agenda for research and design. Digital Media and Learning Research Hub, Irvine, CA
9. McCarthey SJ (2000) Home-school connections: a review of the literature. J Educ Res 93 (3):145–153
10. Boekaerts M (1997) Self-regulated learning: a new concept embraced by researchers, policy makers, educators, teachers, and students. Learn Instr 7(2):161–186
11. Facione PA (1990) Critical thinking: a statement of expert consensus for purposes of educational assessment and instruction — the Delphi report. California Academic Press, Berkeley, CA
12. Anderson RC (1977) The notion of schemata and the educational enterprise: general discussion of the conference. In: Anderson RC, Spiro RJ (eds) Schooling and the acquisition of knowledge. Lawrence Erlbaum, Hillsdale, NJ, pp 415–431
13. McVee MB, Dunsmore K, Gavelek JR (2005) Schema theory revisited. Rev Educ Res 75 (4):531–566
14. Sweller J, van Merrienboer JJG, Paas FGWC (1998) Cognitive architecture and instructional design. Educ Psychol Rev 10:251–296
15. Shelley MW (1998) Frankenstein or the modern Prometheus (the 1818 text). Oxford University Press, Oxford
16. Burns A (2018) Milkman. Faber and Faber, London
17. Tenenbaum JB, Kemp C, Griffiths TL, Goodman ND (2011) How to grow a mind: statistics, structure, and abstraction. Science 331:1279–1285
18. Sannomiya M, Yamaguchi Y (2016) Creating training in causal inference using the idea post-exposure paradigm: effects on idea generation in junior high school students. Think Skills Creat 22:152–158
19. Manalo E (2020) Introduction: establishing a case for sharing research-based instructional strategies. In: Manalo E (ed) Deeper learning, dialogic learning, and critical thinking: research-based strategies for the classroom. Routledge, New York, pp 1–13
20. National Research Council (2012) Education for life and work: developing transferable knowledge and skills in the 21st century. National Academies Press, Washington, DC
21. Salomon G, Perkins DN (1989) Rocky roads to transfer: rethinking mechanisms of a neglected phenomenon. Educ Psychol 24(2):113–142
22. Klein JT (1990) Interdisciplinarity: history, theory, and practice. Wayne State University Press, Detroit
23. Nissani M (1997) Ten cheers for interdisciplinarity: the case for interdisciplinary knowledge and research. Soc Sci J 34:201–216
24. Spelt EJH, Biemans HJA, Tobi H et al (2009) Teaching and learning in interdisciplinary higher education: a systematic review. Educ Psychol Rev 21:365–378

25. Nicolescu B (2014) Multidisciplinarity, interdisciplinarity, indisciplinarity, and transdisciplinarity: similarities and differences. RCC perspectives, No 2, minding the gap: working across disciplines in environmental studies, 19–26
26. Jacobs HH (1989) Interdisciplinary curriculum: design and implementation. ASCD, Alexandria, VA
27. Wood K (1997) Interdisciplinary instruction: a practical guide for elementary and middle school teachers. Merrill, Upper Saddle River, NJ
28. Beckett G, Slater T (2019) Global perspectives on project-based language learning, teaching, and assessment: key approaches, technology tools, and frameworks. Routledge, New York
29. Bender WN (2012) Project-based learning: differentiating instruction for the 21st century. Corwin Press, Thousand Oaks, CA
30. Lonka K (2019) Phenomenal learning from Finland. Edita, Helsinki
31. Phenomenal education. http://www.phenomenaleducation.info/home.html. Accessed 21 Aug 2020
32. van Merriënboer JJG (1997) Training complex cognitive skills: a four-component instructional design model for technical training. Educational Technology, Englewood Cliffs
33. Epstein JL (2019) School, family, and community partnerships: preparing educators and improving schools, 2nd edn. Routledge, New York
34. National network of partnership schools. http://nnps.jhucsos.com. Accessed 21 Aug 2020
35. Taylor SC, Haras C (2020) Beyond classroom borders: linking learning and work through career-relevant instruction. Am Counc Educ, Washington DC
36. Chin C, Osborne J (2008) Students' questions: a potential resource for teaching and learning science. Stud Sci Educ 44(1):1–39
37. Oyama Y (2018) Promoting learners' spontaneous use of effective questioning: integrating research findings inside and outside of Japan. In: Manalo E, Uesaka Y, Chinn C (eds) Promoting spontaneous use of learning and reasoning strategies: theory, research, and practice for effective transfer. Routledge, New York, pp 31–45
38. Pedrosa de Jesus H, Moreira AC (2009) The role of students' questions in aligning teaching, learning and assessment: a case study from undergraduate sciences. Assess Eval High Educ 34(2):193–208
39. Dawes L, Mercer N, Wegerif R (2000) Thinking together: a programme of activities for developing speaking, listening and thinking skills in children aged 8–11. Imaginative Minds, Birmingham, UK
40. Phillipson N, Wegerif R (2020) The thinking together approach to dialogic teaching. In: Manalo E (ed) Deeper learning, dialogic learning, and critical thinking: research-based strategies for the classroom. Routledge, New York, pp 32–47
41. Wegerif R (2007) Dialogic education and technology: expanding the space of learning. Springer-Verlag, New York
42. Wegerif R (2017) Defining 'dialogic education'. http://www.rupertwegerif.name/blog/defining-dialogic-education. Accessed 21 Mar 2019
43. Ahtee M, Juuti K, Lavonen J, Suomela L (2011) Questions asked by primary student teachers about observations of a science demonstration. Eur J Teach Educ 34(3):347–361
44. Tienken CH, Goldberg S, DiRocco D (2009) Questioning the questions. Kappa Delta Pi Record 46(1):39–43
45. Larkin JH, Simon HA (1987) Why a diagram is (sometimes) worth ten thousand words. Cognitive Sci 11:65–99
46. Manalo E, Uesaka Y, Chen O, Ayabe H (2020) Showing what it looks like: teaching students to use diagrams in problem solving, communication, and thinking. In: Manalo E (ed) Deeper learning, dialogic learning, and critical thinking: research-based strategies for the classroom. Routledge, New York, pp 231–246
47. Ainsworth S, Prain V, Tytler R (2011) Drawing to learn in science. Science 333:1097–1097
48. Chen O, Manalo E, She Y (2019) Examining the influence of expertise on the effectiveness of diagramming and summarising when studying scientific materials. Educ Stud 45(1):57–71

49. Corter JE, Zahner DC (2007) Use of external visual representations in probability problem solving. Stat Educ Res J 6:22–50
50. Hembree R (1992) Experiments and relational studies in problem solving: a meta-analysis. J Res Math Educ 23(3):242–273
51. Manalo E, Tsuda A, Dryer R (2019) The effect of cultivating diagram use on the quality of EFL students' written explanations. Think Skills Creat 33. https://doi.org/10.1016/j.tsc.2019.100588
52. Manalo E, Uesaka Y (2016) Hint, instruction, and practice: the necessary components in promoting spontaneous diagram use in students' written work? Lect Notes Artif Int 9781:157–171
53. Schmidgall SP, Eitel A, Scheiter K (2019) Why do learners who draw perform well? Investigating the role of visualization, generation and externalization in learner-generated drawing. Learn Instr 60:138–153
54. Uesaka Y, Igarashi M, Suetsugu R (2016) Promoting multi-perspective integration as a 21st century skill: the effects of instructional methods encouraging students' spontaneous use of tables for organizing information. Lect Notes Artif Int 9781:172–186
55. Manalo E, Uesaka Y, Pérez-Kriz S et al (2013) Science and engineering students' use of diagrams during note taking versus explanation. Educ Stud 39(1):118–123
56. Uesaka Y, Manalo E (2006) Active comparison as a means of promoting the development of abstract conditional knowledge and appropriate choice of diagrams in math word problem solving. Lect Notes Artif Int 4045:181–195
57. Uesaka Y, Manalo E (2018) How to address students' lack of spontaneity in diagram use: eliciting educational principles for the promotion of spontaneous learning strategy use in general. In: Manalo E, Uesaka Y, Chinn C (eds) Promoting spontaneous use of learning and reasoning strategies: theory, research, and practice for effective transfer. Routledge, New York, pp 62–76
58. Hmelo-Silver CE, Chinn CA, Chan CK, O'Donnell AM (eds) (2013) International handbook of collaborative learning. Routledge, New York
59. Rogoff B (1998) Cognition as a collaborative process. In: Damon W (ed) Handbook of child psychology, vol 2. Cognition, perception, and language. Wiley, New York, pp 679–744



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The Learning Society and the New Frontiers of Knowledge on the Web

6

E. Serena Sanseviero

The mind is not a vessel to be filled, but a fire to be kindled.

Plutarco

Summary

In this Chapter, we will try to draw a profile on the knowledge society and then describe the current trend that considers knowledge as deriving from an increase in reality and its continuous and mediated re-elaboration. Nowadays, the new generations are more open to global knowledge and to a greater confrontation with foreign cultures. It is, therefore, required to develop ideas and life plans inherent to the relationship between the family, school, and society. It is with the awareness of one's place in this world that human knowledge can be improved as a fundamental requirement for the challenges that the future presents to today's man. Global knowledge is increasingly the result of the common need for different means of expression, which, through human use, put the world in communication. This expressiveness is characterized by the use of a new literacy of languages that creates and communicates knowledge in an increasingly "expanded" way to the different human realities in the world.

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N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_6

Graphical Abstract/Art Performance

Voussoirs with the liberal arts.
(Reproduced from https://homepages.bluffton.edu/~sullivanm/chartreswest/svoussoirs.jpg, Copyright © Mary Ann Sullivan).

Keywords

Augmented reality · Communication · Digital · Internet of things · Knowledge society · New media · New technologies

QR code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction: On the Shoulders of Giants: Paradigm of the "New Knowledge"

As Bernard of Chartres argued, around 1159 in John of Salisbury's Metalogicon,

> we are like dwarves on the shoulders of giants

that is, today we are in a position to be able to see more things than those who preceded us, and we can refine our gaze even more and to take us far away (to go towards new knowledge), certainly not for the acumen of our sight or for the height of our body, but because we are lifted and carried high by the stature of giants,[1] thus highlighting, with debated positions, our debt towards the ancients.

So, the idea of culture is defined as a continuous fabrication (construction) of men, in which modern thinkers, considered "small" compared to the founding fathers of the knowledge of the past, can overcome them and progress thanks to previous acquisitions. Therefore, we, men and women of the twenty-first century, see the horizons of knowledge technologies not as a frame but as a tool to perceive

[1] Giovanni di Salisbury, *Metalogicon*, Libro III, Capitolo 4.

and reach them. The things of knowledge, the paths of knowledge are many, and the "new technologies" facilitate our step, help us to work together, bring us closer to the future.

Our daily functions, such as learning to collaborate and to know, are often enabled, mediated, and interpolated by the technologies of the network whose extraordinary impact we verify every day. On the way to this new knowledge, the moment seems ripe to look into the distance, hypothesize scenarios, draw inspiration and conclusions ([1], p. 9). The main idea of this intervention is the desire to verify the possibility, in the experimentation anyway, of putting technologies to graft knowledge

> in favor of a socio-technical and socio-cultural system, of the network that increases man in the exercise of vital functions such as research, knowledge and collaboration [ibid].

Through new media, users can collaborate and learn by sharing thoughts, information, and creations in the virtual space. An increase in the human potential of individual intelligence into collective intelligence is generated in digital memories.

The communicative interaction allows the accumulation in the databases of a new form of original knowledge that is not only quantitative but qualitative due to the often random unpublished connection produced by the network beyond individual intentions [2].

Reflecting on knowledge and its novelties or new ways of constructing it, as reported by Pattenati and Sorrentino in *Orizzonti di conoscenza. Strumenti digitali, metodi e prospettive per l'uomo del terzo millennio,* we can see on the horizon of our time, a new knowledge, which takes its particular shape on the trail of a world in constant transformation, crossed by technologies, enveloped by networks.

Man in his multiple dimensions (when he works, when he learns, when he tries) is immersed every day in a multi-faceted reality at kaleidoscopic of times, with shapes that change moment by moment. For this purpose, it is appropriate to be able to express some reflections and decline some themes such as [1]:

- human scenarios of the third millennium;
- digital tools and skills useful for learning; and
- collaboration and knowledge acquisition

The goal is to scan the horizon to understand a future that comes quickly and surprisingly. As has been reported by many, an enhanced human is outlined, a man who enhances his actions with flexible and targeted digital tools and strengthens his mind because he is the master of the highly creative scenarios that technological horizons suggest.[2]

[2] ibid, preface by Dino Giuli University of Florence, p. 10.

1.1 The Scenarios

Possible scenarios for the future play a role even more than before that gives them great charm and, at the same time, great uncertainty. In fact, these forecasts are increasingly measured today with the great epochal changes which, differently from what happened up to about 50 years ago, in just a few years have made the world take unpredictable paths, producing radical transformations in terms of depth, extension, speed, and pervasive capacity. With reference, for example, to the mass media, which have a great influence on this discussion,

> the speed of change in the world of mass media has reached incredibly high and hitherto unknown peaks" ([3], p. 382). Another statement by Manuel Castells has now become famous and compares today's speed with the previous pace of change: "In the United States, the radio took thirty years to reach sixty million people, television has reached this level of spread over fifteen years; the internet has done so in just three years since the birth of the world wide web ([3], p. 382).

The speed of change is affecting our lives involving different sectors, from the economy (today we buy more and more through online sites, therefore fewer physical stores in which to shop) to the study (online lessons), to the different sectors of work, … to architecture. The relationship between people is increasingly virtual as a result of such change [4] (Fig. 1).

Therefore the concept of knowledge can be taken as a mark of the great changes unfolding in the contemporary world. As a basis for exploring the declared content, it is good to start from what is called the knowledge society. The terminology used to define the characteristics, or at least the horizon, towards which contemporary society is moving has a series of broad implications that affect different areas of our life, especially in terms of the dimension linked to education and training. The passage of the phase for the relevance of the educational dimension in the life of individuals and of society is indisputable. The current society is defined by many as a knowledge or learning society, often even preferring the Anglo-Saxon toponym learning society, which more immediately returns the iterative, continuous and repetitive image of learning in the current configuration of society. In fact, lifelong learning and, therefore, the development of the knowledge society or learning, if you prefer, are concepts inevitably linked to each other. These definitions indicate the prevalence of descriptive and metaphorical use of different concepts with the same meaning. However, it must be emphasized that our ability to produce and use data without more references in space and beyond local limits, therefore globally, does not develop or does not necessarily lead to the creation of knowledge. In fact, contemporary media, even in their access to "new media," provide an enormous amount of information, but the same alone do not create knowledge: to create knowledge, a conscious reflection is required that attributes meaning and understanding to information. This collective intelligence, collaborative and cooperative capacity, does not represent a closed universe of a dominant impersonal superior knowledge but rather a connective intelligence open to the multiplication of relationships and integrations of knowledge, which is dynamically renewed with each

Fig. 1 Library of Congress, Rosenwald 4, Bl. 5r (reproduced from Unknown author, Public domain, via Wikimedia Commons, https://upload.wikimedia.org/wikipedia/commons/4/4a/Library_of_Congress%2C_Rosenwald_4%2C_Bl._5r.jpg)

new access. Beyond each codified group, connective intelligence expands with free searches for new ways of knowledge acquisition and learning, which quickly facilitate change and innovation in horizontal and democratic coordination between individuals even in the absence of leadership [5].

Linked to the concept of the knowledge society, there are some paradigms that strongly characterize the time we live in, that of complexity that emerged strongly at the end of the 90s of the last century, that of the fractal nature of things, slightly earlier than the previous one, deriving from a theory implemented by the French mathematician Benoit Mandelbrot as early as 1969 and which is well applied to a structure that remains similar to itself whatever the observed level (L. Manovich highlights this principle as the author of new media and defines it as the principle of modularity); that of liquid nature, a character attributed to contemporary society by the philosopher Zygmunt Bauman for whom liquid modernity, using his own words, is the belief.

> that change is the only permanent thing and that uncertainty is the only certainty

and with this, he wants to reinforce the concept that today more than ever, the substance of our society is elusive, not categorized according to classes or paradigms of the past.

Last but not least and directly connected to the previous paradigms is the new idea of space and time.

1.2 The Complexity

The complexity leads us to reflect on the fact that the problems of contemporary society cannot be standardized, that is, with categories for which tools and methods for finding solutions are uniquely defined; this approach was more evident only in the middle of the last century, above all in the problems studied through the prevailing scientific disciplines. This awareness dates back to the 1980s, when the most appropriate spatial-gravitational paradigm for a hierarchical structuring of space collapsed under the crisis of centralized governance. Nowadays, the new complexity sciences no longer refer to pre-established scientific paradigms of absolute validity.

For contemporary thinkers, it is not possible to refer to a scientific approach that does not cooperate synergistically with others for a theory of knowledge and the universe. Interventions, even in problem-solving, today require approaches, certainly scientific, but which intersect, overlap, often mutually exclude each other in order to re-integrate and arrive at simulating a complex intervention or a complex solution. Complexity is often indicated as the main feature of our living environments, every component and in particular in the aspects inherent to the territory. Therefore.

> the "management of complexity" is the fundamental problem for those involved in reading, representation or knowledge of the city and the territory [6].

In such contexts, therefore, we need a multidimensional approach, and it is necessary to create constructive doubts about usual methods often not supported by convincing results to arrive at the consideration of a multidimensional vision.

It is necessary to abandon old certainties, in the face of realities, not complicated or difficult, but complex, to take new paths represented, for example, multiple interactions between variables. From this approach emerges the need to evoke interdisciplinary synergies that capture, each with its own foundations and disciplinary systems, the aspects of contemporary urban reality, to give them back, represent them "ensemble" ([6], p. 101).

> The theory of complexity, first of all, is not a scientific theory in the strict sense. It would be better to speak (and indeed some authors do) of "complexity challenge" or "complexity thought" or, better still, "complexity epistemology". It is precisely as an epistemological perspective, in fact, that complexity plays a crucial role in contemporary thought. This is because complexity involves three equally relevant epistemological innovations: a new alliance between philosophy and science, a new way of doing science, a new conception of natural evolution ([6], p. 155).

So in the globalized world of information and communication technology (ICT), the beliefs and values of a given culture are transmitted from one community to another, generating a process of new integrated knowledge that overcomes the separation of knowledge and techniques. The breaking of traditional barriers educates to a thought of complexity that feeds new theories and discoveries to respond to the challenges of globality. The balance of the complex system of interactions and exchanges develops through mutual self-regulatory feedback, between differentiations and integrations of opposite functions in the complex organization between man and his natural and social environment [7].

1.3 The Fractal Nature

To introduce the concept of the fractal nature of things, as previously expressed, we refer to the theory developed by B. Mandelbrot, who uses the term fractal to explain and illustrate the (mainly geometric) configuration of irregular structures such as the coastlines, the outline of a tree, the constellations, the shape of clouds or that of minerals, of natural and urban landscapes that cannot be described or simplified through the Euclidean geometry of curves and straight lines, squares and of the spheres. According to Mandelbrot [8], fractal geometry is the one that can best represent the nature of reality and the chaos that regulates itself in it (in a word, it can, rightly, represent complexity); it is used to represent and also to create figures in which a part of one's shape is repeated in its structure on different scales according to the principle of self-similarity: if an image is reduced or enlarged, the same formal characteristics can be found, while adding at each subsequent enlargement (and on the other hand removing at each reduction) new visual details. An interesting conclusion of Mandelbrot is that regularity can be grasped in irregularity, an order in disorder, a principle that is explained by the property of self-similarity. But nevertheless, this last assumption is often not sufficient to explain the order that can be seen there. Deepening the position of the father of fractals, it can be agreed that perceiving the regularity of fractal objects in irregularity is not attributable only to homothety, equality but precisely to self-similarity that characterizes the perceptive mechanism called apophenia, that is, to find patterns or connections in random data and not necessarily connected or meaningful to each other. So the world is made up of simple recursive rules that repeat themselves endlessly, generating emerging sets of new combinations from which the forms of understanding of the most diverse disciplines arise from biology to physics, from economics to sociology. This unifying vision of mathematical models is highlighted above all through computer graphics that show the modular possibilities of fractal geometry, which now surpasses the Euclidean one as a privileged model capable of explaining the shapes of the world.

1.4 Liquid Nature

Zygmunt Bauman focuses on the transition from modernity to postmodernity. With a physical analogy, he compares the two concepts (or periods of contemporary history) to the solid and liquid state and attributes them to society: he argues that while in the modern age everything was given as solid construction, today instead, it is possible to artificially remodel every aspect of life. Here we arrive at the concept of the loss of the border or the limit; nothing has clear, defined, and fixed outlines once and for all. Such a position, as well as in the interpretation of reality, cannot fail to influence human relationships, precarious precisely in the name of that vaunted freedom (in fact, one does not want to feel trapped). In today's society, the protagonists, individuals, undergo a metamorphosis, from producers to consumers, which further contributes to defining that great uncertainty that grips modern society. Postmodernity is characterized by a society of uncertainty in a liquid life of rapid transformations dominated by consumerism in which the active producer man is transformed into a commodity, in the planetary homologation of globalization facilitated by the digital revolution that throws the individual into communicative fashions [9]. According to Bauman, in liquid life, the poor try to conform to common patterns, and at the same time, if they cannot feel like others, they feel frustrated. In a society that lives for consumption, everything is transformed into a commodity, including the human being. However, unlike other authors, Bauman does not use the term "postmodern" and coined "liquid modernity," which indicates the weakness of any construction in our age.

1.5 New Ideas and Concepts of Space/Time

As I have written elsewhere [4]:

> In space we find the first and most tangible evidence of human corporeality and the impact that this has on the perception and experience. But in fact, the visible and represented space through the use of new technologies is an "altered space" in fact, the new communication techniques have now "canceled space by time" (Marx), the different layers of the contemporary city are the result of the different communities that live in it, and into the collective memory places are mixed, and their elements take on a new order according to

new rules. Echoing the words of Virilio, we can say that "ancient societies lived in a local time, the past time, the present and future, the future of history. It was the local time of geography, cities, and so on. Today we begin to live in the worldwide time, in the global time, and this is nothing more than the time "live", it is the instantaneity of the feedback between the transmission and the receptions that favors interactivity and interaction. In this context a work remains to do which can be compared to that if Brunelleschi, Alberti, Piero della Francesca, in order to build a stereoscopic perspective that is no longer that of the fifteenth century, as it is based on real-time, on space-real time in which the action begins to take place. The contemporary city is a need to establish a "new alliance" uniting and finding a balance between the need to live in the body and in the reality, and a new virtual dimension ([4], pp. 365–6).

2 The Knowledge … Ignorant[3]

The speed with which the world we live changes leads us to define this increasingly complex world; and on the other hand, our questions are answered only if you have access to very detailed information, often known only to experts and specialists in the sector. Edgar Morin describes the condition of inadequacy perceived by the individual who, while striving to know, thus fixing both the point of arrival and the starting point, still recognizes the presence of a latent uncertainty that does not give itself and does not reveal itself.[4]

Knowing that in the acquisition of knowledge, there always remains an elusive part that pushes us to explore the territories of knowledge and, even if not in consideration, we come across an inseparable triad: knowledge, ignorance, mystery. Morin mentions several times the idea of knowing him. This knowledge does not coincide with science (as established over time) and specialism (knowledge), but it is a complex knowledge that is contaminated with the arts and poetry; it is not centered on man and his (instrumental) frenzy and voracity to know; it does not aim to be exhaustive but to always arouse new amazement; it does not intend to explain, but to suggest, to show. The wise man is a curious man, a lover of knowledge and disinterested in the implications that knowledge carries within itself; a man who, freed from the ideology and socio-religious functions of knowing (that is, uniting the community within a horizon of the meaning), leans on his own beyond the limits of his humanity. And so if the concept of knowledge can be taken as a mark of the great changes unfolding in the contemporary world, in the transition from the labor society to the different interpretations of the learning society, we can see before us the transformations (or

[3] In [7], "I live more and more with the awareness and feeling of the presence of the unknown in the known, of the enigma in the banal, of the mystery in all things and, in particular, of the increase of mystery in every increase of knowledge ". Knowledge is a process in continuous and perpetual motion that outlines the limits of Being and space–time. We cannot know everything and therefore the point of departure and arrival of knowledge can only be uncertainty. We ignore, and always will ignore, some aspect of reality. Of course, we can reduce uncertainty—lighten the darkness a little more—but we cannot grasp the unspeakable anyway (p. 21): "The unknown is an enigma; the unknowable is a mystery."

[4] Ibid, p. 13.

resistance to changes) that they have characterized the last decades of the history of so-called "complex" societies. The learning society is the new human condition in which capital is given by knowledge and knowledge. In the knowledge society, individuals themselves, their knowledge, their skills are the resource. In the training and production processes, the subject assumes an unusual centrality, and therefore the attention shifts from the amount of information available and the methods of access and treatment of the same to the process of building the knowledge that man activates. In a liquid and constantly evolving society, the human ability to create and use knowledge effectively and intelligently is fundamental. Responding dynamically to the continuous challenges of social life, work, managing one's own life project involves the need to acquire, maintain and develop the knowledge, skills, and competencies necessary for this lifelong. Knowledge is understood as an emerging lever for the development of production processes, and learning is configured as the condition for the functioning and health of the system itself; in this context, attention is focused on the concept of the system. The learning society is an open system society, that is, a system in which the structural dimension is intertwined with the enhancement of intangible resources (human resources). These synergies with information, the dimension of internal and external communication, the progressive ability to control and choose in life and work paths are necessary constitutive aspects for the system to survive by orienting itself towards innovation.

3 New Horizons of Knowledge

Understanding the characteristics of the next society is still a work in progress today, an exercise in definitions all with the aim of grasping and fitting the future configuration of the company to size. To explain the content (meaning) of the information society, the concept of a global media village was used in which information pervades the life of individuals and societies even if in this society there are not necessarily individuals capable of being informed and educated; that is, individuals capable of achieving the ability to restructure and reorganize their knowledge, or to give meaning to the information itself with cognitive autonomy. In this scenario, the web plays a fundamental role; it is a very powerful means through which it is possible to receive education, in different ways, with tutorials or online instructors and clear and versatile examples from Youtube to Patreon. The man of the twenty-first century naturally and extremely easily resorts to a form of knowledge that is external, a digitized and immediate resource that he can no longer do without. Therefore, for many, the affirmation that knowledge represents the engine of innovative development under different profiles is acceptable: economic, social, and cultural. The link between knowledge and growth has strategic importance; in fact, the OECD first and the European Union later, with the Lisbon Council in 2000, traced the political lines of intervention in this sector, indicating lifelong knowledge and learning, the major strengths of a competitive economy. The main problem linked to the knowledge resource is continuous development and, consequently, obsolescence. The competitive advantage depends on the ability to accumulate knowledge to satisfy needs and expectations. Today in the learning society, to maintain the know-how possessed, it is important to feed an open system to acquire relevant information that allows you to grasp all those signals that come from both the outside and the inside. In this way, each individual is himself a constantly evolving cognitive system, and knowledge is the resource and not a firm-specific knowledge. In fact, what we do not yet know can be obtained on the fly from the web, what we have only intuition or only a fragment of, and in our memory, we can reconstruct or consolidate it by relying on the web. Through social networks, we can find experienced colleagues with complementary knowledge able to compensate for our shortcomings. It may seem paradoxical to equate knowing with searching, that is, knowing with searching (deriving from the search engine search), but this is precisely what is happening, and the younger generations are completely involved in it. We only know what we remember.

> Before the web, being a professional meant having a large amount of knowledge accumulated through years of experience in one's "biomemory", today those who possess certain skills such as critical thinking, familiarity with digital tools, the ability to select information by extracting it from the superabundance that surrounds it, he can advantageously find what he needs from outside, rather than from his own memory. Refreshing your working memory by relying on some excellent web tool when needed is better than piling knowledge into your long-term memory. Knowing how to ask the right questions on the web is cheaper than knowing all the facts.

For Dalrymple [10], a researcher at MIT in the Mind Machine Project: once knowledge was an internal property of people and the focus on the task to be performed could be imposed from the outside. Now, with the internet, knowledge can be procured from without, but it is necessary that the focus comes from an internal force. In the story Trough, the looking Glass by Lewiss Carroll, Alice, on a cold winter evening, starts playing by the fireplace with her kitten friends, and while in front of her there is the large mirror on the wall, she begins to fantasize: at a suddenly Alice crosses the mirror and finds another new and unexpected world beyond the mirror. Like the world Alice encounters, the sky seen through looking glass fills us with wonder …

4 The Birth of Co-constructed "Knowledge" Generated by the Masses

Today it is customary to associate the concept of knowledge with new relationships on the part of those who are more exposed than others and are regular web users. About 15 years ago, with the theoretical model developed by Scardamalia and Bereiter [11] of the Ontario Institute for Studies in Education (OISE) of the University of Toronto, there was a change of perspective, and a new model was proposed that is pervasive with respect to society and its institutions, so that knowledge is not promoted, but individuals themselves become a community that creates knowledge. Manipulating knowledge in a creative way and always generating new knowledge of sources to the problems of everyday life and professional life becomes a fundamental assumption of this era. This approach contemplates the concept of competence and situated learning that makes it possible to effectively use the knowledge learned in solving problems when they arise. It is based on the construction of knowledge (knowledge building), which is characterized by helping to develop skills, a mix of skills and knowledge in people, which allow them to move and act consciously and creatively. For today's young people, knowledge has lost all traits of what it meant for our fathers: libraries, lesson books, diplomas, and titles in the frame … Today, knowledge is digital; there is a web that has a significant impact on the distribution and presentation of knowledge. A large part of it is hidden, but, what emerges, is found on virtual shelves lost in the space of computer networks created in different ways and tagged by a multitude of producers.

5 Conclusion

We are therefore convinced that the concept of learning society, a topic on which an intense debate has developed worldwide, is complex (not difficult). For many, it can, in fact, be defined as a social formation that stimulates and allows each member to play a central and active role: each and everyone can continuously develop their knowledge, skills, and attitudes. The role of education in the programs of many social institutions is anchored to culture as its primary condition of existence.

> We switch our gaze to images that appear in infinite succession, we sample our attention on a continuous flow of events. In our time, media, information, entertainment news, everything immaterial, is available in profusion. Like leviathans swimming in a primordial soup we continuously swallow huge quantities of digital plankton. We have to learn to filter what is true nourishment of knowledge ([1], p. 264).

Core Messages

- The Chapter provides an overview of stereoreal reality and the new space–time paradigm.
- Complexity is not a difficulty: the multiple relationships between variables offer not one but more solutions to the same problem.
- Reality is based on the principle of self-similarity, and each piece hides smaller ones with the same characteristics, not traits but clones.
- In stereoreality, we are ubiquitous: in the here and now and in global time at the same time.

References

1. Sorrentino F, Pettenati MC (2014) Orizzonti di conoscenza: Strumenti digitali, metodi e prospett ive per l'uomo del terzo millennio, vol 157. Firenze University Press
2. Lévy P (1996) L'intelligenza collettiva. Per un'antropologia del cyberspazio. Feltrinelli editore,
3. Castells M (1996) The rise of the network society (trad. it., La nascita della società in rete). Milano 2002
4. Sanseviero S (2019) The "LIVE" time and the feedback instantaneity: the need of a new perspective. In: qualitative and quantitative models in socio-economic systems and social work. Springer, pp 363–373
5. De Kerckhove D (1998) Connected intelligence: the arrival of the web society. Kogan Page Publishers
6. Sanseviero S (2016) The representation of the contemporary urban territory. Aracne Ed
7. Morin E (2017) La sfida della complessità. Le Lettere, Roma
8. Mandelbrot B (2005) Nel mondo dei frattali, Di Renzo Editore, Roma
9. Bauman Z (2006) Vita liquida, Laterza, Roma-Bari
10. Dalrymple D (2010) Knowledge is out, focus is in, and people are everywhere. Is the internet changing the way you think
11. Scardamalia M, Bereiter C (1999) Schools as knowledge-building organizations. Today's children, tomorrow's society: the developmental health and wealth of nations, pp 274–289

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7 Creative and Critical Thinking in Early Childhood

Nicole Leggett

Creativity is intelligence having fun.

Albert Einstein

Summary

Early childhood (from prenatal to eight years of life) is the most important period of growth in human development, with peak synaptic activity in all brain regions occurring in the first ten years of life. This time-sensitive course of brain development results in different functions emerging at different times. It is during the preschool years that sensitive periods for cognitive development are formed, in particular, creative and critical thinking skills. Sociocultural perspectives ascertain that a child's cognition is co-constructed through the social environment. This chapter draws from Vygotsky's sociocultural cognitive theory and creative imagination theory to explain the processes involved as young children generate new knowledge. Examples from children's interactions in social learning environments are presented, demonstrating how children think creatively and critically as they solve problems and seek meaning through play and imagination.

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N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_7

Graphical Abstract/Art Performance

Collaborative problem-solving.
(Photography by Nicole Leggett).

Keywords

Creative thinking · Critical thinking · Early childhood · Imagination · Intelligence · Play

QR code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction–Why Early Childhood?

Early childhood is the most significant time in human development. It is during the early years that the brain's basic architecture is formed, commencing soon after conception and continuing from birth. In fact, by the time a child reaches the age of three, more than 90% of the brain has formed, and by five years, it is nearly fully developed [1–3]. How the brain develops is dependant on the combinatory forces of genes and the environment. While genes guide the initial steps of brain development, epigenetic mechanisms can be affected by interactions within an environment [4]. According to neuroscientific evidence, there are critical periods during a child's early growth where the right stimuli can provide the maximum returns on cognitive function and underlying neural circuitry networks [5, 6]. The influence of numerous experiences on the brain is especially strong during brief development times, frequently referred to as sensitive periods, during which a certain type of experience is required to develop behavior, skill, or talent.

The concepts of 'critical' and 'sensitive' periods differ for various areas of development. Research indicates there are critical times for exposure to the right environmental support to develop neurological structuring. A critical period is a subtype of the sensitive phase in which some behaviors and features of the nervous system do not develop normally in the absence of appropriate stimulation [7]. One example of a critical period is from research by Hubel and Wiesel in the 1960s. They showed that monocular deprivation in kittens during the first three months of life could lead to a lasting and largely irreversible decline [8]. Failure can result in irreversible damage as hard-wiring through synaptic activity has already occurred. On the other hand, sensitive periods relate to brief windows of time during which the impact of experiences is exceptionally intense on the growing brain. For this reason, the term 'sensitive' periods will be used in reference to cognitive growth, as evidence suggests there is a good deal of plasticity in the neural systems that underly the emergence of cognition [9]. From neuroscientific evidence that advocates the importance of quality environments on early childhood growth and development, it is clear that early experience matters.

2 Intellectual Growth and Development

Early life experiences affect later stages of development, including health, behavior, and learning [6]. While six to 18 months is a period where children are particularly sensitive to caregiving and attachment, the period of 16 months to five years is a significant time for intellectual development [10]. These small windows of heightened plasticity are dependent on the quality of maternal care, sensitive parenting, sensory experiences, and the richness of early environments [4–6, 11–13]. A child's brain is highly receptive to the quality of early experiences and is shaped by social relationships that drive the development of neural pathways [1]. Berardi et al. [4] described an enriched environment as one that includes social stimulation, motor activity, novelty, cognitive activity, and satisfaction. For the child, learning is a process of developing dispositions and acquiring new knowledge, skills, and abilities. It is an experience-based process.

New knowledge is generated through social experiences and opportunities for the young child to solve everyday situations as they arise through play. For children to overcome difficulties, they need to connect a new situation with what they already know. This cognitive leap involves both creative and critical thinking skills in order for new knowledge, skills, or abilities to be attained. Creative thinking entails lateral or divergent thinking, as well as inductive reasoning and concept exploration. Critical thinking, or convergent thinking, is related to deductive reasoning. Both creative and critical thinking are necessary for successful problem-solving and advances in cognition to occur. The difference lies between critiquing the known and generating the new. Vygotsky's [14] theory on children's cognitive development highlighted the processes involved in advancing knowledge and skills through the ability to problem-solve.

3 Vygotsky: The Zone of Proximal Development

Vygotsky [14] emphasized that collaborative and guided problem-solving leads to higher ways of thinking. Vygotsky's theory of the zone of proximal development (ZPD) identifies the basic social nature of learning and development. In children's lives, cooperative activity and teamwork are expressed as:

> The distance between the actual developmental level as determined by independent problem solving, and the level of potential development through problem solving under guidance or in collaboration with more capable peers [15].

Vygotsky emphasized the collective nature of social learning rather than dyadic relationships. Learning occurs when a child interacts with people in the environment [14, 15]. Children learn about the world through transformation. This comprises information from others' speech and behaviours that children use to recreate knowledge [16]. Vygotsky [14, 15] defines social learning as operating inside the ZPD. Vygotsky says:

> We propose that an essential feature of learning is that it creates the zone of proximal development; that is, learning awakens a variety of internal developmental processes that are able to operate when the child is interacting with people in his environment and in cooperation with his peers. Once these processes are internalised, they become part of the child's independent achievement [15].

ZPD is a relational process that encompasses the unity of social interactions that result in novel cognitive processes. Within the ZPD's social relationships, meaning is created and understood by the individual's "perezhivanie," or ``lived emotional experience" [17]. In his book *Imagination and Creativity in Childhood,* Vygotsky demonstrates the connection between emotion and thought and the role of the imagination [18]. According to Vygotsky, there is no difference between reality and imagination; it is a conscious ability to combine the two [19]. Thus, imagination is both an emotional and an intellectual experience, which is why Vygotsky [18] stated that it fosters creativity. In his theory of creative imagination, Vygotsky discusses the creative process of human consciousness.

4 Vygotsky and Creative Imagination

Through Vygotsky's sociocultural, historical framework, creativity is woven together with learning, teaching, discovery, and transformational change [17]. Vygotsky claimed that all human beings, including children, are creative and that creativity is the foundation for all learning domains [19]. Vygotsky called this creative ability 'imagination', for imagination sparks every creative act. Vygotsky put forth a theory that creative imagination introduces:

> something new into the flow of our impressions, the transformation of these impressions such as something new, an image that did not previously exist, emerges [20].

According to Vygotsky, a creative imagination becomes visible when fantasy and thinking are combined [18]. Humanity and society depend on creativity, not just for artistic talent, but for all endeavors that require thinking [18].

Vygotsky found that children's play was the source of creative imagination [18]. He described play as an act of the imagination. Also, Vygotsky [15] believed that.

> ...the more a child sees, hears, and experiences, the more s/he knows and assimilates, the more elements of reality s/he will have in his/her experience, and the more productive will be the operation of his/her imagination.

Smolucha and Smolucha [21] summarized Vygotsky's theory of creative imagination as a combination of imagination and higher mental activity that occurs through collaborative play.

Vygotsky [22] noted.

> play is…the leading source of development in preschool years.

In early development, play emerges as the child's motivations shift toward fulfilling his/her desires. Due to an inability to achieve these desires in reality, the child realizes them through his/her imagination [23]. Vygotsky emphasized that play is the first manifestation of imagination during development.

4.1 Imagination

> Should we not look for the first traces of imaginative activity as early as in childhood?
>
> Freud [24]

Early childhood is often called 'the golden age of the imagination' [22, 25]. Imagination is a human capacity that exists privately within each of us. The word 'imagine' originated from the Latin *imaginary*, meaning 'to picture oneself.' These images generated in the mind from the imagination begin with sensory perception. The brain receives signals from the senses and draws from past experiences to help interpret or explain them. The environment shapes the brain's neural pathways through response to new stimuli. Exploration through play is therefore essential for children's learning. The imagination can be thought of as a playful type of analogical thought that combines prior experiences to create new patterns of meaning [26]. As children understand the causal structures of the world and develop knowledge, they generate the power of their imagination, which makes creativity possible.

5 The "Period of the Imagination"

In 1946, Montessori believed that the years

> between 3 and 6, especially towards 5, (as) the special period for the construction of the imagination. This is the period during which great power for man is built [27].

Montessori observed that toddlers absorb sensory cues from their environment unknowingly from birth to three years and acquire the ability to imagine between the ages of three and six. Montessori proposed that children construct their imaginations as a distinctively human part of the mind through their efforts. In an unpublished lecture, Montessori stated:

> Just as in the period of the absorbent mind the child studied the world sensorially and received impressions, so now he studies the world in another way and tries to reconstruct through experience he has already had, things which he has never seen. Through this imaginative reconstruction the child makes his way for the first time in the world of real intelligence [27].

During the 'sensorial stage of imagination', children explore their ability to create mental images. These mental constructs are based on the child's real-world knowledge. Play helps toddlers learn to mix elements from different contexts. This process of combinatory imagination is how children make meaning of what is happening around them.

6 Play: Informal Experimentation

Through play, children make sense of their world. New ideas and skills are useful learning aids, and through various challenging experiences, the child can master and understand new concepts [1]. Children develop problem-solving methods through direct encounters with items and other people in their world. This learning process sets the foundation for succeeding in later school life, providing children with strong communication, confidence, persistence, and creativity for completing tasks. McCain et al. [1] highlight the value of play for children's growth and development, stating that play enhances intelligence, stimulates the imagination, provides the foundations for language, literacy, mathematics, and scientific knowledge, promotes the ability to solve problems, develops motor skills, and drives confidence, self-esteem and a positive approach toward learning.

Infants begin playing by first observing how objects move and behave. They gather data, build patterns of their environment, and start to form categories. Toddlers investigate with items, look for cause-and-effect relationships, learn through repetition, solve minor issues as they move through their surroundings, and develop the ability to manipulate entities [1, 6]. For preschool children, inquiry-based approaches such as data collection, prediction, recording, and discussion are used. Numerous challenges develop during play, requiring the child to draw on his/her own thoughts, to hypothesize, and test new theories.

Play is the incentive for children's learning [28]. Gopnik and Wellman [10] demonstrate how children aged 16 months to four years use probabilistic learning mechanisms such as informal experimentation. Together with playful thinking and imagination, children piece together what is known to the unknown to make sense of the world around them. Figure 1 presents some visual representations of three-year-old children's intellectual searching on the phenomenon of 'wind.'

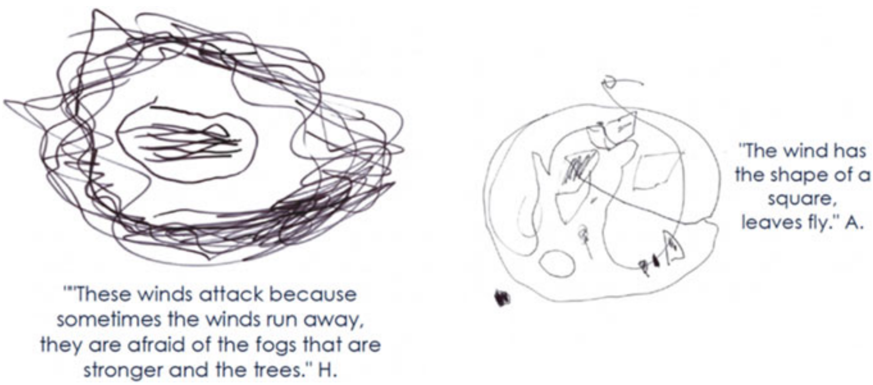

Fig. 1 The wind

From these examples, it is evident that the ordinary thoughts of young children entail a considerable level of creativity. From a young age, they can organize knowledge in creative ways. The combinatory ability to draw together reality and fantasy suggests that they are more open to forms of creative expression due to having fewer inhibitions and not yet receiving formal instruction [29]. Preschool-aged children are compelled to piece together their world knowledge from incomplete clues, often engaging in metaphoric language and personification as a form of imagination. In the above examples, the wind is given human-like characteristics. For example: 'running away' and 'being 'afraid.'

Young children can build intuitive theories of the world that help them organize experiences, make predictions, and causally interpret events [10]. The inquisitive nature of children drives the construction of scientific theories. Children as young as two years can organize experiences and develop spontaneous explanations for events. Children create constructs that extend beyond directly observable entities. In this sense, children's theories are highly creative. Figures 2 and 3 are examples of thinking from a small group of four-year-old children who were outside exploring

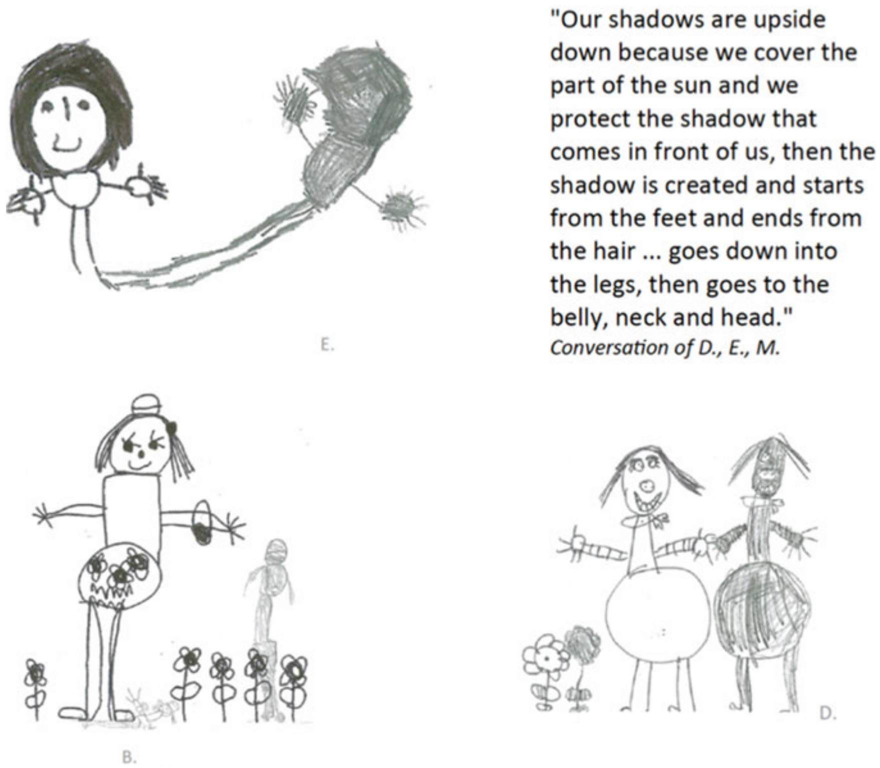

Fig. 2 Exploring shadows

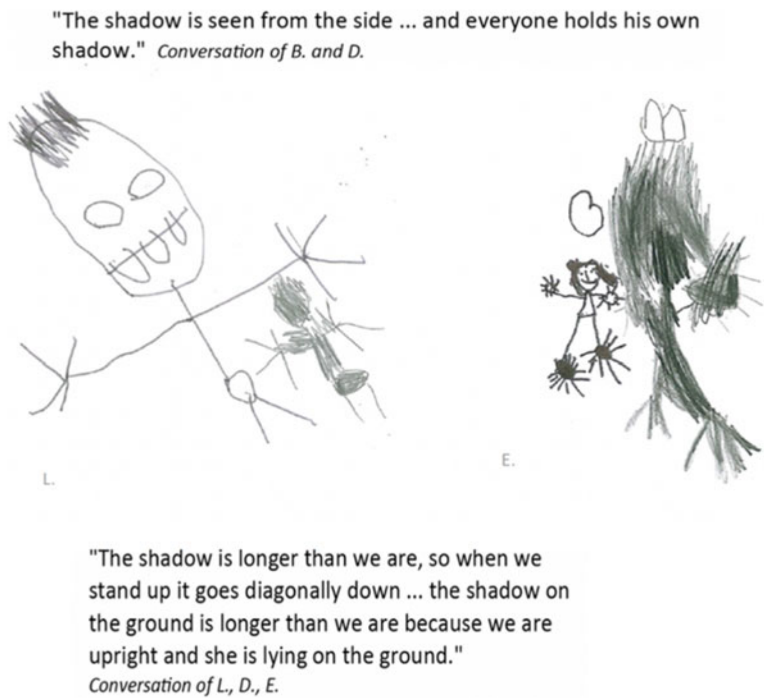

Fig. 3 Light and shadows

an interest in light and shadows. There are different representations as children hypothesize their theories for what is a shadow.

These examples demonstrate how children integrate prior knowledge and experiences with new evidence to make causal inferences. Children draw from their cognitive ability when a problem arises and employ imaginative or possibility thinking. The following responses are from a small group of four-year-old children who theorize about the moon in response to a question proposed by an educator: *Where does the moon go?*

E *It goes to heaven or to sleep.*
O *It falls into the water.*
C *Maybe it went down into the ground.*
L *Maybe it went home with the sun.*
E *The golden bit sinks back into the moon in the daytime.*

Becoming a child in order to comprehend the cosmos and eternity was endorsed by Einstein, who credited his development of the theory of relativity to the fact that he continued to ask questions in the manner of a child [30]. Therefore, it is important for children to develop the ability to ask questions and think about the many possibilities before having to come up with an answer. As Vygotsky [14] demonstrated in his ZPD, mediation with a more knowledgeable other (child or adult) helps the child arrive at answers and solutions that drive intellectual growth and abilities. The power in this transformation lies in creative thought processes.

7 Creative Thinking

Creative thinking refers to the mental processes responsible for developing creative products [31]. Cognitive talents, personality traits, dispositions, and metacognitive skills are all elements that constitute creative thinking. Many experts regard early childhood as a vital period for developing creative thinking in children [32–36]. For a growing child, this means connecting the known with the unknown to solve issues that require greater levels of intellect and aptitude. Through creative thinking, children learn to hypothesize, locate and solve issues, experiment with new knowledge, and evaluate how new knowledge can be useful for understanding new encounters.

Individuals generate creative processes whenever they experience disequilibrium while learning new skills and understandings [37]. Creativity is present when a person imagines, changes or creates something new. The ability to think creatively or imagine something new depends greatly on the richness and variety of a person's previous experience. The following interaction between an educator and a four-year-old child provides an example of creative thinking where the child draws from prior experience and his imagination in response to a question that he does not know how to answer:

Educator	*Do you know why spiders have eight legs, not two like us?*
Child	*Because they are spiders*
Educator	*They spin spider webs don't they. Do you know what their webs are made of?*
Child	*String!*
Educator	*Good guess.*
Child	*Knitting?*
Educator	*Sorry? Knitting, like wool? Is it made of silk?*
Child	*They are like Spiderman; the silk comes out of their mouth.*
Educator	*Out of their mouths, maybe. Maybe we could research that.*

From this scenario, it is evident that the child is drawing from his own experiences and knowledge bases in order to seek an answer. Vygotsky [15] stated that:

> Every act of the imagination starts with this accumulation of experience. The richer the experience, the richer the act of imagination. After the accumulation of experience comes the incubation period [15].

Incubation is an essential aspect of problem-solving; transformation occurs through internal neurological processes and connections.

8 Creative Problem-Solving

According to Wallas [37], four stages exist in creative problem-solving: preparation, incubation, illumination, and verification. Preparation is the "whole process of intellectual education" [37]. It involves a conscious effort on the problem. For Wallas, the processes of preparation and verification are similar. During incubation, new associations occur when you are not consciously thinking about the problem; it occurs while you are not aware of it.

The unconscious mind can incubate numerous thoughts concurrently, but the conscious mind is limited to focusing on a single task at a time [38]. During incubation, mental elements interact, forming connections between what we know and what we envision to discover solutions and answers to everyday difficulties. However, not all problems are easily solved, and not all ideas are novel or appropriate to the situation. For adults and children, some problems require more time. This period that occurs below the surface of consciousness is often referred to as 'incubation.' Over time, usually, when the mind is relaxed, insights occur, emerging into consciousness. Wallas [37] describes this psychological process as an instantaneous 'flash' that lasts for an appreciable time. This moment of revelation or insight is also referred to as the 'ah-ha' moment. Insight occurs when the mind is relaxed–for example, in the early hours of the morning, during long walks, or during play.

Creative insights emerge from elaborate cognitive processes involving different processes and regions [39]. A child requires time to incubate, experiment with ideas, and ponder freely to gain insight. In the following example, a small group of children aged four to five years were painting a cardboard rocket ship that they had made with the educator outside. Together with the educator, the children discussed what else the rocket needed. When a problem was presented, one child had an 'ah-ha' moment after a brief pause for thinking of a solution:

Educator *We need a driver that drives the rocket.*
Child *Yeah.*
Child *We need a thing to make it go up.*
Educator *Yes, that's right, we do.*

There is a brief pause of approximately 8 s as the children continue painting the rocket ship…

Child *I know what can make it go up! String!*
Educator *String, great idea!*

Caregivers and educators must not push children for immediate answers but allow children time to 'incubate' and seek solutions to their problems. Caregivers and educators can assist in the learning process by asking the child to talk about his/her ideas and to select which one they think will work best–and why. This verification stage of creative problem-solving is a form of metacognition. It is helpful for children to visualize their ideas and express their thought processes as they check for errors and evaluate strategies and solutions. Divergent thinking is the ability to develop many thoughts in response to stimuli. A broad search for information and the generation of several innovative responses or ideas has been identified as the most significant operation of the creative thought process.

9 Divergent Thinking

Based on Torrance's [40] dimensions of divergent thinking abilities, characteristics involve fluency, flexibility, originality, and elaboration/enrichment of ideas. Divergent thinking is the pinnacle of problem-solving and learning. It is how young children transform information to new levels of understanding. Creativity is a form of problem-solving that requires flexible thinking and skillful application [41]. This skill is widely regarded as essential to the creative process. Children engage in problem-solving through visualizing solutions, checking for faults, collaborating, talking, and reflecting, as well as metacognition, which involves evaluating techniques and solutions [42].

Children can come up with many ideas, but they must learn that some are superior to others. Children who work together on the same goals and share knowledge and abilities are more successful at problem-solving. Metacognition is the mindful use of procedural information, such as applying tactics and strategies to a situation [43]. The following example is of two four-year-old boys who were discussing strategies for how to build a ramp together in the sandpit:

Child 1 (c1): *The car can go up and zoom into the bucket*
Child 2 (c2): *I wish I could do that, but how?*
c1: *Well, I have a really good one (an idea). How about we put a pipe in there?*
c2: *Yeah, that was my idea!*
c1: *There, is that deep enough?*
c2: *I think you just need a shovel (children proceed to dig deeper together)*
c1: *There, I built a new ramp on the side*
c2: *I have got a great idea! If I build a new ramp on here, it can go broom over and on to here! (from the ramp over the hole and onto his friend's ramp)*
c1: *Okay, try my ramp*
c2: *What about we put the pipe in instead?*
c1: *But how will it go in?*
c2: *Like this way!*

In the Graphical Abstract, it is evident that the boys were working together to solve a problem in their play. Both boys shared their ideas for using a pipe, demonstrating intuitive thinking, which is fast and automatic (creative). Once an idea was selected, the children began to think analytically (critically), which is slow and deliberate in order to select the correct solution to the problem at hand. This was evident when one boy asks: "But *how* will it go in?" Young children employ both creative and critical thought processes for successful problem-solving that sustain playing and further drives the capacity of knowledge and skills. Problem-solving involves stages of generating ideas and using cognitive processes that call for critical thinking in the evaluation and implementation of ideas [44]. Thinking is intrinsically creative and critical.

10 Critical Thinking

One of the most important cognitive traits young children should develop is critical thinking. Current considerations for twenty-first-century skills require equipping children with the necessary dispositions and competencies essential for lifelong learning as well as for navigating the future workforce [45, 46]. Critical thinking involves describing, interpreting, analyzing, reflecting, evaluating, critiquing, explaining, sequencing, reasoning, comparing, questioning, inferring, hypothesizing, and testing.

Young children can learn to think critically [47] and can:

> develop strategies for exploration, thinking and reasoning as well as create working theories to make sense of the natural, social, physical and material worlds they live in.

Supportive environments and quality interactions with caregivers and educators have been found to be significant factors for fostering children's thinking skills. Environments that connect children to real-life experiences, use multimedia technology, provide reading materials and promote a safe emotional climate support the development of critical thinking in children [48, 49]. Figure 4 is an example from children aged four years who were encouraged to access Google sky/space and select satellite images as a stimulus to create their own 'galaxies' using paint.

Educators and caregivers who value children's contributions must encourage their participation, use purposeful questioning, create opportunities for talk and provide feedback to extend children's thinking [49]. A study by Taggart et al. [50] examined young children's existing practices and types of thinking skills. Their findings revealed that children are capable of quite a wide range of higher-order thinking skills by age seven.

11 Intelligence

> If people can learn to think better, they can learn to be intelligent.
>
> Halpern [52]

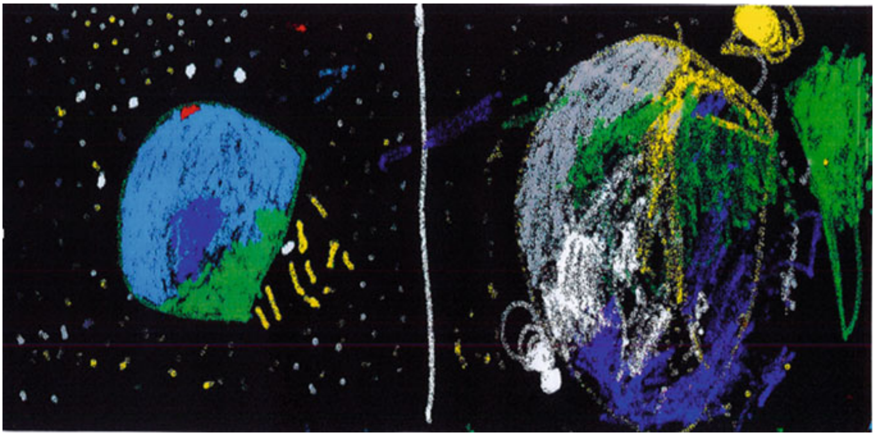

Fig. 4 Creating galaxies

A frequently asked question is whether learning to be a creative and critical thinker can make someone more intelligent. While both thinking skills are required for learning, the answer to this question depends on how intelligence is defined. One good definition offered by Gottfredson states that:

> Intelligence…. involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather it reflects a broader capability for comprehending our surroundings–'catching on', 'making sense' of things, or 'figuring out' what to do [51].

There is no single score that can represent the complexity of human intelligence. While Intelligent Quota (IQ) tests may be useful for predicting grades in school or success at work, they represent a subset of thinking skills necessary for success in life [52]. For example, IQ tests can be good measures for testing how well one can hold information in their short-term memory; however, they do not assess a person's ability to form new understandings when presented with evidence. It is creative and critical thinking that is largely absent from intelligence tests. As Halpern [52] suggests, if people can learn to think better, they can learn to be intelligent.

Rather than testing children on what they know, it is better to assess 'how' they know. Teaching children to think critically requires avoiding common biases and not being misled by commonly overused tactics. Critical thinking skills require the development of specific instruction, practice, feedback, and time [52]. While there will always be differences in how well some people can think more than others, as well as other influences on intelligence such as genetics and environmental factors, we can all learn to be better thinkers and to think more intelligently.

Sternberg [53] proposes three categories of intelligence:

i. analytical, problem-solving;
ii. creative, creating new solutions; and
iii. practical, dealing with everyday problems

Sternberg, Torff, and Grigorenko [54] tested the triarchic model of intelligence with children in third grade and found that students who received a curriculum that involved all three forms of thinking performed better than those who received a traditional curriculum. Table 1 demonstrates a range of thinking skills between five children aged between four and five years of age as they extend their knowledge and understanding of bees.

In this example, a range of creative and critical thinking skills is demonstrated as children share and scaffold each other's knowledge. Two concepts are being explored: how honey is made and how bees sting you. Through the discussion on how honey is made, they all (except for Max) refer to nectar as 'honey.' It is not until the very end of the discussion that an 'ah-ha' moment or point of illumination is

Table 1 Honey bees

	Thinking skill	Triarchic intelligence
Jay: The Queen bee tells the little bees where to get the honey from. If people try to stop them, they sting	Explaining, reflecting	Analytic
Max: Once a bee come and sting me on the shoe. I pulled it off the right way. I didn't squeeze the poison. I shaved it off	Describing, reflecting	Practical
Bailey: Bees make honey from grass and pancakes —they mix it up	Hypothesizing, imagination	Creative
Jules: The bees make the honey with a turning thing. A bee lives in a bee hive, not a house. It doesn't need to live in a house	Describing, reasoning, explaining	Creative/analytic
Yasmin: Bees make honey with their bodies. They mix up the honey with their stingers then the man rubs it off the trays, mixes it and puts it in the trays	Explaining, describing, sequencing	Analytic
Bailey: If you put bees in a cup, they can't sting you	Problem-solving	Practical
Jules: You could get sticky tape. All the bees could stick to the tape so they can't sting you	Problem-solving, divergent thinking	Creative
Jay: The baby bees and the little Kings collect the honey for the Queen's babies. They make it in triangle and square shapes using salt and water	Describing, reasoning, divergent thinking	Analytic
Jay: Honey is in flowers. We need to get honey from bees because we can't reach inside flowers	Explaining, reasoning	Analytic
Jules: When the bees have their honey, they move to the next flower	Explaining	Analytic
Max: They get nectar from the flowers	Illumination and verification	Analytic

reached with Max stating that it is called ‘nectar’ from flowers. The second is the problem that bees sting. Interestingly, although the children are thinking analytically about honey, they are also thinking practically about how to avoid bee stings. The children have shared their prior knowledge and experiences through both intellectual searches, demonstrating analytic and practical thinking skills. In both cases, children used their imaginations to fill in knowledge gaps and solve problems together.

According to Tomasello, Kruger, and Ratner [55], this type of learning is referred to as ‘collaborative learning.’ Collaboration involves two or more people, neither of whom is an authority or expert. Rather, learning occurs when two or more people work together to solve a problem. According to Dissanayake [56], belonging is essentially linked to our capacity for meaning, competence, and to raise elaboration. Children work together to create meaning, expand it, and transform it using the collective gifts of the learning community. An environment of rich potential is created through the experiences that each person brings. The giving and taking of ideas can evolve into learning experiences beyond individual possibility.

12 Conclusion

One of the main cognitive competencies for our century is the ability for children to think creatively and critically. This means that children require both concrete and abstract experiences to develop intellectually. Developing intelligence in young children involves a focus on the holistic and multidirectional nature of cognition. Learning environments that promote imaginative and creative thinking also need to encourage children to think critically and to evaluate their ideas. Educators can support children’s cognitive growth by providing rich environments that encourage children to be powerful thinkers who bring forth new ideas from their play–who knows, one little idea may just be big enough to change the world! Imagine that.

Core Messages

- Early childhood is a sensitive stage of neurological growth for developing creative and critical thinking skills.
- Rich environments and quality interactions with educators are significant factors fostering creative and critical thinking.
- The ability to think creatively depends greatly on the richness and variety of a person’s previous experience.
- Children who work together on the same goals and share knowledge and abilities are more successful at problem-solving.
- Children learn to hypothesize, solve problems, experiment, and analyze through creative and critical thinking.

References

1. McCain MN, Mustard F, Shanker S (2007) Early years study 2. Putting science into action. Canada: The Council for Early Child Development, pp 7
2. Shonkoff J, Boyce WT, McEwen B (2009) Neuroscience, molecular biology, and the childhood roots of health disparities: building a new framework for health promotion and disease prevention. J Am Med Assoc 301:2252–2259
3. Siegel DJ (2012) The developing mind: how relationships and the brain interact to shape who we are, 2nd edn. The Guilford Press, New York, NY
4. Berardi N, Sale A, Maffei L (2015) Brain structural and functional development: genetics and experience. Developmental Med Child Neurol 57 (2):4–9. https://doi.org/10.1111/dmcn.12691
5. Hensch TK, Bilimoria PM (2012) Re-opening windows: manipulating critical periods for brain development. Cerebrum. 2012 Jul–Aug; 2012: 11. PMCID: PMC3574806
6. Mustard F (2010) Early brain development and human development. In: Conference proceedings
7. Knudsen EI (2004) Sensitive periods in the development of the brain and behavior. J Cogn Neurosci 16:1412–1425
8. Voss P (2013) Sensitive and critical periods in visual sensory deprivation. Frontiers in Psychology. https://doi.org/10.3389/fpsyg.2013.00664
9. Fox NA (2014) What do we know about sensitive periods in human development and how do we know it? Hum Dev 57(4):173–175. https://doi.org/10.1159/000363663
10. Gopnik A, Wellman HM (2012) Reconstructing constructivism: causal models, Bayesian learning mechanisms, and the theory theory. Psychol Bull 138:1085–1108
11. Armstrong VL, Brunet PM, He C Nishimura M, Poole HL, Spector FJ (2006) What is so critical?: A commentary on the re-examination of critical periods. Developmental Psychobiology 48(4):326–31. https://doi.org/10.1002/dev.20135
12. Zhang TY, Labonté B, Wen XL, Turecki G, Meaney MJ (2013) Epigenetic mechanisms for the early environmental regulation of hippocampal glucocorticoid receptor gene expression in rodents and humans. Neuropsychopharmacology 38:111–123
13. Wen XL, Turecki G, Meaney MJ (2013) Epigenetic mechanisms for early environmental regulation of hippocampal glucocorticoid receptor gene expression in rodents and humans. Neuropsychopharmacology 38:111–123
14. Vygotsky LS (1930/1978) Mind in society: the development of higher psychological processes. Cambridge, MA: Harvard University Press
15. Vygotsky L (1930/1967/2004) Imagination and creativity in childhood. J Russian East European Psychol 42(1):7–97
16. John-Steiner V, Moran S (2012) Creativity in the making: Vygotsky's contemporary contribution to the dialectic of development and creativity. Oxford Scholarship Online. https://doi.org/10.1093/acprof:oso/9780195149005.001.0001
17. John-Steiner V, Connery MC, Marjanovic-Shane A (2010) Dancing with the muses. In: Connery MC, John-Steiner V, Marjanovic-Shane A (eds), Vygotsky and creativity: a cultural-historical approach to play, meaning-making, and the arts. New York: Peter Lang Publishing, Inc, p 6
18. Vygotskij LS (1995) Fantasi och kreativitet i barndomen [Imagination and creativity in childhood]. Göteborg: Daidalos. (Original work published 1950)
19. Lindqvist G (2003) Vygotsky's theory of creativity. Creat Res J 15(2):245–251. https://doi.org/10.1207/S15326934CRJ152&3_14
20. Vygotsky LS (1987) Imagination and its development in childhood. In: Rieber RW, Carton AS (eds) The collected works of L.S. Vygotsky (vol 1) New York: Plenum Press, pp 339

21. Smolucha L, Smolucha FC (1986, August). LS Vygotsky's theory of creative imagination. Paper presented at 94th Annual Convention of the American psychological Association, Washington, DC, pp 4
22. Vygotsky LS (1976) Play and its role in the mental development of the child. In: Bruner JS, Jolly A, Sylva K (eds) Play-Its role in development and evolution. Penguin Books Ltd., New York, pp 537–554
23. Connery MC, John-Steiner V, Marjanovic-Shane A (eds), Vygotsky and creativity: a cultural-historical approach to play, meaning-making, and the arts. New York: Peter Lang Publishing, Inc
24. Freud S (1907) Creative writers and day-dreaming, pp 21
25. Scarlett WG, Naudeau S, Salonius-Pasternak D, Ponte I (2005) Play in early childhood: the golden age of make-believe Children's play (pp 51–73). Thousand Oaks, CA: SAGE Publications, Inc
26. Policastro E, Gardner H (1999) From case studies to robust generalisations: an approach to the study of creativity. In: Sternberg RJ (ed) Handbook of creativity. Cambridge University Press, New York, pp 213–225
27. Montessori (1946) Unpublished London Lecture #24, pp 95–96
28. Wang Z, Wang L (2015) Cognitive development: child education. In: Wright JD (ed) in chief), International Encyclopedia of the Social & Behavioural Sciences, vol 4, 2nd edn. Elsevier, Oxford, pp 38–42
29. Gelman SA, Gottfried GM (2006) Creativity in young children's thought. In: Kaufman JC, Baer J Creativity and reason in cognitive development. New York: Cambridge University Press
30. Holton G (1973) Thematic origins of scientific thought. Harvard University Press, Cambridge, MA
31. Weisberg R (2006) Expertise and reasons in creative thinking. In: Kauffman JC, Baer J (eds) Creativity and reason in cognitive development. New York: Cambridge University Press
32. Doidge N (2007) The brain that changes itself. Stories of personal triumph from the frontiers of brain science. Penguin Group, New York
33. Eliot L (1999) What's going on in there? How the brain and mind develop in the first five years of life. Bantam Books, New York
34. Goswami U (2004) Neuroscience and education: from research to practice? Br J Educ Psychol 74(2004):1–14
35. McCain M, Mustard F (1999) Reversing the real brain drain: early years study, final report. Toronto, ON: Ontario children's secretariat
36. Siraj-Blatchford I (2005) Birth to eight matters! Seeking seamlessness—Continuity? Integration? Creativity? Paper presented at the TACTYC Annual conference, Cardiff
37. Wallas G (2014) The art of thought. Kent, England: Solis Press [first published in 1926]:39
38. Sawyer R (2006) Explaining creativity. Oxford University Press, The science of human innovation New York
39. Pfenninger K, Shubik V (2001) Insights into the foundations of creativity: a synthesis. In: Pfenninger K, Shubik V (eds.) The origins of creativity, pp 213–236. New York: Oxford University Press
40. Torrance EP (1996) Cumulative bibliography on the Torrance tests of creative thinking (brochure). Georgia Studies of Creative Behaviour, Athens
41. Moran J (1988) Creativity in young children. ERIC Clearinghouse on Elementary and Early Childhood Education ED306008
42. Gifford S (2010) Problem solving. In: Miller L, Cable C, Goodliff G (Eds.) Supporting children's learning in the early years (2nd ed). London: Routledge
43. Runco M (2007) Creativity. Theories and themes: research, development, and practice. MA: Elsevier Academic Press
44. Sternberg R (2006) The nature of creativity. Creat Res J 18(1):87–98. https://doi.org/10.1207/s15326934crj1801_10

45. Galinsky E (2010) Mind in the making. The seven essential life skills every child needs. Harper Collins Publishing, New York NY
46. Jones C, Pimdee P (2017) Innovative ideas: Thailand 4.0 and the fourth industrial revolution. Asian Int J Soc Sci 17(1): 4–35. https://doi.org/10.29139/aijss.20170101
47. Lubawy J (2006) From observation to reflection: a practitioner's guide to programme planning and documentation. NSW, Australia: Joy and Pete Consulting, pp 15
48. Dangel JR, Durden TR (2008) Teacher-involved conversations with young children during small group activity. Early Years: An Int J Res Dev 28(3):235–250
49. Robson S, Hargreaves DJ (2005) What do early childhood practitioners think about young children's thinking. Eur Early Child Educ Res J 13(1):81–96
50. Taggart G, Ridley K, Rudd P, Benefield P (2005) Thinking skills in the early years: a literature review. Slough: NFER
51. Gottfredson LS (1997) Mainstream science on intelligence: an editorial with 52 signatories, history, and bibliography. Intelligence 24:13–23
52. Halpern DF (2014) Thought and knowledge: an introduction to critical thinking, 5th edn. Psychology Press, New York, NY
53. Sternberg RJ (2005) Creativity or creativities. Int J Hum Comput Stud 63(4–5):370–382
54. Sterberg RJ, Torff B, Grigorenko EL (1999) Teaching triachically improves school achievement. J Educ Psychol 90:374–384
55. Tomasello M, Kruger AC, Ratner HH (1993) Cultural learning. Behav Brain Sci 16:495–511
56. Dissanayake E (2000) Art and intimacy: how the arts began. University of Washington Press, Seattle

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Development of Critical Thinking Skills Through Science Learning

8

Johar Maknun

> *Critical thinking relies on content, because you can't navigate masses of information if you have nothing to navigate to.*
>
> *Kathy Hirsh-Pasek*

Summary

Education needs to be directed towards increasing the nation's competitiveness to handle the global competition. This will be achieved as long as learning is directed towards improving students' abilities, especially critical thinking skills. Therefore, science education aims to improve thinking skills and prepare students for future success. These abilities are trained with learning that requires them to conduct experiments, discover, and solve problems through small group discussions. A constructive learning approach is believed to facilitate and develop these skills.

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N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_8

Graphical Abstract/Art Performance

Development of critical thinking skills through science learning.

(Adapted with permission from the Association of Science and Art(ASA), Universal Scientific Education and Research Network (USERN); Made by Sara Bakhshi)

Keywords

Critical thinking skills · Education · Learning · Science learning

QR code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

Science education is expected to facilitate an established epistemological and axiological foundation, which will help students compete in an increasingly complex world. They are expected to develop thinking skills through scientific methods in dealing with everyday problems. Meanwhile, science contains four factors, which are content (product), process (method), attitude, and technology [1]. It means accepted facts, laws, principles, and theories as a content. Also, as a product, science is structured knowledge, and it is obtained through active, dynamic, and explorative processes of inductive activities [2]. Furthermore, as a method, it is a process of gaining knowledge. As an attitude, science is open, objective, and honest. Lastly, as a technology, it correlates with everyday life.

Thinking skills are one of the intellectual potentials needed in various aspects of life. Therefore, students need to develop these skills through learning. Stated that it is very important for students and prepares them for future success [3]. Also, one of the most relevant lessons for developing students' thinking skills is science [4].

As an effort to improve education quality, applied learning should be focused on teaching higher thinking skills [5]. Also, thinking is a cognitive activity to gain knowledge that is grouped basic and complex based on the process. The former relies on memory, imagination, comparison, evaluation, generalization, analysis, synthesis, deduction, and inference, whereas the latter includes decision-making, problem-solving, and critical and creative thinking [6]. Critical thinking is a reflective pattern based on focused reasoning to determine what should be believed and carried out [7]. In addition, it is a comprehensive introduction for better reasoning [8].

Critical thinking is one of the mandatory skills to deal with various situations, from school to community. Students with these skills can develop systematic plans and solve problems effectively. Broadly, it is a skill beneficial to have in everyday life [9]. Therefore, one of the criteria needed by an individual to contribute to society is the ability to think critically [10].

2 Literature Review

2.1 Science Learning

Understanding the nature of science is one of the influencing factors of its learning. Teachers and students can carry out science learning according to its nature by having good knowledge. Furthermore, there are three inseparable scientific factors: processes, products, and attitudes. Science is defined as a system for understanding the universe through controlled observation and experimentation [1]. Also, the nature of science (NOS) is the knowledge about epistemology (methods), occurrence process, or the values and beliefs inherent in its development [11].

Science is defined as a way of thinking that includes curiosity, belief, imagination, thinking, cause-effect relationship, self-examination, objectivity, doubt, and open-mindedness. It also offers a way of investigation, using various approaches to construct knowledge, namely scientific methods, inquiry, and science process skills. This is achieved through observation, hypothesis, and experimentation. Furthermore, science corresponds to the body of knowledge from different fields that are products of human inventions. Meanwhile, facts, concepts, principles, laws, theories, and models are forms of scientific content. These products have personal meanings which cannot be separated from the investigation process. In addition, science and its interaction with technology and society can be interpreted as influencing each other. In conclusion, many scientific works are influenced by society and the availability of technology [12].

For both teachers and students, learning the NOS is essential. It will give them an essential background on how scientific knowledge is created, validated, and influenced [13]. Furthermore, it will help them have a precise view of what science is about, including the types of questions that can be answered, what contrasts it from other disciplines, and the strengths and shortcomings of the knowledge [14], as well as recognize and reject the claims of pseudoscience in everyday life [15]. Based on this opinion, understanding the NOS impacts the ability of scientific work and its utilization in everyday life.

In harmony with the nature described above, learning should emphasize more on the process. Meanwhile, the activity of students helps build knowledge through a series of operations. In this learning, students act as scientists and use scientific methods to find out a problem. This aligns with the constructivist theory considering that learning builds a base of knowledge from previous experiences [16].

Therefore, the application needs to be varied and develop various students' potentials. One of them is learning that is oriented to the taxonomy for science education. Taxonomy for science education includes five domains, which are:

i. knowing and understanding, in the form of facts, concepts, laws, hypotheses, and theories used by scientists;
ii. science process skills, which consist of basic processes: observation, communication, classification, measurement, inference, and prediction. Integrated science processes also play a role, including variable identification, table preparation, graphic making, intervariable relationship description, provisioning and data processing, investigative analysis, hypothesis formulation, operational variable definitions, investigation design, and experiments;
iii. imagination and creativity, which involve combining several objects and ideas, generating alternatives, imagining, and producing extraordinary ideas;

iv. attitude and value, which involve being positive towards science and developing self-traits, sensitivity, respect for others, as well as making decisions related to social and environmental issues; and
v. connecting and applying, in the form of observing the examples of concepts and learned science skills [17]

Based on this explanation, the learning is achieved through an exploration phase of experience using scientific activities, which begins with observing primary and secondary data until new knowledge can be reached. Also, learning is an activity of applying new knowledge to relevant problems. To face future challenges, science learning needs to provide opportunities for students to gain knowledge, act, and collaborate.

This process needs to be carried out by emphasizing a scientific approach through direct experience to develop competencies by scientifically learning the natural environment. Meanwhile, an inquiry-based type can be used as a student-centered model [18]. Students work with new and challenging concepts; they are actively involved in making questions and seeking answers, planning, reflection, and evaluation. Therefore, the inquiry processes that develop students are critical, creative, and reflective thinking [19].

2.2 Critical Thinking Skill

There are various understandings of critical thinking. Beyer offered the simplest definition, stating that "critical thinking means making logic judgments." Beyer viewed it as the kind of criteria proper to assess the quality of something, from simple activities to concluding complex problems [20]. Also, Facione stated that it is useful as self-regulation in deciding something to produce interpretation, analysis, evaluation, and inference. It can also facilitate exposure using evidence, concept, methodology, criteria, or contextual considerations that form the basis of decision making [10].

Critical thinking is a method for students to acquire new knowledge by solving problems and collaborating with each other. In fact, these skills are a strategy that increases the probability of expected outcomes [21]. Moreover, it also involves analysis, synthesis, judgment, creation, and application of new knowledge to today's cases. Lastly, critical thinking is crucial to learning new things since it provides possibilities to learn through discovery for students [22].

These skills help students develop multiple abilities, among which are the ability to ask pertinent questions, collect relevant data, draw thoughtful conclusions, decide precisely and logically, evaluate sources' credibility, establish causal links, analyze probability, engage in effective communications with others to arrive at solutions [23], predict, and solve complex problems [24].

A study of students' critical thinking abilities showed that it is not necessarily developed but deliberately implanted [25]. This means that a student cannot develop the skills efficiently without being challenged to practically use them in the

Table 1 Critical thinking skills indicators

Critical thinking skills	Sub-critical thinking skills
Elementary clarification	1. Focusing questions 2. Argumentation analyzing 3. Asking and answering clarifying and challenging questions
Basic support	1. Considering credibility (criteria of a source) 2. Observing and considering the results of observations
Inference	1. Making deduction and considering its result 2. Making induction and considering its result 3. Making and considering the value of the decision
Advanced clarification	1. Defining terms, considering definitions 2. Identifying assumptions
Strategies and tactics	1. Deciding an action 2. Interacting with others

learning process. Meanwhile, those without critical thinking cannot set the ability to think naturally. In conclusion, this skill is a learnable ability; therefore, teaching it is needed.

An appropriate test is needed to measure students' critical thinking skills. Tiruneh et al. proposed that such a test must link the skills and problem-solving indicators [26]. The developed test can be associated with the concept of physics, as concluded in a meta-analytical review [27]. Critical thinking skills consist of 12 indicators grouped into five, as shown in Table 1 [7].

3 Science Learning to Develop Critical Thinking Skills

In many countries, critical thinking has become one of the competencies of educational purposes, even as one of the learning targets. Studies show that it is a high-level skill known to aid in an individual's social, moral, mental, cognitive, and scientific development [28]. Therefore, thinking critically should be developed early through learning, especially in science. Moreover, this skill can be learned, estimated, taught [29], and improved through various learning strategies. The following studies are examples of learning that empowers and enhances students' skills.

3.1 Impact of Inquiry Learning to Improve Critical Thinking Skills

Improving the quality of thinking skills can be done by applying learning models that actively involve students in the thinking process [30]. Meanwhile, inquiry-based learning is one of the models that play an important role in constructing paradigms that provide means for skill development [31]. Inquiry-based learning science exposes students to concrete experiences; therefore, they learn actively to solve problems, make decisions, and develop research skills. In summary, it will train students to become lifelong learners. Through the inquiry activities, those with different ability levels can collaborate to solve similar problems and find solutions. In this process, they are motivated to be directly involved or physically and mentally active in the learning process [32]. Therefore, the classroom environment where students are actively involved as well as the teacher serves as a catalyst for achieving the learning competencies or objectives [33].

The first example is a study investigating how the application of guided inquiry learning improved critical thinking skills in vocational high school students [34]. The research instrument tests critical thinking skills based on the concept of static fluid. An overview of critical thinking skills indicators is shown in Fig. 1.

The experimental class had an average pretest score of 46.6, while the control class had an average pretest score of 46.1 (Fig. 1). The experimental class's post-test critical thinking skills averaged 84.5, while the control class' averaged 61.4 [34]. The normalized gain (n-gain) value indicates an increase in critical thinking skills (n-gain). Figure 2 shows the rise in scores for each critical thinking indicator in the experimental and control classes. The experimental class increased by 0.82 on the strategies and tactics indicator and by 0.64 on the elementary clarification indicator. For the control class, the biggest increase is 0.36 and the

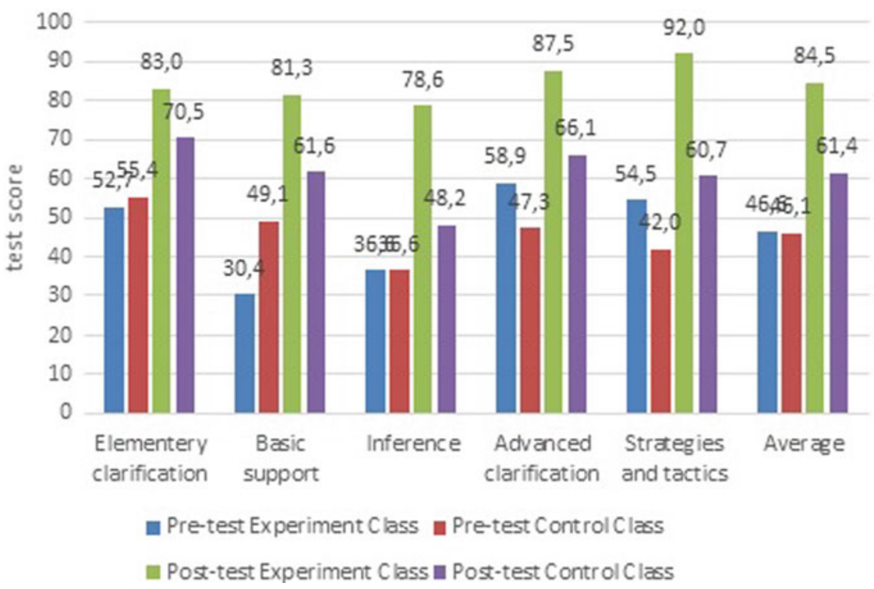

Fig. 1 Description of critical thinking skills of vocational high school students (reproduced from [34] © Johar Maknun under Creative Commons Attribution license 4.0 International, CC BY 4.0)

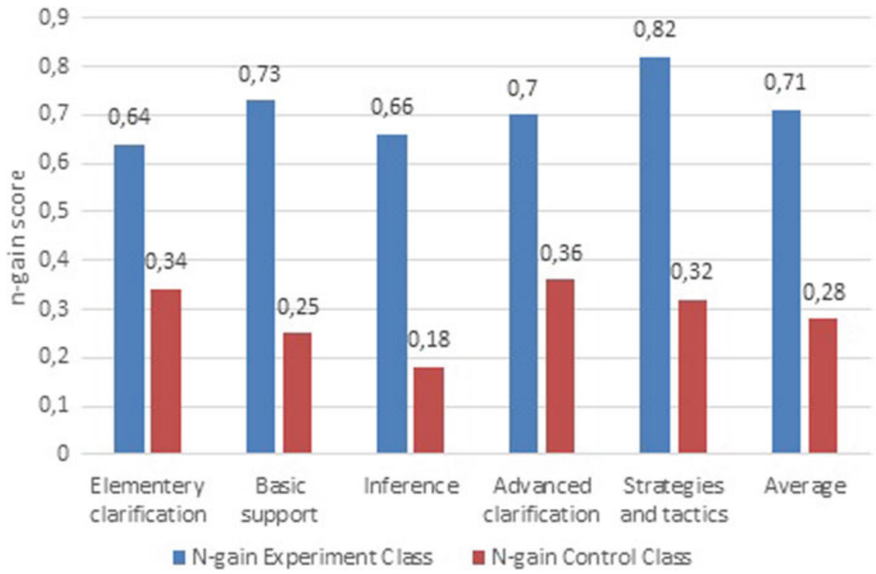

Fig. 2 The n-gain of critical thinking skills in vocational high school students (reproduced from [34] © Johar Maknun under Creative Commons Attribution license 4.0 International, CC BY 4.0)

lowest is 0.18. The experimental class improved critical thinking skills by 0.71, whereas the control class improved by 0.28. In terms of the n-gain, guided inquiry learners develop critical thinking skills faster than conventional learners [34].

In guided inquiry learning, students construct their own observations with the help of a teacher. In the control class, the teacher plans the activities. Students are guided to solve problems using analysis, synthesis, data assessment, and decision-making [35]. Also, students who think critically will effectively make fact-based decisions, analyze conditions, assess arguments, and draw conclusions appropriately [36]. Furthermore, students must also analyze, synthesize, and make associations between information and reasoning [37]. In fact, this skill can be fostered through activities that require students to support their assessments, choices, claims, or statements with logical reasoning, evidence, or arguments [37]. Impacting this skill through learning is expected to provide benefits and direct students in finding solutions to problems. Therefore, critical thinking is a useful and important basic capital for everyone, and it shows the maturity level of an individual.

3.2 Improving Critical Thinking Skills Through Problem-Solving Laboratory Learning

Problem-solving laboratory learning is carried out with different activities, which include orienting students to problems, determining the equipment to be used in

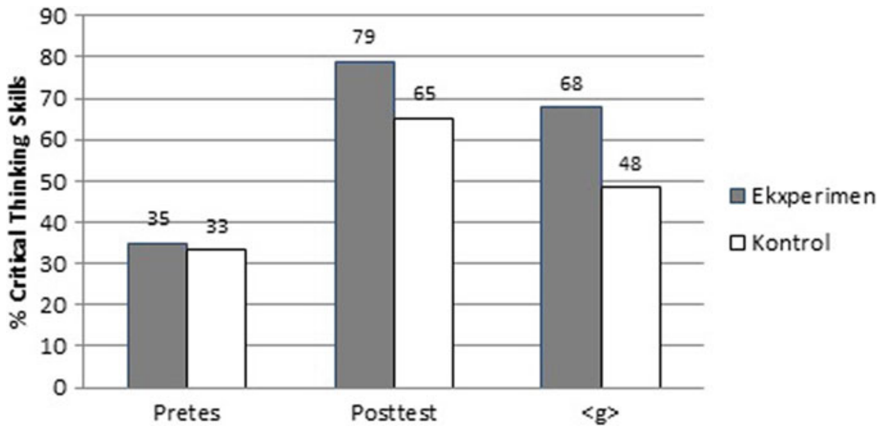

Fig. 3 Comparison for a normalized gain average of critical thinking skills [38]

experiments, making predictions, guiding students to develop methods to be used in practicums through questions, conducting explorations, measurements, data analysis, and drawing conclusions [38]. The research results are shown in Fig. 3.

Based on the hypothesis testing results, the n-gain of the two classes showed a significant difference between students who get dynamic learning through problem-solving laboratory learning and those who learn through verification activities. Meanwhile, the increase in experimental class gain is because learning with problem-solving activity approach provides opportunities for students to be more flexible. It helps them to independently exchange ideas with each other in completing the task given by the teacher. The results of this study support previous research, which stated that learning through a laboratory activity approach can improve students' critical thinking skills [38].

Through presenting a problem, students feel the need to know how the phenomenon occurs and what causes it. Therefore, their curiosity will encourage them to study, ask questions, or discuss. Presenting a problem is the most important step to visualize the situation and identify the actual and relevant problems [39].

Furthermore, problem-solving learning can foster several aspects of critical thinking skills. Therefore, experiments that motivate students to think about results and simplify assumptions about problems are conducted [40]. In critical thinking, there is the ability to reason and think reflectively, which is directed to decide convincing things to be carried out [6]. Therefore, developing this skill is important because it can foster sensitivity to problems that occur, which will make students able to understand an issue and help them apply concepts in different situations.

3.3 Physics Learning with Multi Representation: An Effort to Foster Critical Thinking Skills in Vocational High School Students

Critical thinking skills are crucial for problem-solving [41]. With these abilities, students can identify, evaluate, construct arguments, solve problems, and make appropriate decisions [22]. Therefore, developing these skills is important and achieved through conditioned learning [42].

Physics learning is based on the concept of science as a product, process, and attitude. Implementation of the scientific process based on a scientific attitude is aided by interaction with the environment. Critical thinking skills provide opportunities for students to cope with issues of social, scientific, and practical significance [43].

The critical thinking skills of vocational high school students who apply physics learning with a multi-representation approach are higher than conventional learning. This is based on an n-gain score: the students who carry out physics learning with this approach have a normalized gain value of 0.60, which is of the medium category while, those who carry out conventional physics learning have a gain value of 0.26, which is of the low category [44]. Based on these results, multi-representation can train students in solving problems related to critical thinking skills. Students use representations to comprehend the situation of the problem and evaluate the results, and representations that are non-verbal means in problem statements can affect the student's performance differently. Therefore, the superiority of those who carry out multi-representation learning is the basis for this approach to increase critical thinking skills and abilities [45].

4 Conclusion

One of the expected outputs of science learning is critical thinking skills. This ability is not inherent in humans from birth but can be trained through a learning process. Therefore, the development is expected to be beneficial for students in finding a solution to a problem. Furthermore, this ability is important to train and develop because it helps students make reasonable decisions and solve problems in school, personal life, and the work environment.

Active learning is believed to promote critical thinking skills in students. Meanwhile, the model with a constructivism approach can promote critical thinking skills in students. This approach views that knowledge cannot be transferred directly from one person to another, but students are given the opportunity to construct their own knowledge with the teacher's help. Therefore, learning that characterizes a constructivist approach includes inquiry, problem, and project-based education.

Core Messages

- Critical thinking is an important skill for students in the twenty-first century.
- Critical thinking skills can be achieved by improving the quality of science education.
- Science education with a constructivism approach can improve students' critical thinking skills.

References

1. Carin AA, Sund RB (1990) Teaching modern science. Merril Publishing Company, New York
2. Carin AA (1997) Teaching science through discovery, 8th edn. Prentice Hall, New Jersey
3. Morgan WR (1995) Critical thinking what does that mean? J Coll Sci Teach 24(5):336–390
4. Arnyana IBP (2004) *Pengembangan Perangkat Model Belajar Berdasarkan Masalah Dipandu Strategi Kooperatif dan Pengaruh Implementasinya Terhadap Keterampilan Berpikir Kritis dan Hasil Belajar Siswa SMA pada pelajaran Ekosistem.* Disertasi tidak diterbitkan. Malang: Program Pasca-sarjana Universitas Negeri Malang
5. Zoller U, Ben-Caim D, Ron S (2000) The disposition toward critical thinking of high school and university science student: a inter-intra Isreali-Italian study. Int J Sci Educ 22(6).
6. Costa AL (1985) Goals for a critical thinking curriculum. In: Costa AL (ed) Developing mind: a resource book for teaching thinking. ASCD: Alexandria, Virginia
7. Ennis RH (1985) Curriculum for critical thinking. In: Costa AL (ed). Developing mind: a resource book for teaching thinking. ASCD: Alexandria, Virginia
8. Hughes W, Lavery J (2014) Critical thinking: an introduction to the basic skills-seventh edition, Canadian: Phil-papers
9. Verlinden J (2005) Critical thinking and every day argumen. Balmont. Wadsworth/the msou learning Inc., CA
10. Facione PA (2015) Critical thinking: what it is and why it counts. Hermosa beach: measured reasons LLC
11. Abd-El Khalick F, Lederman NG, Bell RL (1998) The nature of science and instructional practice: making the unnatural natural. Sci Educ 82: 417–436
12. Chiappetta EL, dan Koballa TR (2010) Science instruction in the middle and secondary schools: developing fundamental knowledge and skills. United State of America: Pearson Education Inc
13. McComas WF (2015) The nature of science & the next generation of biology education. Am Biol Teach 77(7):485–491. https://doi.org/10.1525/abt.2015.77.7.2
14. Bell RL (2008) Best practices in science education teaching the nature of science: three critical questions. Cengage
15. Good R (2012) Advances in nature of science research, (Id), 97–106. https://doi.org/10.1007/978-94-007-2457-0
16. Ramsey J (1993) Reform movement implication social responsibility. Sci Educ 77(2):235–258
17. Loucks-Horsley S, Stiles KE, Mundry S, Love N, Hewson PH (2010) Designing professional development for teacher of science and mathematics. California: Corwin

18. Brickman P, Gormally C, Armstrong N, Hallar B (2009) Effects of inquiry-based learning on students’ science literacy skills and confidence. Int J Scholarsh Teach Learn 3:1–22
19. Kruse D (2009) Thinking strategies for the inquiry classroom. Curriculum corporation. Diambil pada tanggal 23 Juli 2014, dari. http://www.curriculumpress.edu.au/sample/pages/978174200313 9.pdf
20. Beyer BK (1995) Critical thinking. Phi Delta Kappa Educational Foundation, Bloomington
21. Kalman CS (2002) Developing critical thinking in undergraduate courses: a philosophical approach. Sci Educ 11(83–94):2002
22. Walker GH (1998) Critical thinking. Tersedia pada: http://www/utr.edu/administration/walkerteachingresoursecenter/facultydevelopment/criticalthinking
23. Ennis RH (1989) Critical thinking and subject specificity: clarification and needed research. Educ Res 18(3):4–10. https://doi.org/10.3102/0013189X018003004
24. Tiruneh DT Cock MD, Weldeslassie AG, Elen J, dan Janssen R (2017) Measuring critical thinking in physics: development and validation of a critical thinking test in electricity and magnetism. Int J of Sci and Math Educ 15:663–682
25. Zohar A (1994) The effect of biology critical thinking project in the development of critical thinking. J Res Sci Teach 31(2):163–196
26. Tiruneh DT, Weldeslassie AG, Kassa A, Tefera Z, Cock MD, Elen J (2016) Systematic design of a learning environment for domainspecific and domain-general critical thinking skills. Educ Tech Res Dev 2016(64):481–505
27. Abrami PC, Bernard RM, Borokhovski E, Waddington DI, Wade CA, Persson T (2015) Strategies for teaching students to think critically: a meta-analysis. Rev Educ Res 85(2):275–314. https://doi.org/10.3102/0034654314551063
28. Hashemi SA, Naderi E, Shariatmadari A, Naraghi MS, Mehrabi M (2010) Science production in iranian educational system by the use of critical thinking. Int J Instr 3(1)
29. Facione PA (2010) Critical thinking: what it is and why it counts. Insight Assesment, pp 1–24
30. Deming JC, Cracolice MS (2004) Learning how to think. Sci Teach 71(3):42–47
31. Straits WJ, Wilke RR (2002) Practical considerations for assessing inquiry-based instruction. J Coll Sci Teach 31(7):432–435
32. Jufri AW (2007) Pengaruh Implementasi Perangkat Pembelajaran Berbasis Inkuiri Melalui Strategi Kooperatif Terhadap Keterampilan Berpikir Kritis, Sikap, dan penguasaan konsep Siswa SMA di Kota Mataram. *Disertasi*, tidak dipublikasikan. Malang: Program Pascasarjana Universitas Negeri Malang
33. Mestre JP (2002) Probing adults’ conceptual understanding and transfer of learning via problem posing. J Appl Dev Psychol 23:9–50
34. Maknun J (2020) Implementation of guided inquiry learning model to improve understanding physics concepts and critical thinking skill of vocational high school students. Int Educ Stud 13(6). https://doi.org/10.5539/ies.v13n6p117
35. Peter EE (2012) Critical thinking: essence for teaching mathematics and mathematics problem solving skills. African J Math Comput Sci Res 5(3):39–43. https://doi.org/10.5897/AJMCSR11.161
36. Stobaugh R (2013) Assessing critical thinking in middle and high schools. Routledge, New York
37. Rosen Y, Maryam T (2014) Making student thinking visible through a concept map in computer-based assessment of critical thinking. J Educ Comput Res 50(2):249–270. https://doi.org/10.2190/EC.50.2.f
38. Hakim L (2010) Pembelajaran Konsep Listrik Dinamis Melalui Kegiatan Laboratorium Problem Solving untuk Meningkatkan Penguasaan Konsep dan Keterampilan Berpikir Kritis Siswa. Sekolah Pascasarjana Universitas Pendidikan Indonesia, Tesis
39. Heller, Heller (1999) Cooperative group problem solving in physics, supported by national science foundation (NSF), the department of education, fund for improving post-secondary education (FIPSE), and by the University of Minnesota

40. Iselin JP (2007) Teaching critical thinking through simple experiment. In: proceeding of the 2007 ASEE North Midwest Sectional Conference
41. Cabera GA (1991) A framwork for evaluation the teaching of critical thinking. Education 113 (1):59–63
42. Lipman M (2003) A thinking in education, 2nd edn. Cambridge University Press, Cambridge
43. Shakirova DM (2007) Technology for the shaping of college students' and upper-grade students' critical thinking. Russ Educ Soc 49(9):42–52
44. Maknun J (2019) The development of critical thinking skills in vocational high school students in Indonesia. Int J Innov Creativity Change 7(12):2019
45. Rosengrant D, Etkina E, Heuvelen AV (2007) An overview of recent research on multiple representations. [online] Tersedia: www.percentral.org/items/264 [18 Jan 2013]

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9 Constructivist Education: The Learner Tongue as a Prerequisite to Constructivist Practice

Ghsoon Reda

> *Language is the blood of the soul into which thoughts run and out of which they grow.*
>
> *Oliver Wendell Holmes*

Summary

Constructivism is adopted as the twenty-first century education model because it rests on stimulating thinking development. Constructivist practice, however, is surrounded by controversies that center around such issues as the effectiveness of different techniques on learning different areas or skills, the learning environment, and the student–teacher relationship. The medium of instruction is never brought into focus as an essential component of constructivist practice. This study draws attention to the need to accord the learner tongue importance in this practice showing that a constructivist classroom culture can only be sustained when the medium of instruction is not foreign to the learner. A model of proper applications of constructivist principles is also provided to address ambiguities surrounding the concept of constructivism as an educational practice.

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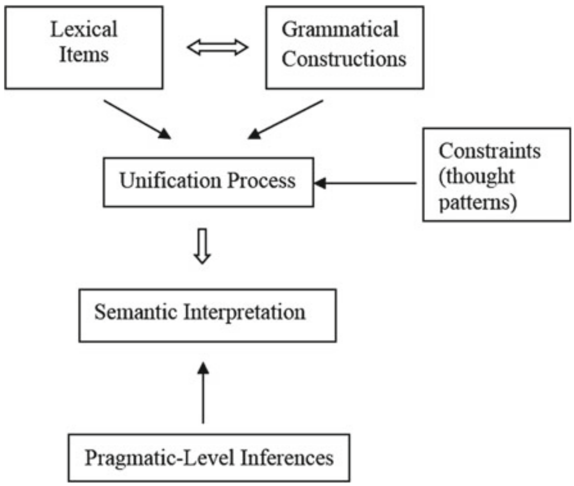
N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_9

Graphical Abstract/Art Performance



Meaning construction and interpretation from the perspective of the Lexical Constructional Model (LCM).

Keywords

Constructivism · Constructivist practice · Educational psychology · English-medium instruction · Scaffolding

QR code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword

and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

Present-day educators perceive the learner as an actor (rather than a recipient) who plays a vital role in the learning process. This perception is represented by the shift of focus from the teacher-centered to the student-centered approach characterizing the twenty-first century education model [1]. The student-centered approach is a teaching model based on *"constructivism"*–a learning theory that concerns itself with the cognitive and socio-linguistic conditions underlying human learning [2–4]. Constructivist educationists view learning as a meaningful process of effortful construction of knowledge whereby the learner brings past experiences and cultural concepts to the learning situation. The process is mediated by the teacher, who creates opportunities for the learner to actively build newly received information on existing knowledge [5–7]. In such a learning environment, the teacher's assistance should not exceed *scaffolding* – providing the guidance that the learner needs in order to understand a given learning task and start working on it [2].

In this way, the learner's existing linguistic experience (which is the vehicle of all experiences) may be described as a prerequisite to constructivist practice. This point can be clarified through such cognitive linguistic theories as Conceptual Metaphor Theory (CMT) [8] and the Lexical Constructional Model (LCM) [9]. CMT depicts language as a reflection of thought patterns representing speakers' experiences. Take the English expression "I can't afford the time" as an example. This expression reflects the conceptual metaphor "TIME IS MONEY," a thought pattern of the "A is B" structure deriving from the way time is dealt with in English society. In Piagetian constructivist terminology [3], learning is organizing new information within or in relation to existing thought patterns (as elaborated on in the section to follow). The LCM, however, deals with thought patterns as conceptual constraints governing the construction and interpretation of meaning. For example, in the sentence "The audience laughed the actor off the stage," the verb "laugh" integrates into "the caused-motion construction." The LCM shows this integration to be licensed by the metaphor "AN EXPERIENTIAL ACTION IS AN EFFECTUAL ACTION," considering that an action's psychological or emotional impact can be structured/understood in terms of a physical impact. Meanings that become conventionally associated with a structure are inferences interpreted at the pragmatic level. An example of this is a rhetorical question like "Who was in my room?" which English speakers interpret as a complaint [9–11]. Graphical Abstract is a simplified sketch of meaning construction and interpretation from the perspective of the LCM.

Cognitive linguistic theories like the ones mentioned above may be said to complement Vygotsky's theory of social constructivism [4] in that they show how knowledge as the product of the learners' interaction with their environment is organized as thought patterns that shape the way the speakers of a language think and express their thoughts. Hence, if a constructivist practice is a matter of developing the learner's existing thoughts, then the learner tongue needs to be accorded importance in this practice. The point here is that the observation that constructivist instruction can take the student to higher levels of critical thinking and problem solving and improve their attitude towards learning [1] is only valid when the medium of instruction is not foreign to the learner. Constructivist techniques require the learner to take the mental action of restructuring existing thought patterns or creating new patterns. It is only through this kind of action that the learner's thinking can develop. This, in turn, is only possible through the learner tongue. The term "learner tongue" is used in a very broad sense in this study to include any language (not only the mother tongue) acquired at an early age in a natural setting. The following report on some research in the area shows the effectiveness of using the learner tongue in primary education:

> … children in school learned to read quickly and fluently because … the songs, poems and rhymes were taught in Ibanag … [one of the native languages used in the northern most part of the Philippines]… children enjoyed playing, singing with local instruments like coconut shell and improvised tambourines, dancing, dramatizing, writing paragraphs and simple essays. Thus, children are able to understand the lesson, think well, argue well and ask questions properly and critically [12, p. 2].

The present study is not concerned with issues related to the language of instruction per se [13]. Rather, it aims at contributing to work that attempts to clear ambiguities surrounding the idea of constructivism in practice. Windschitl [14] pointed out the equation of the constructivist practice with the insertion of discrete instructional techniques (inquiry learning, problem-based learning, etc.) into any learning environment [14]. This fact signals a distorted understanding of the practice [15], considering that it is a culture that modifies all aspects of the learning environment, from student–student/teacher-student interaction to the subject matter experience and assessments [16]. The study adds to the elaboration of this point by drawing attention to the learner tongue as a vital component of constructivist classroom culture. What triggered the study is the emergence of higher education programs that immerse students in a foreign language without providing sufficient training in that language or even contextualizing the instructional materials. Such programs are inappropriate environments for embracing constructivist instruction for a twofold reason:

i. the language of instruction is foreign to the minds of the students; and
ii. not all students are good language learners.

Based on findings of research on foreign language learning, Petriciuc [17] noted that:

It turns out that in a classroom setting there is more learning about the language, than learning the language itself [17, p. 28] (i.e., as a system of communication for communicating and developing thoughts).

In this way, the foreign language classroom lacks the linguistic dimension necessary for embracing constructivist instruction. This observation can be supported by the development of the field of English language teaching (ELT). As shown in Fig. 1, although this development represents a departure from grammatical, teacher-centered approaches to cognitive and socio-cultural, or student-centered, approaches [18, 19], it is still rooted in traditional instruction in the sense that it incorporates constructivist techniques (problem-solving tasks) into didactic instruction fostered by textbooks. In such an environment, the teacher can go way beyond scaffolding students' learning by conveying the information they need to do the task. In addition, teaching textbook tasks is not different from the traditional "one-size-fits-all" approach. Such an approach does not create a constructivist learning environment where different individuals are involved in decision-making [20].

Work in the field of ELT may well be described as built on the same distorted understanding affecting the establishment of a constructivist classroom culture (i.e., inserting constructivist techniques into any learning environment), but with the added element of language foreignness which can strip any constructivist technique

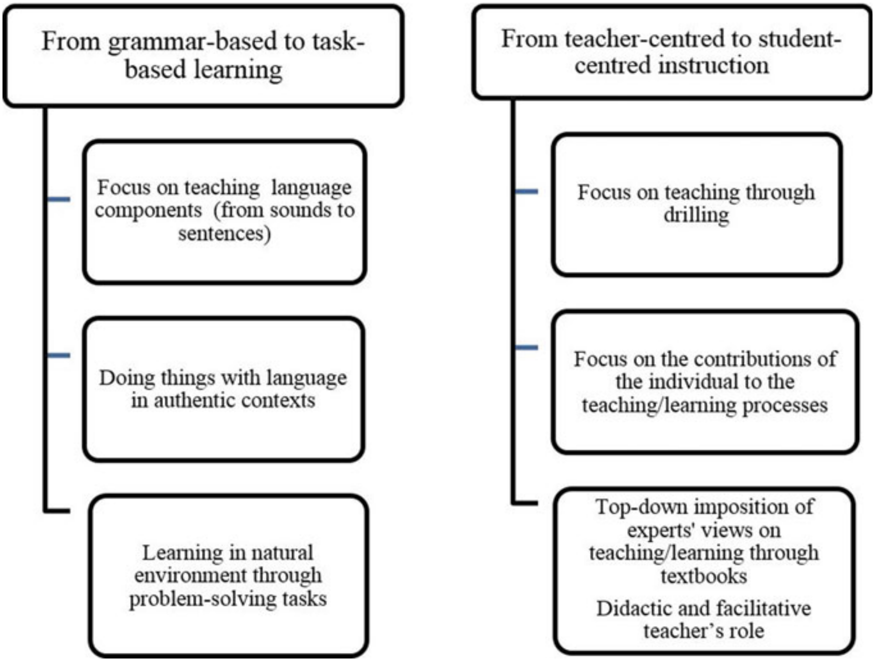


Fig. 1 The development of ELT methodology

of its main function (i.e., creating conceptual development and change in the learner). This is reflected in the large body of literature available to practicing and trainee teachers of English as a foreign language in that it is composed of studies examining the effectiveness of discrete constructivist techniques (story-telling, games, discussion, role play, etc.) for developing learners' language skills, treating these techniques as teaching strategies rather than tools for creating a constructivist classroom culture.

The section to follow introduces constructivism as a theory of learning/teaching. Then, the challenges of establishing a constructivist classroom culture are introduced. A comprehensive model of constructivist instruction follows this. The model is abstracted from the teachings of the Quran. The reason why the Quran methodology has been chosen is that it is congruent with scientific research on human learning and is, therefore, a representative sample of ideal constructivist practice. It is shown that the model treats the learner tongue as a prerequisite to knowledge construction. The study ends with a summary of points.

2 Constructivism

Constructivist positions may be described as developments of the following stance:

> [L]earning is a process of constructing meaning; it is how people make sense of their experience [21, p. 260].

The attention given to the role of the learner in the process of constructing knowledge is often attributed to the Piagetian [3] or Chomskyan view of the learner as an epistemological subject [22, 23]; that is to say, as Noddings [24] put it, as:

> an active knowing mechanism that knows through continued construction [24, p. 9].

Windschitl [14] described the process of continued construction as involving intellectual transformations that:

> occur when students reconcile formal instructional experiences with their existing knowledge, with the cultural and social contexts in which these ideas occur, and with a host of other influences that serve to mediate meaning [16, p. 752].

Such a conceptualization of learning has three dimensions: radical, cognitive, and social. The radical dimension of constructivism:

> breaks with the foundations of empirico-realism, which claims to encode reality in terms of substances and phenomena which are independent of the observers involved. So doing, it challenges age-old beliefs which maintain that facts speak for themselves, and that language objectively refers to this reality [25, p. 5].

This means that meaning/knowledge is not discovered but subjectively construed by the individual learner based on experiences, ranging from everyday observations to scientific knowledge [6, 26–29]. However, the cognitive dimension of constructivism is concerned with how learners actively construe knowledge.

Piaget [3] showed that learning is an adaptation process that occurs by solving problems. The process is a two-stage learning activity that involves the assimilation and accommodation of new interactions with the world. Assimilation is the stage of changing, modifying, or merging new knowledge in mind to fit into existing thought patterns (or schemas), a process that can involve "overgeneralisation" (e.g. all round objects are balls). As for accommodation, it is the stage of modifying existing schemas to include the new information (e.g. not all round objects are balls; they need to be organised under different or new schemas). This stage of the adaptation process is examined in other traditions as involving "categorization" based on "family relationship" and "degree of resemblance to a prototype" (e.g., the category of birds) [30, 31].

Vygotsky elaborated on Piaget's learning theory by adding a social dimension to human learning [4]. Vygotsky explored the role of social interaction in cognitive development, showing that the focus should not be on the individual child acting on his environment, as Piaget suggests, but on "the child as a product of social interaction." This means that knowledge is handed down from the "experienced adult" to the "inexperienced child." These beliefs necessitate the following two principles [4]:

i. the More Knowledgeable Other (MKO), anyone who has more knowledge than the learner (e.g., a teacher, trainer, parent, or peer); and
ii. the Zone of Proximal Development (ZPD), an individual's potential to learn. It refers to what an individual can achieve with the help of the MKO.

A relevant concept to the ones mentioned above is *scaffolding* or learning support that is gradually withdrawn as the learner's ability to perform a task increases.

Bruner [2] contributed to the development of constructivism by focusing on the role of language in cognitive growth. Starting with the assumption that language is the tool that adults use to mediate the world for children, he stressed the importance of conceptual development for knowledge construction. Bruner identified three levels for information processing, showing how physical experience is the basis on which humans build conceptual knowledge:

i. *enactive*, it is referred to as the muscle memory level whereby learning is dependent on direct handling of objects;
ii. *iconic* (from the age of one), this level is related to visual images (including sound and smell images) considered as icons that the child recognizes for what they represent; and
iii. *symbolic* (around the age of seven), this level refers to learning via language that represents thoughts and experiences.

Considering these three modes of thinking, Bruner suggested that any teaching program should take the learner from the more concrete to the more abstract and then to the symbolic in a graded manner.

Clearly, constructivism is a complex learning theory and, therefore, implementing it in the classroom requires not only teachers that understand its principles but also autonomous learners and supporting administrators. As shown in the following section, these facts have been considered in the literature as challenges impacting the establishment of a constructivist classroom culture.

3 Constructivism in Practice

Windschitl [14] built a framework of challenges that face teachers who attempt to embrace constructivist instruction using four frames of reference: conceptual, pedagogical, cultural, and political dilemmas. Outlining the sources of these dilemmas, he wrote:

> Conceptual dilemmas are rooted in teachers' attempts to understand the philosophical, psychological, and epistemological underpinnings of constructivism. Pedagogical dilemmas for teachers arise from the more complex approaches to designing curriculum and fashioning learning experiences that constructivism demands. Cultural dilemmas emerge between teachers and students during the radical reorientation of classroom roles and expectations necessary to accommodate the constructivist ethos. Political dilemmas are associated with resistance from various stakeholders in school communities when institutional norms are questioned and routines of privilege and authority are disturbed [14, p. 132].

These dilemmas are, in turn, attributed to the unavailability of constructivist explanations that cohere with widely applicable instructional models [6, 24]. In an attempt to clear ambiguities surrounding the concept of constructivism in practice, Windschitl [14] provided the suggestions in Box 1 below bringing together constructivist views on human learning and types of classroom activities that are likely to optimize meaningful learning opportunities.

Box 9.1
Windschitl's [14] suggestions for sustaining a constructivist classroom culture [14, p. 137].

- *Teachers elicit students' ideas and experiences in relation to key topics, then fashion learning situations that help students elaborate on or restructure their current knowledge;*
- *Students are given frequent opportunities to engage in complex, meaningful, problem-based activities;*
- *Teachers provide students with a variety of information resources as well as the tools (technological and conceptual) necessary to mediate learning;*
- *Students work collaboratively and are given support to engage in task-oriented dialogue with one another;*

- *Teachers make their own thinking processes explicit to learners and encourage students to do the same through dialogue, writing, drawings, or other representations;*
- *Students are routinely asked to apply knowledge in diverse and authentic contexts, to explain ideas, interpret texts, predict phenomena, and construct arguments based on evidence, rather than to focus exclusively on the acquisition of predetermined "right answers;"*
- *Teachers encourage students' reflective and autonomous thinking in conjunction with the conditions listed above; and*
- *Teachers employ a variety of assessment strategies to understand how students' ideas are evolving and to give feedback on the processes as well as the products of their thinking.*

Note that there is no mention of the language of instruction in Windschitl's suggestions. This may be due to the fact that the national language is presumed to be the only language of instruction, particularly in Western countries. Bilingual education is available to the children of immigrants to these countries, but as a transitional stage to their enrollment in the regular instructional programs [16].

Quran methodology, however, treats the learner language as a prerequisite to knowledge construction. As the following section shows, it is a model of constructivism in practice in which all aspects of what can be described as a constructivist instruction culture play complementary roles.

4 Constructivist Principles in Qur'an Teachings

Quran teachings may be described as incorporating all three dimensions of constructivism: radical, social, and cognitive. The three dimensions overlap in the sense that they consist in mediating the world for readers triggering them to build knowledge of the unknown/unobservable in terms of concepts representing existing knowledge and observable reality. This is analogous to Bruner's suggestion that a teaching program should progress from the more concrete to the more abstract and symbolic.

Figure 2 represents the themes under which Quran constructivism will be discussed. The discussion will demonstrate that the process of constructing knowledge cannot start and complete successfully unless it takes place through the learner tongue.

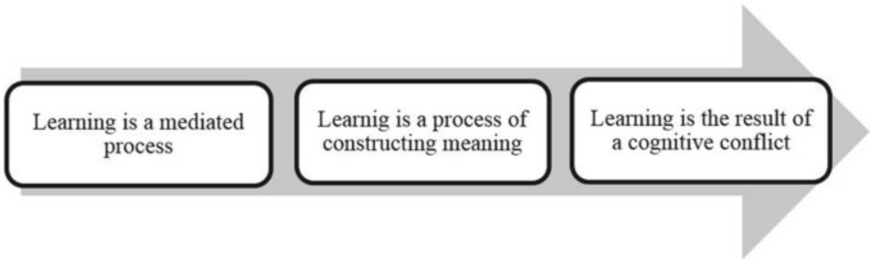


Fig. 2 Stages of constructivist instruction

4.1 Learning as a Mediated Process

Quran teachings demonstrate that human learning is mediated by knowledge transfer from the MKO to the learner. God is the MKO for the prophets and humans in the following verses:

> And He taught Adam the names of all things [i.e. words]… [32].

> taught humanity which they knew not [33].

> There they found a servant of Ours, to whom We had granted mercy from Us and enlightened with knowledge of Our Own [34].

An important point about the Quran is that it was descended in the language of the people to whom the message of Islam was sent so that they understand it, as is clear from the following verse:

> Indeed, We have sent it down as an Arabic Qur'an so that you may understand [35].

However, the Quran, like the other Scriptures, is a wealth of information about the unknown that is presented through observable realities. Such information does not require only mental efforts on the part of the learners to be constructed, but also an understanding of the scientific dimension embedded in the verses. Learners are, therefore, guided to resort to the MKO if they find it hard to interpret Qur'an teachings:

> … And We sent not before you except men to whom We revealed [Our message]. So ask the people of the message [i.e., former scriptures] if you do not know [36].

The Quran approaches the learner as a thinker with free will; he/she can choose between learning and remaining ignorant. However, those who choose to remain ignorant are not placed on a par with those who learn. In addition, consistent with the radical dimension of constructivism (or the dimension concerned with the subjective construal of reality), knowledgeable people are depicted as capable of seeing facts that other people cannot see, as the verses below show:

> Say, [O Prophet,] "Are those who know equal to those who do not know?" None will be mindful [of this] except people of reason?? [37]

> …Only those fear Allah, from among His servants, who have knowledge. Indeed, Allah is Exalted in Might and Forgiving [38].

However, the process of knowledge construction (be it autonomous or mediated) needs to be initiated in the learners' language, as the following section demonstrates.

4.2 Learning as a Process of Constructing Meaning

Understanding to lead to thinking development requires concepts that the learner is familiar with. Considering learners' ZPD, learning is dealt with in the Quran as a process of meaning construction that is achievable through existing concepts and thought patterns. Berrada [39, p. 19]showed that:

> "the Qur'an resorts to reific metaphors—using concepts pertaining to some domains that were very familiar to the people who first received the Qur'anic revelations in order to delineate the less accessible notions of faith and the eschaton" [39].

Abstract notions related to faith (i.e., belief and disbelief) are mapped onto familiar contrasting concepts like *seeing* and *blindness*, *light* and *darkness*, *shade* and *heat*, and *life* and *death*, as shown in Table 1 [39, 40].

For notions related to the eschaton that are beyond the ability of man to understand, analogies are used. In the verse below, for example, "resurrection" and "bringing a dead land back to life" are presented as two analogous processes:

> And it is Allah who sends the winds, and they stir the clouds, and We drive them to a dead land and give life thereby to the earth after its lifelessness. Thus is the resurrection [41].

Note that the verse opens with an *it-clause.* From a grammatical perspective, this clause emphasizes the known information contained in the relative clause that follows. That is, starting the verse with the emphasis that it is God who brings a dead land back to life, a statement in which the fact that a dead land can come back to life is a familiar piece of information, makes it possible for the reader to understand the process of resurrection and to believe in it as happening when God wills. This involves adding "resurrection" to the learner's schema of possible events.

Table 1 Dichotomous concepts as sources for the Qur'anic concepts of belief and disbelief

Source	Target	Metaphor	Example
Seeing/blindness Light/darkness Shade/heat Life/death	Belief	Belief is seeing/light/shad/life	"Not equal are the blind and the seeing, nor are the darkness and the light, nor are the shade and the heat, and not equal are the living and the dead…" [62]
	Disbelief	Belief is blindness/darkness/heat/death	

The above examples demonstrate how the readers' conceptualization of their reality forms the basis on which Quran teachings are built. This aspect of Quran constructivist instruction may lead to conceptual modification as it involves (1) helping learners to accommodate new ideas or viewpoints within their existing schemas and (2) stimulating cognitive conflicts that challenge existing beliefs, a process whereby existing schemas cannot deal with new experiences causing *disequilibrium* (in Piagetian terminology [3]) and subsequent conceptual modification. However, the process can only occur effectively through the language in which these experiences are organized. Some important Qur'an techniques that stimulate cognitive conflict are examined below.

4.3 Learning as the Result of Cognitive Conflict

It is clear from the above that constructing Quran teachings requires critical reading that considers both form and content. Most Quran lessons have implications that need to be inferred via the following reasoning patterns:

- *induction,* specific to general,
- *deduction,* general to specific; and
- *abduction,* incomplete set of observations to the likeliest possible explanation for the group of observations.

In this way, Quran teachings set an example of how effective knowledge construction can be created by designing tasks that stimulate critical reading to be extended to critical thinking. The aforementioned essential patterns of thinking are activated in the Quran by such techniques as descriptions, narratives, and hypothetical situations whereby words and grammatical structures play a vital role in bringing about conceptual change. In their conceptual change theory, Posner et al. [42] demonstrate that learning is a social process and that the restructuring of an individual's knowledge requires appropriate instructional techniques that enhance learners' curiosity, creativity, and development of thinking skills that are characteristic of meaningful learning. This is the learning environment created by Quran instructional techniques that foster conceptual change. The learner's understanding of the linguistic triggers in the techniques is vital for bringing about the change, as shown below.

4.3.1 Descriptions

Quran descriptions focus on observable realities to prompt the readers to go beyond what their eyes can see, forming concepts that can conflict with their existing ones. For instance, in the example below, the perfect creation of the heavens, which is a sign that people can see, is indicated to the addressees, challenging them to see any breaks. Disbelievers are challenged twice to find any imperfection in the creation of the heavens and shown that such a search is hopeless:

> [And] who created seven heavens in layers. You do not see in the creation of the Most Merciful any inconsistency. So return [your] vision [to the sky]; do you see any breaks? Then return [your] vision twice again. [Your] vision will return to you humbled while it is fatigued [43, 44].

The observable reality (the perfect creation of the heavens) is indicative of the perfect ability of the Creator. It is a specific premise that leads to the following generalization: The Creator of the perfect heavens is Omnipotent. That is to say, the teacher of the Prophet is not a human being, as some disbelievers said. The message here is a response to the disbelievers' claim reported in the following verse:

> And We certainly know that they say, "It is only a human being who teaches the Prophet." The tongue of the one they refer to is foreign and this Qur'an is [in] a clear Arabic language [45].

Two important points can be drawn from the above example. First, a full-fledged interpretation of the verse requires knowledge of why the verse was descended. It is intended to challenge an existing belief, and it can serve this purpose only when the teacher and the students are aware of it. This is consistent with a constructivist principle stating that the teacher should have *prior awareness* of the concepts students bring to the classroom [46]. Second, the verse that reports the belief in question equates teaching and learning with the learner tongue (which embeds all kinds of knowledge). This equation also appears in the following verse:

> And we did not send any messenger except [speaking] in the language of his people to state clearly for them … [47].

All this means that effective learning and teaching start with employing the learner tongue.

The importance of understanding the language of instruction for completing constructivist tasks may be demonstrated by the verse below. The verse is a description that reflects God's omnipotence and management in his creation. At the same time, reading the description requires understanding the task it includes:

> And you see the mountains, thinking them rigid, while they are passing as the passing of clouds. [It is] the work of Allah, who perfected all things. Indeed, He is acquainted with that which you do [48].

This verse challenges existing beliefs about the mountains obtained from sensual experience (i.e. the belief that mountains are stationary). It is, therefore, a premise that can arouse readers' curiosity or invite them to search for a generalization that interprets the premise. The generalization required can now be found in the observational astronomy literature that explores the orbiting of the earth.

The description in verse below is different because it gives a challenging observation that can have more than one explanation (a case of abduction):

> He released the two seas, meeting [side by side]; Between them is a barrier [so] neither of them transgresses [49, 50].

Scholars gave different interpretations to this observation, as follows [51]:

- an invisible barrier exists between rivers of fresh water and seas of salty water;
- a virtual barrier that results from the differences in density between fresh and salty water prevents the rivers and seas from mixing by pushing against each other; and
- the barrier is the dry land that prevents them from reaching the other.

Although all three interpretations are possible, different individuals will adopt the one they see as more likely than the others.

Quran descriptions are learning tasks that require critical reading of form and content. Critical reading is the first step to a critical exploration of the facts underlying the description. Hence, Quran descriptions as constructivist tasks demonstrate that the learner tongue (with the socio-cultural aspects it embeds) is essential for embracing constructivist principles in education. The same applies to Quran narratives.

4.3.2 Narratives

Quran narratives cover events from Creation to God's judgment. However, they are not simply stories with morals that focus on punishment and reward. They are triggers that can enhance readers' thinking and curiosity and challenge erroneous beliefs. Words and structures play a vital role in making the narrative a constructivist technique. The verse below, for example, narrates the story of Creation. The details are introduced by an *it-clause,* emphasizing an observable reality:

> It is Allah who erected the heavens without pillars that you [can] see; then He established Himself above the Throne and made subject the sun and the moon, each running [its course] for a specified term. He arranges [each] matter; He details the signs that you may, of the meeting with your Lord, be certain [52].

Starting the verse with the emphasis that "it is Allah Who erected the heavens without pillars that humans can see," a statement in which the fact that the heavens have no pillars is an already known piece of information, prepares the reader for reasoning about the other indicated signs as evidence of God's omnipotence (i.e., the creation and subjection of mighty entities like the sun and moon) referring to his control over all matters and to the fact that there is nothing everlasting. Hence, the opening statement is a specific premise that leads to the following generalization: The Creator who erected the heavens without visible pillars is the unseen controlling power of life and death. "He established Himself above the Throne" is consistent with the omnipotence inference as "throne" represents power. The verse challenges disbelievers' conception of death as the end of life underlying such speeches as the one reported in the following verse:

> And they used to say, "When we die and become dust and bones, are we indeed to be resurrected?" [53].

Those who give thought will reach certainty about meeting God through resurrection. Other narratives create an apocalyptic discourse that can have the effect of changing disbelievers' concept of death from "the reaper of life" to "the gate to the afterlife", transforming the act of choosing the path of God into an immediate necessity (before it is too late). Such narratives are tasks that provide the readers with a learning opportunity involving decision-making. The narratives below focus the reader's attention on time's end so that the mental images created through the narratives share space and time with the here and now or on the termination of the journey of life, which can be around the corner [54]. The grammatical structure, *if only*–used in the narratives–instills in the readers the same feeling of regret to be experienced by disbelievers in the afterlife. This feeling can make them reach certainty about meeting God through resurrection and, hence, make them take action or choose the right path before it is too late:

> If you could but see when they are made to stand before the Fire and will say, "Oh, would that we could be returned [to life on earth] and not deny the signs of our Lord and be among the believers [55].

> Or [lest] it say when it sees the punishment, "If only I had another turn so I could be among the doers of good [56].

Quran narratives that provide conceptual change opportunities involving decision-making are also framed within rhetorical questions. Consider the verses below:

> Have they not seen [as considered] how many generations We destroyed before them - that they to them will not return? [57]

> Have you not considered how your Lord dealt with 'Aad -[With] Iram - who had lofty pillars, The likes of whom had never been created in the land? And [with] Thamud, who carved out the rocks in the valley? And [with] Pharaoh, owner of the stakes? -[All of] whom oppressed within the lands; And increased therein the corruption. So your Lord poured upon them a scourge of punishment [58].

The use of negative rhetorical questions to narrate known events, the morals of which disbelievers cannot understand, is intended to stimulate readers to read critically. Put differently, the narratives, which are specific instances of the generalization that God is the most Powerful, evoke in the reader's mind images of the death and destruction of disbelievers, notwithstanding their power. Such images, which can bring about conceptual and behavioral change, are likely to be evoked by words and structures that readers can reason through.

4.3.3 Hypothetical Situations

Hypothetical situations can be demonstrated by *counterfactuals*. Quran counterfactuals are of the form "if antecedent then consequent"–a form whereby a conclusion is drawn by assuming an antecedent to be true and verifying it by its consequent [59]. In verse below, the counterfactual is part of a narrative:

> And when Moses arrived at Our appointed time and his Lord spoke to him, he said, "My Lord, show me [Yourself] that I may look at You. [Allah] said, "You will not see Me, but look at the mountain; if it should remain in place, then you will see Me." But when his Lord appeared to the mountain, He rendered it level, and Moses fell unconscious. And when he awoke, he said, "Exalted are You! I have repented to You, and I am the first of the believers"" [60].

The narrative is a counterfactual reasoning schema in which seeing God is conditional upon an event that humans believe to be impossible (the mountain (being an immovable entity) not to remain in place). The occurrence of this condition after God's saying, "You will not see me," instills in the reader the belief that God can move the mountain. The subsequent crumbling of the mountain confirms this belief. Such a counterfactual can achieve its intended effect (i.e., convince humans to believe in God, the Imperceptible Power, and surrendering to Him, as Moses did) if, and only if, the readers appreciate the language used in the narrative [61].

The above Quran teaching techniques demonstrate how the learners' linguistic experience (as the vehicle of all other experiences) is vital for creating an effective constructivist environment for learning. Through this experience, learners can read critically, think critically, and take the right actions that reflect the conceptual development and change the learning tasks created in them. Effective tasks can be of any genre, from descriptions to hypothetical situations rather than straightforward questions or statements. Straightforward questions and statements may well motivate learners' curiosity and provide them with a meaningful learning environment but at the expense of developing their individuality and critical reading and thinking skills. The topics of tasks should also be structured in terms of the learners' observable reality and conceptualization of this reality. Such an effective constructivist learning environment can only be established through the learner tongue.

5 Conclusion

This study highlights the importance of the learner tongue in establishing a constructivist classroom culture. Attempts to establish this culture through a foreign language have been considered under Windschitl's [14] conceptual frame of reference where the distorted understanding of constructivist instruction is shown to be reflected in the insertion of constructivist techniques into any learning environment [2]. Drawing on insights from cognitive linguistic theories like the LCM and CMT, it has been noted that the learner tongue is vital for embracing constructivist instruction because it is the language through which learners conceptualize and organize their experiences and constructivist learning is a matter of restructuring these experiences. A model of proper application of constructivism in which all constructivist principles play complementary roles, particularly the learner tongue, was provided.

The study does not argue for the abandonment of foreign languages in education. Rather, it draws attention to the unsuitability of the foreign language environment for embracing constructivist instruction. Learning academic subjects in a foreign language is a positive thing needed to enable students to function in their areas beyond the borders of their countries. However, the solution is not to use a foreign language as the main language of instruction but to incorporate some foreign language courses into regular educational programs.

Core Messages

- Embracing a constructivist education model faces challenges, particularly when the language of instruction is foreign to learners.
- A proper application of constructivist practice rests on treating the learner tongue as a prerequisite to knowledge construction.
- Learning content in a foreign language is needed to enable students to function in their areas beyond the borders of their countries.
- Producing good graduates–graduates who had the opportunity to construct knowledge through their language–remains a priority.

References

1. Overby K (2011) Student-centered learning. Essai 9(1):109–112
2. Bruner JS (1963) The process of education. Harvard University Press
3. Piaget J (1970) The science of education and the psychology of the child. Viking Press
4. Vygotsky LS (1987[1934]) thinking and speech. In: the collected works of L.S. Vygotsky. Plenum Press, pp 39–285
5. Bentham S (2002) Psychology and education. Routledge
6. Fosnot CT (1996) Constructivism: a psychological theory of learning. In: Constructivism: theory, perspectives and practice. Teachers College Press, pp 8–33
7. Fox R (2001) Constructivism examined. Oxf Rev Educ 27(1):23–35
8. Lakoff G, Johnson M (1980) Metaphors we live by. The University of Chicago Press
9. Ruiz de Mendoza Ibáñez FJ, Galera Masegosa A (2014) Cognitive modeling: a linguistic perspective. John Benjamins
10. Ruiz de Mendoza Ibáñez FJ (2007) High level cognitive models: in search of a unified framework for inferential and grammatical behaviour In: Perspectives on metonymy. Peter Lang, pp 11–30
11. de Mendoza R, Ibáñez FJ, Pérez L (2001) Metonymy and the grammar: motivation, constraints, and interaction. Lang Commun 21:321–357
12. Bernardo E, Aggabao N, Tarun J (2018) The mother tongue-based multilingual education (MTB-MLE) program: teachers competencies and pedagogical practices in teaching mother tongue. In: the Asian conference on education & international development 2018 official conference proceedings
13. Rossell CH, Baker K (1996) The educational effectiveness of bilingual education. Res Teach Engl 30(31):7–74

14. Windschitl M (2002) Framing constructivism in practice as the negotiation of dilemmas: an analysis of the conceptual, pedagogical, cultural, and political challenges facing teachers. Rev Educ Res 72(2):131–175
15. Cobb P, Yackel E (1996) Constructivist, emergent and socio-cultural perspectives in the context of developmental research. Educ Psychol 31(3–4):175–190
16. Windschitl M (1999) The challenges of sustaining a constructivist classroom culture. Phi Delta Kappan 80(10):751–755
17. Petriciuc L (2015) Some reflections on factors influencing foreign language learning. Revista de Pedagogie 62(2):27–32
18. Hall CJ, Smith PH, Wicaksono R (2011) Mapping applied linguistics: a guide for students and practitioners. Routledge
19. Richards JC, Renandya WA (2002) Methodology in language teaching: an anthology of current practice. Cambridge University Press
20. Zmuda A (2009) Leap of faith: take the plunge into a 21st-century conception of learning. School Library Monthly 26(3):16–18
21. Merriam SB, Caffarella RS (1999) Learning in adulthood: a comprehensive guide. Jossey-Bass Publishers
22. Chomsky N (1965) Aspects of the theory of syntax. The MIT Press
23. Chomsky N (1972) Language and mind. Brace & Jovanovich
24. Noddings N (1990) Constructivism in mathematics education. In: Constructivist views on the teaching and learning of mathematics. National council of teachers of mathematics, pp 7–18
25. Larochelle M, Bednarz N (1998) Constructivism and education: beyond epistemological correctness. In: Constructivism and education. Cambridge University Press, pp 3–20
26. Crotty M (1998) The foundations of social research: meaning and perspective in the research process. Sage Publications
27. Terhart E (2003) Constructivism and teaching: a new paradigm in general didactics? J Curric Stud 35(1):25–44
28. Molebash P (2002) Constructivism meets technology integration: the cufa technology guidelines in an elementary social studies methods course. Theory Res Soc Educ 30(3):429–455
29. Richardson V (2003) Constructivist pedagogy. Teach Coll Rec 105(9):1623–1640
30. Rosch E (1975) Cognitive representations of semantic categories. J Exp Psychol 104:192–233
31. Taylor JR (1989) Linguistic categorization: prototypes in linguistic theory. Oxford University Press
32. Qur'an 2:31. https://quran.com/2/31
33. Qur'an 96:5. https://quranenc.com/en/browse/english_saheeh/96/5
34. Qur'an 18:65. https://quran.com/18/65
35. Qur'an 12:2. https://quran.com/12/2
36. Qur'an 16:43. https://quranenc.com/en/browse/english_saheeh/16/43
37. Qur'an 39:9. https://quran.com/39/9
38. Qur'an 35:28. https://quranenc.com/en/browse/english_saheeh/35/28
39. Berrada K (2007) Food metaphors: a contrastive approach. Metaphorik.de 13:1–38
40. Shokr AM (2006) The metaphorical concept "life is a journey" in the Qur'an: a cognitive-semantic analysis. metaphorik.de 10:94–132
41. Qur'an 35:9. https://corpus.quran.com/translation.jsp?chapter=35&verse=9
42. Posner GJ, Strike KA, Hewson PW, Gertzog WA (1982) Accommodation of a scientific conception: toward a theory of conceptual change. Sci Educ 66(2):211–227
43. Qur'an 67:3. https://corpus.quran.com/translation.jsp?chapter=67&verse=3
44. Qur'an 67:4. https://corpus.quran.com/translation.jsp?chapter=67&verse=4
45. Qur'an 16:103. https://corpus.quran.com/translation.jsp?chapter=16&verse=103
46. Appleton K, Asoko H (1996) A case study of teacher's progress toward using a constructivist view of learning to inform teaching in elementary science. Sci Educ 80(2):165–180
47. Qur'an 14:4. https://corpus.quran.com/translation.jsp?chapter=14&verse=4

48. Qur'an 27:88. https://corpus.quran.com/translation.jsp?chapter=27&verse=88
49. Qur'an 55:19. https://corpus.quran.com/translation.jsp?chapter=55&verse=19
50. Qur'an 55:20. https://corpus.quran.com/translation.jsp?chapter=55&verse=20
51. Tafseer of the verse "*He has let loose the two seas (the salt water and the sweet) meeting together. Between them is a barrier which none of them can transgress"* [ar-Rahmaan 55:19–20]. (2011). https://islamqa.info. Retrieved from https://islamqa.info/en/answers/165094/tafseer-of-the-verse-he-has-let-loose-the-two-seas-the-salt-water-and-the-sweet-meeting-together-between-them-is-a-barrier-which-none-of-them-can-transgress-ar-rahmaan-5519-20
52. Qur'an 13:2. https://corpus.quran.com/translation.jsp?chapter=13&verse=2
53. Qur'an 56:47. https://corpus.quran.com/translation.jsp?chapter=56&verse=47
54. Newby GD (2003) Folded time: a socio-rhetorical analysis of Qur anic and early Islamic apocalyptic discourse. In: the fabrics of discourse: essays in honor of Vernon K. Robins. Trinity Press International, pp 333–354
55. Qur'an 6:27. https://corpus.quran.com/translation.jsp?chapter=6&verse=27
56. Qur'an 39:58. https://corpus.quran.com/translation.jsp?chapter=39&verse=58
57. Qur'an 36:31. https://corpus.quran.com/translation.jsp?chapter=36&verse=31
58. Qur'an 89:6–13. https://corpus.quran.com/translation.jsp?chapter=89&verse=6-13
59. Fauconnier G (1997) Mappings in thought and language. Cambridge University Press
60. Qur'an 7:143. https://corpus.quran.com/translation.jsp?chapter=7&verse=143
61. Reda G (2020) Echoing-contrast combination in non-ironic constructions. Rev Cognitive Linguist 18:458–479
62. Qur'an 35:19–22. https://corpus.quran.com/translation.jsp?chapter=35&verse=19-22

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10 Thinking Extended Trans Level Based on Local Culture to Achieve Super-Smart People

Wahyu Widada and Dewi Herawaty

Twenty years from now you will be more disappointed by the things that you didn't do than by the ones you did do.

Mark Twain

Summary

The development of industrial revolution 4.0 supports the creation of a super-smart society 5.0. Every individual has the opportunity to become a member of that society. They are individuals who have Twenty-first-century skills and competence as super-smart people. This chapter discusses thinking super-extended trans based on local culture to achieve super-smart people. We have examined various studies substantially in mathematics education, given that mathematics is a basic science that serves science and technology. We explain that super-smart society 5.0 comprises individuals with a super-extended trans character.

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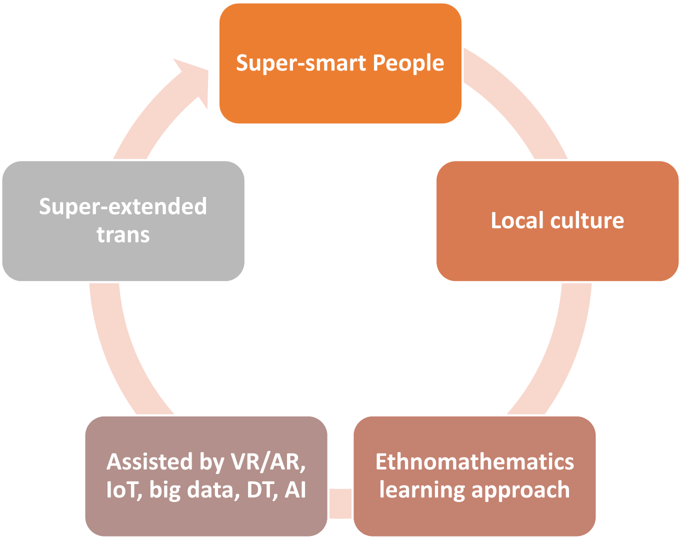
N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_10

Graphical Abstract/Art Performance



The road to super-smart society.

VR, virtual reality; AR, augmented reality; IoT, internet of things, DT, digital transformation; and AI, artificial intelligence.

Keywords

Extended trans level · Local culture · Super-smart society

QR code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword

and put it in place in the puzzle according to the clues provided in chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

Science concepts are built on observation and experimentation by measuring knowledge through scientific thinking, problem-solving, critical thinking [1], and creative and innovative thinking. The cognitive theory views individuals as active information processors who can represent any information that matches the body of knowledge. Such a knowledge representation is structured in the form of a frame, schema, or script that is stored in long-term memory [2–5]. It is a genetic decomposition [6].

Genetic decomposition is the structured assemblage of a person's mental activity. It represents forming and achieving mathematical concepts and principles in the memory system [7–9]. The collection is represented in actions, processes, objects, and schema (APOS) [10]. Action is a procedural activity to change an object physically or mentally [11]. It is an activity to respond to stimuli received from outside, namely a detailed statement of the steps that must be carried out [12]. Interiorization is a change in procedural activity by increasing one's cognitive structure. The indication is to carry out an activity internally by reducing physical activity. It is the reduction of dependence on physical objects and the increased utilization of mental activity in one's mind.

In mathematical thinking activities, Dubinsky and Mcdonald [6] provide several concepts related to cognitive activity. If all actions can be placed in the individual's mind or imagined without carrying out the particular stages, then action after being interiorized becomes a process. A person performs internal activities that do not always come from external stimuli. It is a stage that is carried out implicitly. Encapsulation is the process of producing an object. It is a function of mental transformation in the cognitive interaction of a process on a cognitive object. If the process itself is transformed by some action, there will be an encapsulation that matches an object. It forms a unity from encapsulation in several processes to the thematization process. Thematization is a mental construction of the interconnection of actions, processes, and objects in such a way as to produce other objects. The activity generates a schema. It is a comprehensive entity of disparate objects constructed through cognitive interaction and capable of generating mature schemas. A mature schema is a system that contains integrated actions, processes, objects, and other schemas that are stored in the body of knowledge. It occurs as something synthesized by the individual in the form of a structure that is used to deal with a particular problem situation—also, a person's conception of mathematical objects and other parts related to problem-solving. People with a mature schema can solve problems related to the objects that make up the scheme. They can solve problems using rules, not by registering anymore. Schematic behavior is a pattern of interrelated ideas that appear clearly linked in a person's mind. This is a schema development in the context of APOS theory. It is used by someone to respond to a problem. This pattern will be represented in the form of a list of schema developments that are expressed as a response to the problems faced. They are coherent activities of actions, processes, objects, or schemes. It is a result of genetic decomposition analysis.

2 Level of Thinking Based on Genetic Decomposition

Based on genetic decomposition, thought processes are classified into certain levels. Schema development can be achieved through the theorizing process, which, in turn, takes place within a fixed comparative analysis [13]. The basic levels of the thought process are [14]:

i. APOS-based triad level (action-process-object-schema) [11];
ii. APOS-based triad levels about mathematics [6]; and
iii. APOS-based double triad on graph sketching of non-routine functions [15]

Building a theory about cognitive processes is done by synthesizing various related theories and making restrictions on the theory to be built. Before concluding the character of the cognitive levels, we will first determine the limitations of this theory. This area of cognitive thinking is the development of schemas of calculus concepts and principles. Meanwhile, the analytical tool to determine the scheme's development is genetic decomposition analysis, which is an analysis based on the APOS theory.

We conducted research from 2003 to 2016 on cognitive processes for calculus content. It is a substantive theory in schema development in understanding calculus. These levels are:

i. level 0 (intra-level): individuals entered at this level can only carry out an action, a process, or an object separately and cannot establish a relationship for that action, process, or object;
ii. level 1 (semi-inter level): individuals entered at the semi-inter level can only carry out an action, a process, or an object, but they can only perform actions and processes of the same nature;
iii. level 2 (inter-level): individuals entered at the inter-level can construct action-process-object linkages of several related properties to form a premature schema. However, in the formation of the premature schema, it does not use an earlier scheme that has been previously owned (no retrieval of the previous schema);
iv. level 3 (semi-trans level): individuals entered at the semi-trans level can construct action-object-process linkages so that a part of the mature schema is formed (premature schema). In the formation of the premature schema, someone may use the initial schema (retrieval of the previous schema); and

v. level 4 (trans-level): individuals entered at the trans-level can build mature schemas based on the interrelationships between actions, processes, objects, and other schemas in the body of knowledge. The scheme can be used to solve the problem. The important functions and characteristics of a mature schema are used to decide about the objects included in the schema.

We found seven cognitive models of the concept of real analysis among students:

i. pre-intra-level;
ii. intra-level;
iii. semi-inter-level;
iv. inter-level;
v. semi-trans-level;
vi. trans-level; and
vii. extended-trans-level [16]

Also, there were six levels of students' abstraction ability:

i. level 0: concrete objects;
ii. level 1: semi-concrete models
iii. level 2: theoretical models;
iv. level 3: the language in the example domain;
v. level 4: mathematical language; and
vi. level 5: the inference model

Altogether, our study proposed seven extended levels plus triad plus (consisting of five triads + levels plus two new levels) [8, 9, 16, 17]. The character of each level of the triad plus is described as follows.

2.1 Extended-Trans-Level

In addition to being in the trans-level, individuals who enter this level can build new structures by using their mature schemes. These individuals are ready to welcome the super-smart 5.0 society. They are characterized as solid–people who can learn individually, both virtually and online, through information and communication technology.

2.2 Trans-Level

Individuals in the trans-level can build a mature schema to be stored in long-term memory. They possess a mental activity related to other actions, processes, objects, and schemas helpful in improving academic skills and solving problems. Hence, they become prepared to enter the super-smart society.

2.3 Semi-Trans-Level

Individuals in this level can construct action-object-process linkages to form a premature schema. In the formation of the premature schema, there is a possibility that someone will use the initial schema (retrieval of the previous schema).

2.4 Inter-Level

Individuals in the inter-level can construct action-process-object linkages with several related properties to form a premature schema. However, in the formation of the premature schema, it does not use the previously owned scheme (no retrieval of the previous schema).

2.5 Semi-Inter Level

Individuals in the semi-inter level can perform actions, processes, or objects; however, they only coordinate actions and processes in the same nature.

2.6 Intra-Level

Individuals in the intra-level can only perform an action, process, or object separately and cannot establish a relationship for that action, process, or object.

2.7 Pre-Intra-Level

At this level, individuals can only perform actions separately and cannot interiorize, so they remain unable to reach the process or object.

These levels are hierarchical and functional. Students have been able to understand certain mathematical concepts mapped to exactly one level. In certain conditions, they can take advantage of their ability to solve problems, think critically, think creatively in the domain of conceptual understanding to meta-cognition abilities. These students in the extended trans level are capable of inference level abstraction. Combining these two abilities can make it easier for humans to apply skills that can meet individual traits in industry 4.0 and twenty-first-century skills. Hence, they can be a member of super-smart society 5.0.

3 Super Smart People: Super Extended Trans of Thinking Levels

The ability to understand a concept or principle depends on cognitive processes. Everyone has an information processing system. Through this system, they can process the information they receive actively. Individuals can produce a body of knowledge according to their level of cognition. Information stored in long-term memory is in the form of codes, which are arranged in an active structural network [4]. The word "active" implies that the structure consists of data and processes [18]. The structural network includes several points which are connected by several relations. Each relation has a label and a direction. A relation connects two points depending on the label and the direction. The memory system uses this relation as a logical code linking the points.

The super-smart society framework requires a humanistic approach [19]—society 5.0. consists of super-smart individuals who play an important role in advancing and discovering technology in various fields. Those are the internet of things (IoT), artificial intelligence (AI), cyber-physical systems, virtual reality (VR), augmented reality (AR), big data, digital transformation (DT), etc. Gladden [20] explains that those in super-smart society are humans and robots (non-humans). If viewed qualitatively, they are different from each other. Some dynamics can be conceptualized that can shape the membership of society 5.0. Also, describing membership of a super-smart society is different from before (i.e., society 1.0 to society 4.0). However, the characteristics of candidate members of society 5.0 have analogies to those of previous societies because the social characteristics of past societies can explain the unpredictable nature of society 5.0.

The Japanese government has developed the society 5.0 program. This is a very prestigious policy. Super-smart society is designed to provide solutions and address all economic and social problems in Japan and the world. It takes advantage of Japan's technological advances and trading capabilities and provides a mature and futuristic-looking strategy. Japan has a strong determination and foundation to carry out a technological revolution. Super-smart society 5.0 is a great vision of the Japanese government, business people, and academics. They combine advanced technological systems in various fields for the benefit of humankind [21].

According to Alhefeiti [19], reaching society 5.0 is a new goal through technological perspectives and the necessary economic growth for many people. In the Japanese industry, various activities have started after disclosing the concept of society 5.0, especially in the academic field. This initiative will benefit from community 5.0, enabling it to tackle such community development challenges as technical problems and their effect on the economic status of a country.

To create a super-intelligent society, reliable human resources are needed. They are AI engineers knowledgeable about the latest technology, data scientists, cyber-security experts, and entrepreneurial-minded people [22]. This can help provide a clear vision of the impacts of community 5.0. The path to super-intelligent society stems from the role of technology in various fields such as the internet, AI, the physical system of the internet, AR and VR, and data mining [19].

Efforts to improve the appropriate learning environment are needed for super-smart people. It is intended to focus more and more on creative work in super-smart societies. The arrangement of the learning environment should start from pre-school to college programs. In preparing a super-smart society to anticipate changes and respond to them quickly, higher education must be reformed in various ways to ensure no mismatch exists between the human resources needed by the company and the human resources fostered by the university [22].

In facing super-smart society 5.0, the world of education must prepare students who are high in three abilities: problem-solving, critical thinking, and creativity [23]. Students must have high-level cognitive abilities. Their ability can be seen from their maturity and readiness to face a problem and solve it. This requires mature schemes that are stored in long-term memory. Students should make interconnections between these schemes into an integrated sequence. It is a cognitive process that combines recognizing, building, and constructing [24]. It is a process of abstraction. In mathematics learning, abstraction is a process for constructing mathematics vertically in a mathematical structure. It is the communal extraction of a set of examples and their corresponding categorization. The abstraction process is a mental activity to collect mathematical objects that prioritizes the similarity of characters and relationships between these objects. The result of abstraction is a set of all objects that can distinguish properties and observe different relationships. This abstraction process is a decontextualization process by ignoring the object and some of its characteristics and relationships. The abstract is seen as intrinsically different from the object in the cognitive approach, so it cannot be accessed directly.

Our research has found that students can reach the extended abstract level [25]. Such students can make several possible correct conclusions, interpret concrete facts, and design appropriate responses apart from the context. It is done using abstract principles. Students do it consistently so they can build new structures. Also, we found that students can establish interconnections between components of genetic decomposition: interiorization, encapsulation, and thematization activities in the memory system. Students can carry out abstraction, idealization, and generalization through actions, which are interiorized in the process, encapsulated through objects, and thematized into a schema in the body of knowledge. It is done by selecting a procedure, operating it in a system, and applying concepts and principles to problem-solving. Students can build mature schemas in these mental activities and solve mathematics problems and other problems. Also, they can construct new structures based on those mature schemas, make conjectures and prove them, and create new concepts and arrange them in an axiomatic deductive structure.

In facing a super-smart society, individuals get a new character in solving problems that is a super extended-trans character [18], with a variety of cognitive styles (field-dependent and field-independent) [26], predicative-functional cognitive structures [27], and the ability to literate big data and take advantage of AI. They are always connected to the IoT, VR and AR, and DT and handle everything with digital money (blockchain).

The cognitive model is a source for intelligent behavior of students in entering the super-smart society 5.0. It also has a role in forming cognitive structures [27]. Students' cognitive structure has a positive relationship with the ability to understand mathematical concepts [28]. Cognitive structures also positively affect mathematics solving abilities [29]. These results mean that cognitive models and cognitive structures make a positive contribution to improving twenty-first-century skills [18].

Twenty-first-century skills are challenging and must be developed: critical thinking, creativity, problem-solving, metacognition, motivation, collaboration, awareness, self-efficacy, fortitude, and persistence [30]. These skills can be achieved through learning. It should be considered in the curriculum, teaching standards, student assessment, professional development, and learning environment [31]. The implementation is that each subject incorporates twenty-first-century skills into the syllabus and lesson plans.

4 Local Culture for Mathematics Learning

Mathematics is a compulsory subject for high school students. It is a vehicle for developing logical thinking skills [32, 33]. It is an educator's effort to improve twenty-first-century skills. These abilities are critical and creative thinking, innovativeness, collaboration skills, problem-solving, and communication skills. That is the capital to become a member of the super-smart society 5.0.

Local culture is a builder of human character. Strengthening character through local culture can help develop thinking skills. Local culture is one vehicle for compiling mathematics teaching materials. It is a hands-on activity of students in learning mathematics [32, 34–45]. Culture-based mathematics began to develop rapidly. These are often called ethnomathematics [36]. Ethnomathematics is an effort to study aspects of mathematics in a certain society's culture. It is a school mathematics concept linked to students' everyday experiences and culture. Learning mathematics through an ethnomathematical approach can improve mathematical understanding skills. The ethnomathematics approach can develop students' academic potential, self-confidence, social skills, thinking intelligence, emotional control, and mathematical communication skills. Also, students can use their local culture to represent their knowledge, skills, and affections [37].

Mathematics learning must be based on cultural diversity. It should be applied in mathematics class. Ethnomathematics is culture-based mathematics. It must be integrated into mathematics class. Learning mathematics through an ethnomathematical approach provides a good provision for students' multicultural understanding of mathematics. It has been able to improve students' greater interest in understanding mathematics [38].

According to [39], mathematics is a valuable aspect of human understanding. Mathematics education plays a role in improving the understanding of mathematics for everyone. People in society create culture as a form of crystallization of their activities. It shows that people can teach through their culture. Therefore, ethnomathematics plays a role in mathematics education and helps change the paradigm of mathematics teaching.

Mathematics educators are expected to manage the complexities of society's culture in the teaching and learning process in the classroom. Therefore, the ethnomathematical approach becomes an important strategy in learning mathematics. Students are active in learning mathematics in a meaningful way by exploring aspects of mathematical literacy. Ethnomathematics is used as an appropriate alternative, based on an implicit philosophy of school mathematics practice [40]. Ethnomathematics is developing rapidly when it is associated with the mathematics teaching and learning process [41].

Grounded mathematics learning can be linked informally to context and culture. Learning through contextual media that is appropriate and in accordance with the needs can increase student creativity. It can also improve the ability to achieve mathematical concepts and principles. In this context, the learning approach can improve student learning mastery. Contextual learning media helps students construct assumptions through cognition patterns. That is for the process of achieving the concept. It is a trajectory of learning mathematics to formal mathematics through a process of vertical mathematization. Through culture-based learning, it was found that the majority (>82%) of junior high school students were able to rediscover mathematical concepts or principles. They have been able to apply critical and creative thinking skills. Students can write definitions of the concepts found (78%), and 86.5% of students classically have completed learning mathematics. The genetic decomposition of students experienced a good improvement until there were 14% of students who reached the extended-trans level. Also, they have been able to generate new mature schemas and store them in system memory. It is an achievement of good cognition of mathematical concepts and principles [42]. This is a form of achievement of twenty-first-century mathematics skills. Students have been able to solve problems and think critically and creatively.

Students who learn through the ethnomathematics approach excel in achievement and retention than those taught using conventional approaches. This shows a significant difference in the average academic achievement scores and knowledge retention between students taught by ethnomathematical and conventional approaches [36]. They recommend training mathematics teachers on implementing ethnomathematics in mathematics learning in schools. It aims to make learning meaningful, relevant, and interesting. Therefore, ethnomathematics has high benefits from a multicultural perspective. It is also useful in developing the school mathematics curriculum [44].

Teaching geometry in a socio-cultural context has developed the teaching competence of multicultural groups. It has helped students significantly improve their content and pedagogical content knowledge in geometry. They have been able to understand the importance of ethnomathematics learning activities related to student culture and other cultures [45].

Local culture-based learning can be used to generate mathematical arguments in the classroom. Local culture has been included in the mathematics syllabus. It can also create new mathematics terms in the local language as a mathematics textbook preparation and class activities [46]. Thus, ethnomathematics becomes the right vehicle for the mathematics learning approach. Teachers must start compiling syllabus, lesson plans, teaching materials, and learning media based on local culture. It is to help students achieve mathematical competence and twenty-first-century skills.

5 Levels of Thinking Super Extended Trans Through Local Cultures

Education experts state that many teachers still apply twentieth-century learning, even most schools are still managed like nineteenth-century school management. Even though today is the twenty-first century with a super-smart society [47], this is a challenge for science and mathematics educators to enlighten teachers. Incorporating twenty-first-century competencies in curriculum and education for every subject has become an important issue worldwide [48]. This means that the educational curriculum at every level must be designed to build holistic individuals and achieve twenty-first-century skills. Therefore, each level of education has a mission to create individuals who have the character of super-smart people. Students who fit are those who have a super extended trans thinking level.

To align education with culture is a necessity. It was an act aimed at strengthening character. We give examples of research results that have successfully utilized local culture to strengthen students' character in learning mathematics. During mathematics learning with an ethnomathematics approach, we found *Andun* dance to be the starting point for learning mathematics to achieve the concept of function. This is a horizontal mathematical process. *Andun* dance is a traditional dance originating from South Bengkulu, Indonesia. It is a social dance often performed in a series of weddings. The dance is a group dance performed by single men and women. It is a dance from the ancestors and is one of the most famous traditional dances in South Bengkulu [32]. Based on students' initial knowledge about the dance, in this study, students could use it as a starting point to simplify the concept of function from a very general definition to a more straightforward definition. Also, students used the *Andun* dance as a starting point for contextual learning that is the application of an ethnomathematical approach. Through horizontal mathematization, students could make a formal definition of the concept of a simplified function using ordered pairs of dancers. It is a concept image. They were very active in collaborating in the learning process. Finally, students could find the concept of function formally through vertical mathematization.

People manage the information they receive through a processing system. They receive information, process it, store it, and recall it for further processing. Ethnomathematics is a vehicle for learning that has improved students' cognitive processes reaching the super-extended level. Our other research found that low-level students have enhanced critical and creative thinking skills. They could reach the inter-level and coordinate two or more actions. This genetic decomposition allowed these students to understand mathematical concepts through ethnomathematical learning and higher-order thinking processes. Before studying through the ethnomathematical approach, these students were at a low level (i.e., intra or pre-intra level) [8]. Through an ethnomathematical approach, the ability to achieve and implement mathematical concepts was higher than students who learned through a direct learning approach [49]. Students' mathematical problem-solving skills have increased after participating in mathematics learning through ethnomathematical approaches and outdoor learning [50]. Therefore, if you have difficulty solving mathematics problems, one solution is outdoor learning with the ethnomathematics approach.

Mathematics in a cultural context is a long-term response to the constant exclusion of language, culture, and pedagogy. It has brought together parents, mathematicians, mathematics educators, education researchers, teachers, and school districts [51]. Ethnomathematics as mathematics is practiced among identifiable cultural groups. It is a form of mathematicians who are aware of mathematics and mathematics education's social and cultural aspects [52].

Mathematics plays an important role in human understanding. Mathematics education plays a role in improving the understanding of mathematics for everyone. We need to change the mindset and function of mathematics in society. The ethnomathematics concept has become a vehicle and approach to making these changes [39]. Mathematics education can be applied in schools through an ethnomathematics approach. Changing the ethnomathematics paradigm, scientists gather empirical data on the practice of mathematics from culturally differentiated groups, literate or not. The concept of ethnomathematics has been changed and enriched, which affects the paradigm in learning mathematics. Ethnomathematics becomes meaningful in every class because multicultural classroom arrangements can be implemented in various nations and are diverse regarding ethnicity, culture, language, social setting, gender, and so on [40].

The ethnomathematics approach has significantly improved students' cognitive level skills. Some students rise from the intra-level to reach the trans-level. Students who have a trans-level can thematically arrange various components of genetic decomposition, that is, APOS. Trans student schemes can be used as raw material to understand problems, develop problem-solving plans, solve problems according to plan, and define new problems. Such students can form a mature scheme [34] and reach the inter-level through a two-level upgrade. They are well on graph sketches of certain functions [53].

The implementation of mathematics learning through an ethnomathematical approach positively impacts mathematical representation abilities. This learning, combined with the inquiry learning model, can also improve students' mathematical connection and representation abilities. On the other hand, students who are taught using conventional learning have the mathematical representation ability better than those taught using the inquiry learning model without an ethnomathematics approach. It is shown that the ethnomathematical approach plays an important role in improving students' mathematical cognition abilities [54]. Thus, teaching mathematics through an ethnomathematical approach positively impacts students' mathematical representation abilities and other mathematical abilities.

In our country [55], students can learn non-Euclidean geometry, especially Lobachevsky's parallel axioms, with the starting point of real problems related to local culture. It is the culture of the people of Bengkulu and surrounding areas regarding fishing gear called *Bubu*. Students use the activity sheet to trigger their cognitive process of understanding and achieving the principle of the parallel line. The expected ignition is the Lobachevsky parallel line axiom. Students experience increased cognitive processes about Lobachevsky's geometry based on the local Bubu culture. It is a reflection of high-level ability. These students can construct parallel line features that they do not usually find in regular lessons [55].

Students using smartphones have their own culture. Mathematical thinking processes are connection and communication, representation, and solving mathematical problems [33]. Students can connect the graphic concept with the communication culture using cell phones. They analyze the definition of graph G and describe that G is a system that contains two sets, and the two sets are related to each other. They state that the first set is a non-empty set. The first set contains the dots. The second set contains the sides. Their definition will suffice if every edge in the second set is an unordered pair of points from the members of the first set. Therefore, the description became our inspiration to relate it to the students' use of cell phones. Each cell phone is associated with a dot. Meanwhile, the connection between mobile phones is analogous to the sides in the second set. If two mobile phones can be connected, it is represented by one side in G. If the phone has several cards, it can call itself. It forms a loop in G. Mathematical thinking makes us smarter, careful, and proficient in every problem-solving.

The thinking process of students is also improved by trying to provide answers to the challenge of constructing the concept of graph G based on the connection of several cellular phones [33]. The students formally formulated a graph definition based on these cognitive processes. Each phone is represented by a dot. Each connection between two sim cards is represented by one side; so also, if both sim cards are in the same phone, they are represented by a loop. This is the achievement of a graph concept.

The description above shows that, through local culture, students can achieve twenty-first-century skills. That is a big asset to enter and compete in the era of super-smart society 5.0. Such individuals have a strong character in achieving super-smart people. That is what will become a member of the super-smart society 5.0. Furthermore, local culture can be the basis for learning science and mathematics, such as students' mathematical thinking processes to understand vector concepts through an ethnomathematical learning approach and realistic mathematics education [56]. Researchers describe students' cognitive processes about infinite sequences through ethnomathematics in Bengkulu, Indonesia [8].

Thus, local culture-based learning can achieve the super extended-trans character. This is an effort to strengthen character education. Individuals can literate big data, take advantage of AI, always be connected to the IoT, create with VR and AR, as well as DT, and connect as a blockchain. It will all go to the super-smart society 5.0 [18].

6 Conclusion

In the era of super-smart society, it requires that community members have twenty-first century skills. The curriculum must harmonize local cultural conditions as the basis for education and competence in the twenty-first century. This is a vehicle for strengthening education to achieve super thinking skills and preparing individuals in the super-smart society 5.0. Super-smart people are individuals with super extended trans characteristics.

Core Messages

- Science education in the era of 2026 to 2050 realizes the super-smart society through local culture as a whole.
- The future of science learning is to combine student-centered learning, anywhere, anytime, and virtually and real.
- The ethnomathematics approach can improve life skills in the era of disruption and serve as a reliable problem solver.

References

1. Budden L (2007) Critical thinking skills. Developing effective analysis and argument 25(1–2)
2. Slavin RE (2014) Educational psychology theory and practice, 10th edn. United States of America: Pearson
3. Tall D (1975) A long-term learning schema, pp 1–16
4. Solso RL (1995) Cognitive psychology. Allyn and Bacon, Boston
5. Hunt RR, Ellis HC (2003) Fundamental of cognitive psychology, Sixth. McGraw-Hill College, Boston, p 2003
6. Dubinsky E, Mcdonald MA (2001) APOS : a constructivist theory of learning in undergraduate mathematics education. Kluwer Academic Publishers, Netherlands
7. Dubinsky E, Weller K, McDonald MA, Brown A (2000) Some historical issues and paradoxes regarding the concept of infinity: an APOS analysis, Part 2, 265 Northwoods Rd. Hermon, NY, p 13652

8. Widada W, Efendi S, Herawaty D, Nugroho KUZ (2020) The genetic decomposition of students about infinite series through the ethnomathematics of Bengkulu, Indonesia. In: IOP conference series journal of physics conference series 1470 012078 https://doi.org/10.1088/1742-6596/1470/1/012078 1470, pp 1–9
9. Widada W, Herawaty D (2017) Dekomposisi Genetik tentang Hambatan Mahasiswa dalam Menerapkan Sifat-sifat Turunan. J. Didakt. Mat 4(2):136–151
10. Dubinsky (2000) Using a theory of learning in college mathematics courses. MSOR Connect 1(2):10–15
11. Cooley L, Trigueros M, Baker B (2007) Schema thematization: a framework and an example. J Res Math Educ 38(4):370–392
12. Widada W (2017) Beberapa Dekomposisi Genetik Siswa dalam Memahami Matematika. J. Pendidik. Mat. Raflesia 1(1):44–54
13. Glaser BG, Strauss AL (2006) The discovery of grounded theory, strategies for qualitative research. Aldine transaction, New Brunswick
14. Piaget J, Garcia R (1989) Psychologies and the history of science. http://www.piaget.org/
15. Baker B, Cooley L, Trigueros M (2000) A calculus graphing schema. J Res Math Educ 31 (5):557–578
16. Widada W (2016) Profile of cognitive structure of students in understanding the concept of real analysis. J Math Educ 5(2):83–98
17. Widada W, Herawaty D (2018) The effects of the extended triad model and cognitive style on the abilities of mathematical representation and proving of theorem. Adv Soc Sci Educ Humanit Res 218, no ICoMSE 2017, 89–95
18. Widada W (2019) Realizing super smart people 5.0 through ethnomatematics. In: Seminar Nasional S-2 Pendidikan Dasar Universitas Bengkulu, 30 November 2019
19. Alhefeiti FSO (2018) Society 5.0 A human-centered society that balances economic advancement with the resolution of social problems by a system that highly integrates cyberspace and physical space. The British University in Dubai
20. Gladden ME (2019) Who will be the members of Society 5.0? Towards an anthropology of technologically posthumanized future societies Soc Sci 8(5)
21. Holroyd C (2020) Technological innovation and building a 'super smart' society: Japan's vision of society 5.0. J Asian Public Policy, p 17516234
22. Anonimous (2019) The development and securing of the human resources that will contribute to a super smart society. 1:158–179
23. Supendi A, Nurjanah (2019) Society 5.0 : Is it high-order thinking ? In: 2nd international conference on elementary education 2(1):1054–1059
24. Hershkowitz R, Schwarz BB, Dreyfus T (2001) Abstraction in context: epistemic actions. Dimuat dalam JRME. J Res Math Educ 32(2)
25. Widada W, Herawaty D, Jumri R, Wulandari H (2020) Students of the extended abstract in proving Lobachevsky's parallel lines theorem. In: IOP conference series journal of physics conference series 1470 012098 https://doi.org/10.1088/1742-6596/1470/1/012098 1470, pp 1–10
26. Witkin HA (1971) Manual embedded figures test, children's embedded figures test, group embedded figures test. Consulting Psychology Press Inc., California
27. Schwank I (2014) On predicative versus functional cognitive structures. Eur Res Math Educ I.II Gr. 5. http//www.fmd.uni-osnabrueck.de/ebooks/erme/cerme1-proceedings/cerme1-proceedings.html, vol 5, no April
28. Suharto S, Widada W (2019) The cognitive structure of students in understanding mathematical concepts. Adv Soc Sci Educ Humanit Res. vol 295, no ICETeP 2018, pp 65–69
29. Suharto S, Widada W (2019) The contribution of mathematical connection and mathematical communication to problem-solving ability. Int J Sci Res 8(1):155–159
30. Lamb S, Doecke E, Maire Q (2017) Key skills for the twenty first century: an evidence-based review. NSW Gov., p 70

31. AAMT (2009) School mathematics for the twenty first century some key influences. AAMT Inc, no May
32. Herawaty D, Widada W, Adhitya A, Sari RDW, Novianita L (2020) Students' ability to simplify the concept of function through realistic mathematics learning with the ethnomathematics approach. In: IOP conference series journal of physics conference series 1470 012031 https://doi.org/10.1088/1742-6596/1470/1/012031 vol 1470, pp 1–8
33. Widada W, Herawaty D, Andriyani DS, Marantika R, Yanti ID (2020) The thinking process of students in understanding the concept of graphs during ethnomathematics learning. In: IOP conference series journal of physics conference series 1470 012072 https://doi.org/10.1088/1742-6596/1470/1/012072 vol 1470, pp 1–8
34. Widada W, Herawaty D, Nugroho KUZ, Anggoro AFD (2019) The scheme characteristics for students at the level of trans in understanding mathematics during etno-mathematics learning. Adv Soc Sci Educ Humanit Res 253, no Aes 2018, pp 417–421
35. Widada W, Herawaty D, Ariska S, Afifah R, Anggoro AFD (2020) The characteristics of relational students in understanding the concepts of normal subgroups. In: IOP conference series journal of physics conference series 1470 012069 https://doi.org/10.1088/1742-6596/1470/1/012069 vol 1470, pp 1–9
36. D'Ambrosio U (2015) From mathematics education and society to mathematics education and a sustainable civilization. In: Proceedings of eighth international mathematics education and society conference vol 2, no June. Portland, Oregon, United States.
37. Rosa M, Orey DC (2011) Ethnomathematics: the cultural aspects of mathematics. Rev. Latinoam. Etnomatemática 4(2):32–54
38. Brandt A, Chernoff E (2015) The importance of ethnomathematics in the math class. Ohio J Sch Math 71(71):31–37
39. Barton B (1996) Making sense of ethnomathematics: ethnomathematics is making sense. Educ Stud Math 31:201–233
40. François K (2010) The role of ethnomathematics within mathematics education. In: Cent. Log. Philos. Sci. Free Univ. Brussels, no. December, pp 1517–1526
41. Orey DC, Rosa M (2004) Ethnomathematics: teaching and learning mathematics from a multicultural perspective. J Math Cult, vol 1, no May 2006, pp 139–148
42. Widada W (2015) Proses Pencapaian Konsep Matematika dengan Memanfaatkan Media Pembelajaran Kontekstual. J. Penelit. Pendidik. Mat. dan Sains 22(1):31–44
43. Achor EE, Imoko BI, Uloko ES (2009) Effect of ethnomathematics teaching approach on senior secondary students' achievement and retention in locus. Educ Res 4(8):385–390
44. Balamurugan M (2015) Etnomathematics: an approach for learning mathematics from multicultural perspective. Int J Mod Res Rev vol 3, no 6, pp 716–720
45. Massarwe K, Verner I, Bshouty D (2012) Ethnomathematics and multicultural education: analysis and construction of geometric ornaments. J Math Cult vol 4, no January 2014, pp 344–360
46. Palhares P, Shirley L (2015) The role of ethnomathematics in mathematics education. In: The proceedings of the 12th international congress on mathematical education, pp 575–578
47. OECD (2019) OECD future of education and skills 2030: project background, p 15
48. Wang Y, Lavonen J, Tirri K (2018) Aims for learning 21st century competencies in national primary science curricula in China and Finland. Eurasia J Math Sci Technol Educ 14 (6):2081–2095
49. Herawaty D, Widada W, Nugroho KUZ, Anggoro AFD (2019) The improvement of the understanding of mathematical concepts through the implementation of realistic mathematics learning and ethnomathematics. Adv Soc Sci Educ Humanit Res vol 295, no ICETeP 2018, pp 21–25
50. Widada W, Herawaty D, Anggoro AFD, Yudha A, Hayati MK (2019) Ethnomathematics and outdoor learning to improve problem-solving ability. Adv Soc Sci Educ Humanit Res vol 295, no ICETeP 2018, pp 13–16

51. Lipka J, Andrew-irhke D (2019) Ethnomathematics applied to classrooms in Alaska : math in a cultural context. J Math Cult no Mcc, pp 2–4
52. Gerdes P (1994) Reflections on ethnomathematics. Learn Math 14(2):19–22
53. Widada W, Herawaty D, Nugroho KUZ, Anggoro AFD (2019) The ability to understanding of the concept of derivative functions for inter-level students during ethnomathematics learning. J Phys Conf Ser 1179(012056):1–6
54. Widada W, Herawaty D, Jumri R, Zulfadli Z, Damara BEP (2019) The influence of the inquiry learning model and the Bengkulu ethnomathematics toward the ability of mathematical representation. J Phys Conf Ser 1318(012085):1–6
55. Herawaty D, Khrisnawati D, Widada V, Mundana P (2020) The cognitive process of students in understanding the parallels axiom through ethnomathematics learning. In: IOP conference series journal of physics conference series 1470 012077 https://doi.org/10.1088/1742-6596/1470/1/012077. vol 1470, pp 1–8
56. Widada W, Herawaty D, Beka Y, Sari RM, Riyani R (2020) The mathematization process of students to understand the concept of vectors through learning realistic mathematics and ethnomathematics. In: IOP conference series journal of physics conference series 1470 012071 https://doi.org/10.1088/1742-6596/1470/1/012071. vol 1470, pp 1–10

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Integrated Science Curriculum in the Unpredictable World

11

Abdurrahman Abdurrahman

> *Equipped with his five senses, human explores the universe around them and calls the adventure Science.*
>
> *Edwin Powell Hubble*

Summary

Nowadays, an integrated science curriculum is necessary not merely for the young generation to master the scientific content for advanced knowledge and technology but also to reach more extension capabilities. The science curriculum and learning contributed to the movement of human life from the hard skills to the soft skills continuum. Good character building, caring, creativity, criticality, responsibility, collaboration and communication, innovation, motivation, self-confidence, and even endurance have become learning outcomes of science learning in the twenty-first century. The primary mission of the integrated science curriculum has been able to direct humans to carry out the purpose of a wiser life and oriented to aspects of a more prosperous life. Indonesia, a country with all its unique potential, has become a "pilot project" to implement an integrated science curriculum throughout its development history. The science education curriculum reform in Indonesia succeeded in moving the young generation to align themselves with their peers worldwide in mastering scientific literacy, technology, engineering, art, and mathematics. Besides, it has grown its resilience in the face of the threat of natural and non-natural disasters that sometimes its appearance is unpredictable.

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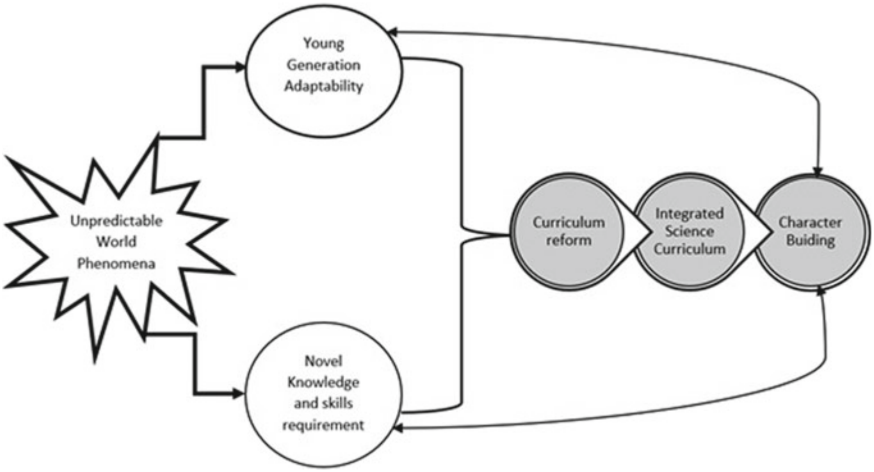
N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_11

Graphical Abstract/Art Performance



Unpredictable world.

Keywords

Character building · Curriculum reform · Integrated Science · Literacy · Unpredictable phenomena

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

Recently, integrated science has become a trending issue in dealing with increasingly complex human daily problems. Almost three decades since the emergence of global awareness about the importance of young people having analytical and practical power to solve complex problems, an integrated science curriculum has become a logical choice for the worldwide education community [1–3]. The integrated curriculum has to accommodate the curious young mind not to distinguish between subject matter areas when it tries to find out about the environment and contribute to solving the problems it faces. Generally, the issues faced are interdisciplinary. The concept of integrated science that emphasizes science as a whole, bringing together a mosaic of separate parts of separate sciences, will be a powerful weapon for solving these problems [4, 5].

Besides, scientific literacy has a long history contribution in many roles of science education discipline for everyday life activities [6, 7]. Therefore, science education allows students to understand global challenges and participate in activities to solve daily life problems. It has progressed continuously in an integrated learning approach that connected science with various fields of study and its application. Since 1960, the science curriculum reform emerged in response to the concern of nature of science (NOS) has been an aspiration to develop a rapidly and broadly integrated science curriculum with the primary goal of building scientific literacy [8–10].

Furthermore, the framework for developing the science curriculum was designed to bring the younger generation closer to technology products, so the learning approach with the theme of integration of science and technology began to be popularized massively in the early 1990s [11, 12]. Along with that, the need for expanding the impact of all levels of society on science programs with the aim of all citizens to have scientific literacy is evenly distributed [13, 14], followed by the desire to make learning science to build a model of state awareness and become citizens with good character in the context of science for civilization [15, 16].

On the other hand, integrated science education reform continues to develop towards efforts to improve the environment, which is increasingly experiencing a decline in levels that impact the quality of human life. The integrated science learning approach leads to movements around social-scientific Issues (SSI) [17–19]:

- science education for sustainability, including issues of climate change and global warming [20–22];
- science, technology, society, and environment (STSE) [23, 24] and other sociocultural perspectives for science education [25]; and
- building power resilient to natural and non-natural disasters through the integration of science in the context of disaster awareness and disaster literacy [26–28].

For further development, integrated science began to be directed towards preparing the young generation with several abilities to anticipate the challenges of twenty-first century progress in the context of industrial revolution 4.0 and society 5.0. A part of this preparation was the information and communication technology (ICT) progress that rapidly shaped humans' way of thinking to have many abilities to build wisdom digital literacy for longer than three decades, especially in teaching and learning science. Therefore, the presence of this educational technology by promising wider access at all school levels has demonstrated the potential for a crucial role in designing integrated science curriculum reforms. In particular, ICT has facilitated the younger generation to conduct experiments inside and outside the classroom by various access to internet resources and other digital technology tools that support mobile learning to achieve a learning outcome and promote their nation's welfare [29–32].

The challenges of twenty-first century progress in the context of industrial revolution 4.0 and society 5.0 have given rise to the science, technology, engineering, and mathematics (STEM) learning approach, which is currently a trend in science learning issues worldwide [1, 33, 34]. The STEM education approach has led science education to move beyond the interdisciplinary and even multidisciplinary contexts that lead to science without borders. Over the past several decades, several studies have emerged in which science has crossed the boundaries across scientific and cultural disciplines [35–38]. Even when the COVID-19 pandemic swept the world today, integrated science and beyond became one of the tools of knowledge that can reduce the impact of the risk of virus infection. Besides, the phenomenon inspired new cultures that are smarter and wiser for future generations in interacting with the universe for a more dignified human life [3, 39, 40].

The main objective of this chapter is to describe how an integrated science curriculum is developed and how it has contributed to the lives of the world community. Indonesia, a country with various uniqueness, is an integral part of science curriculum progress. The integrated science curriculum in Indonesia is an exciting part of the discussion related to the application in which Indonesian geographical location is prone to experiencing natural disasters, also inseparable from the threat of other unpredictable events such as novel coronavirus disease (COVID-19).

2 Brief History of Some Efforts for the Development of Integrated Science Across the Globe

Interested in the teaching and learning innovation of integrated science has promoted rapidly aligning with science and technology advances. It also became an international movement of scientists and science education experts who were also greeted with enthusiasm by professional teacher education organizations throughout the world starting in the early 1960s. A science process approach is the first and largest project the American Association for the Advancement of Science (AAAS) launched in 1963 [41]. In addition, UNESCO has crucially contributed to popularizing integrated science and its implementation worldwide. Since the first international symposium in 1967 organized by UNESCO, integrated science has continued to develop in various countries. In 1968, UNESCO handled an international conference on integrated science education in Droujba, Bulgaria, in association with the Committee on the Teaching of Science (CTS) and the International Council of Scientific Unions (ICSU). This conference has produced 15 conclusions and recommendations in the form of guidelines and several ideas in developing integrated science education [42]. These ideas and instructions have led almost all countries to carry out many innovations and develop integrated science education approaches.

Furthermore, in 1973, the Federation for Unified Science Education (FUSE) in the United States held a conference on *New Trends in Teacher Education for Integrated Sciences* sponsored by the International Council of Scientific Unions (ICSU), which took place in the University of Maryland, College Park. This conference has produced many innovations with regards to teacher training and found various alternative solutions to the problem of education around integrated science [43]. In the same year, two symposia occurred at the Christian Albrechts University in Kiel, West Germany, sponsored by the Institute of Pedagogic fur der Naturwissenschaften. The support of these organizations develops continuously in the form of integrated science education standards aimed at satisfying modern education and respective needs in all parts of the world [44].

In 1975, another international symposium was held in Oxford, England, especially discussing integrated science education and its assessment and evaluation, followed by an international conference with the theme "Integrated Science Education Worldwide Collaboration" between ICASE (the International Confederation of Associations for Science Education) and NVON (the Dutch Science Teachers Association) in Nijmegen, the Netherlands in 1978, with several recommendations for developing integrated science education in a broader context of life [41]. Until the early 90s, integrated science curriculum studies focused on mastering content, forming scientific attitudes, and science process skills and contexts with the theme of unification from physics, chemistry, biology, earth sciences, and astronomy [2].

In the context of a 20-year evaluation of the journey of the integrated science curriculum that began massively since the recommendations of the 1968 Droujba Conference, the concept and implementation of the integrated curriculum were successfully developed and produced progressively. Mid-1989, the focus of development on environmental aspects and a higher concentration on meeting the needs of professional work in developing countries had become the main highlight of the implementation of this integrated curriculum. Furthermore, at this time, the role of mathematical modeling has begun to be discussed to enrich and solve problems in many contextual integrated science themes, including ecological issues that were starting to become a trending issue at that time [2, 45].

The integrated science curriculum has received a lot of support from various parties. The support addressed not only has provided meaningful learning experiences for increasing knowledge and conceptual understanding but also the skills to carry out scientific processes and products that are very useful in daily life due to high-level thinking exercises [1, 46]. The core basis for the massive application of integrated science curriculum throughout the global order is to reduce the narrow perspective of students about the nature of the universe. A single knowledge cannot adequately explain the universe's phenomena. Cross-disciplinary knowledge will provide more accurate solutions, a more comprehensive understanding, and a more efficient presentation in the learning process [4, 40].

The development of integrated science is directed towards simply learning about science in a narrow sense and emphasizes building experience in solving complex problems. This effort involved elements of the scientific field on an ongoing basis with increasingly sophisticated scientific concepts and products in the context of scientific literacy (SL). Students must be trained to become lifelong learners so that they are no longer just memorizing a set of facts to pass exams, but they must be able to process and understand large amounts of data and solve complex problems at the time. Therefore, for almost 30 years since the integrated science curriculum was introduced to global society, all the literature defining SL emphasizes understanding the NOS and scientific knowledge [47–50].

Besides, they must know which information is relevant and reliable and which facts are alternatives. Thus, integrated science can encourage them to become creative thinkers who make innovations in support of open-access knowledge presented in the major themes of natural phenomena in everyday life in the context of the NOS [4, 40, 51]. As reported by Roberts [7], the beginning of the ideas of developing integrated science at all levels of education, the vision of integrated science continues to be extended to SL into a broader context. For example, Roth and Barton [52] present a new perspective about the collective view of SL in a community perspective where individuals propose original contributions and perspectives to shoulder socioscientific issues. Many studies have addressed how the concept and implementation of science education are effective. The framework of the issue of socio-sciences is developing rapidly with the orientation not only crucial for acquiring new science knowledge but also helpful in building a character [19]. Furthermore, the discourse of socio-science not only represents the mode of understanding and skills of students but also guides in solving problems related to socioscientific issues problems [53].

To evaluate the extent to which programs and policies implementing integrated science curricula support young generations' achievement of scientific literacy, in 1997, the Organization for Economic Cooperation and Development (OECD) developed an international science literacy assessment program, which is also referred to as the Program for International Student Assessment (PISA). The main focus of the assessment is to measure the performance of 15 years old citizen acquisition in reading, mathematical, and scientific literacy [54]. Previously, in early 1996, the International Association for the Evaluation of Educational Achievement (IEA) launched the Third International Mathematics and Science Study (TIMSS) program, which focused on conducting assessments to measure the mathematical and scientific abilities of teenagers throughout the whole world [55]. PISA and TIMMS are still available as a reference for successfully implementing integrated science curricula in all countries globally that actively include the young generation in the international survey [56–58].

3 The Highlight of the Integrated Science Curriculum Reform in Indonesia

Since 1945, the Indonesian national curriculum has undergone several changes that are generally attributed to the year it was issued, namely:

- 1975 Curriculum;
- 1986 curriculum;
- 1994 curriculum;
- 2004 curriculum or competency-based curriculum;
- 2016 curriculum based on education units that refer to National Education Standards; and
- 2013 curriculum or national curriculum [59–61].

Figure 1 shows the chronology of curriculum development in Indonesia. More detailed curriculum elaboration, contained in the policies and standards of the integrated Indonesian science curriculum. The curriculum refers to the Science Education Standards issued by the National Science Education Standards starting from the 1975 curriculum to the 1994 curriculum with the orientation [59, 60]. Furthermore, in this phase, the science curriculum's reform is marked by hands-on activities based on learning activities both at primary and secondary levels of education [62]. Practical activities that developed in the study of science in Indonesia became excellent as scientific curriculum reforms in almost all developing countries, especially in the Southeast Asia region [63, 64]. In the next period,

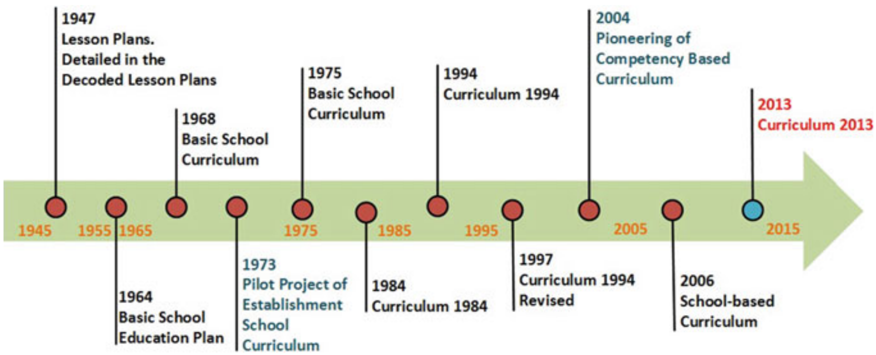


Fig. 1 Diagram representation of Indonesia curriculum reform map

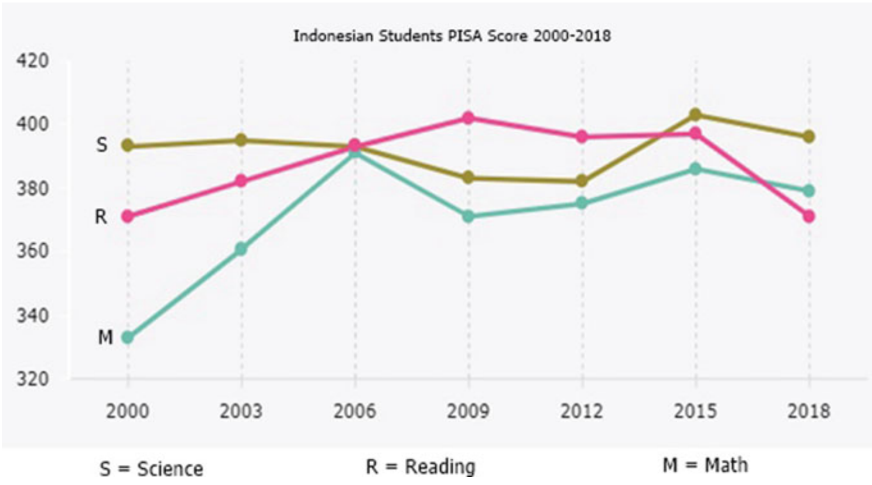


Fig. 2 Indonesian students PISA score 2000–2018

the 2004 and 2006 curriculum, the reform of the science curriculum in Indonesia relies on the development of science process skills with the general theme Cara Belajar Siswa Aktif (CBSA), which is student-centered innovative science with an active learning approach in the context of science education standard [65, 66]. One of the main supporting programs of this period is the emergence of the science quality improvement project (SEQIP). The project is a cooperation program between the Indonesian and German governments, aiming to improve the quality of integrated science education at the elementary education level [67, 68]. This project has been able to encourage the young generation of Indonesia to be more motivated and interested in learning science and significantly boost Indonesian students' achievements in the international literacy survey, such as the PISA score, as shown in Fig. 2.

4 Integrated Science Curriculum for Unpredictable Situations: Disaster Education in Indonesia

Indonesia is a country that has a high level of natural disaster vulnerability. Most of Indonesia's territory often occurs in earthquakes, floods, landslides, volcanic eruptions, and tsunamis. These hazards happened due to the geographical location of the Indonesian territory, which spreads at the confluence of four tectonic plates consisting of the Asian, Australian, Indian Ocean, and Pacific Ocean plates. In addition, the volcanic belt stretches in almost all parts of southern and eastern Indonesia. Even the volcanic belt extends from the islands of Sulawesi-Nusa Tenggara-Java to Sumatra by inheriting ancient volcanic mountains and swamps that meet some of the lowlands of Indonesia [69].

Various studies show that Indonesia is a country with a high level of seismicity globally, more than ten times the level of seismicity in other countries around the globe [70–72]. The activity of the earthquake in Indonesia is very high in a month. It is recorded 400 times on average. During the 1991–2007 period, there were 24 major earthquakes, including December 26, 2004, Aceh earthquake of magnitude 9.3 that caused a devastating tsunami [73].

Since the earthquake and tsunami in Aceh in 2004, the integrated science education curriculum in Indonesia, particularly at the level of primary education, includes disaster literacy as an aspect of curriculum development in science classes by bringing the latest issues into the integrative thematic context. In the 2006 and 2013 curriculums, science education at the level of primary education level contained several essential themes such as "I and my environment," "events around me," "the area where I live," and "my earth." The themes can be integrated into formulating learning objectives related to increasing disaster literacy among young Indonesian generations [74, 75]. Along with this science curriculum reform oriented towards disaster literacy, the government of Indonesia, notably the Ministry of Education and Culture, has collaborated with the German government by developing a flagship Disaster Awareness in Primary School (DAPS) program, which began as a pilot project in 2006 [76, 77]. This program has succeeded in providing a curriculum integration model that prepares students to have an outstanding amount of knowledge, attitudes, and mitigation skills. The scientific inquiry-based learning approach applied to integrative themes shows the extraordinary power of students when they actively participate in learning and practice disaster mitigation [78].

Furthermore, Abdurrahman et al. [79] have developed a disaster mitigation cycle model that involves three institutional levels: school, community, and government in the learning community context. The model is called the Learning Community Cycle Model for Disaster Awareness (LC2MDA), shown in Fig. 3. This model has succeeded in building public awareness of the importance of synergizing in the mitigation skills improvement program and the preparedness of young people in facing the threat of natural disasters in their environment. The LC2MDA model has been applied intensively in science classrooms at the elementary school level with a thematic-integrative approach using EXCLUSIVE learning models. The learning model consists of exploring, clustering, simulating, valuing, and evaluating, where students actively participate in learning, as shown in Fig. 4.

Through thematic-integrative EXCLUSIVE learning models, students are actively involved in meaningful learning, given direct experience through observation and simulation, and using their intuition in internalizing the value or meaning of disaster. They explore freely through varied learning experiences, arguing based on solving contextual problems such as making evacuation maps. Through structured training, discussion, collaboration, and multidirectional communication, students get good knowledge, positive attitudes, and mitigation skills; students will naturally have sufficient awareness and literacy to be resilient to natural and non-natural disasters.

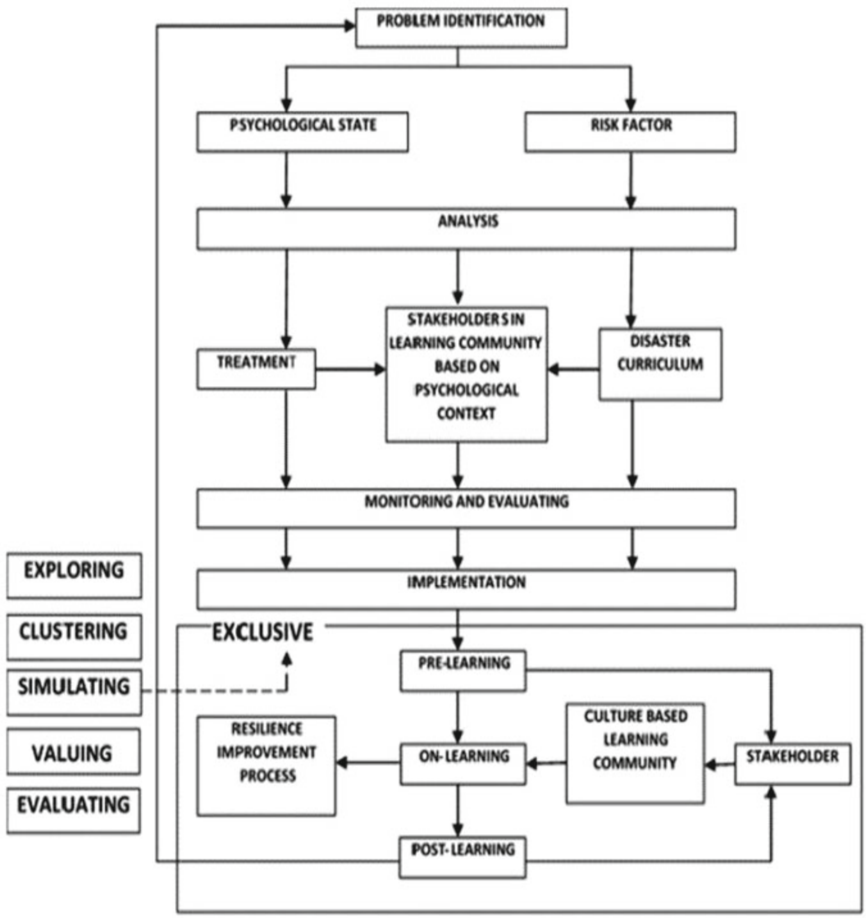


Fig. 3 LC2MDA model for disaster education (reproduced from [79] © Abdurrahman Abdurrahman under the terms of Creative Commons Attribution 4.0 International License)

5 Integrated Science Curriculum for Sustainability in Indonesia

Furthermore, at the junior and senior high school level in Indonesia, climate change is one of the essential concept contents that is the subject of an integrated science curriculum related to aspects of disaster and energy literacy in the context of sustainability. The curriculum content emphasizes learning outcomes related to global warming and its impact on all aspects of human life. In addition, learning achievements on this topic in the 2013 curriculum stresses the formation of students' character and attitudes in utilizing green technologies and cultures that are expected to help in reducing the risk of climate change impacts [80, 81].

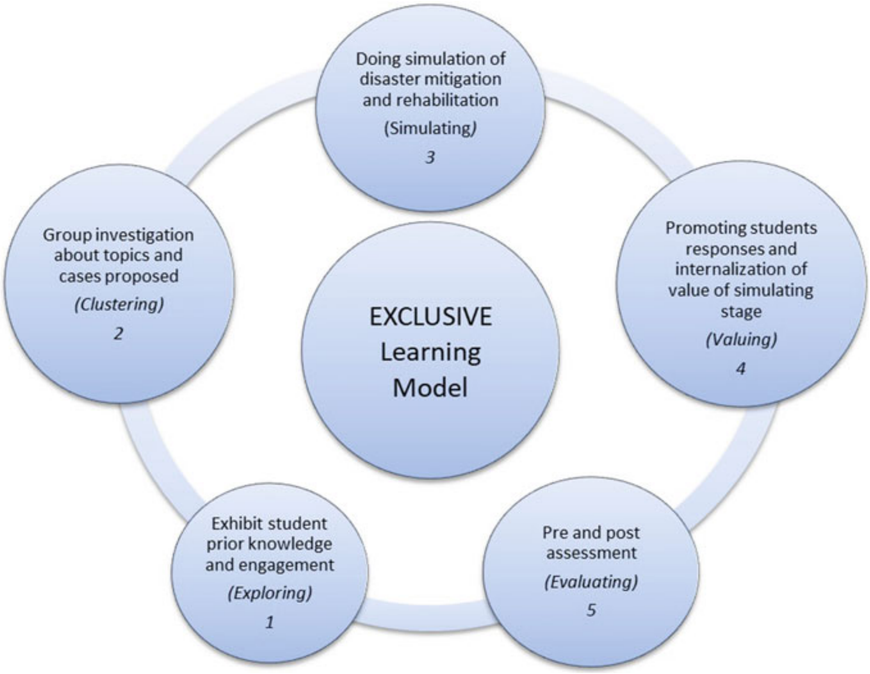


Fig. 4 Activity stages of the EXCLUSIVE learning model (reproduced from [79] © Abdurrahman Abdurrahman under the terms of Creative Commons Attribution 4.0 International License)

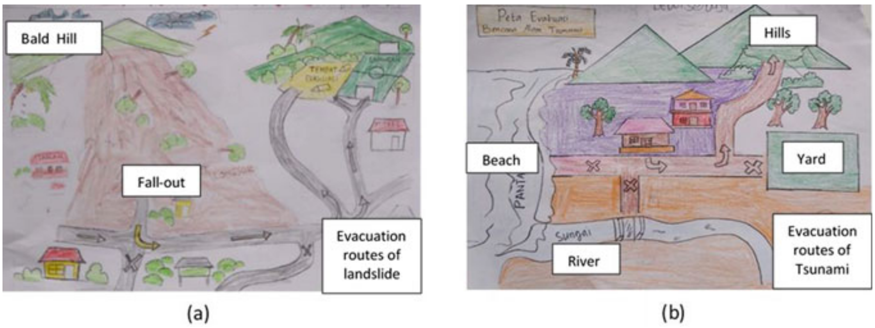


Fig. 5 Five grade students' visual representations of evacuation map: **a** landslide; and **b** tsunami

Strengthening climate change literacy packaged in the 2013 curriculum is presented through daily classroom activities and integrated into extracurricular activities such as young scientist groups, scouting, voluntary corps, cross red youth, and students' mountaineering club.

Rahman et al. [82] proposed a model of implementation of school-based management for schools with green character by involving the community (parents of students) as the controlling element. This model emphasizes the role of the academic leadership of principals and teachers in integrating the topic of global warming in the integrated science curriculum to foster awareness and knowledge of young people in schools so that they have a caring attitude towards universe sustainability. Schematically, the hypothetical model of school-based management for green schools as an effort to integrate school-based sustainability issues can be seen in Fig. 6.

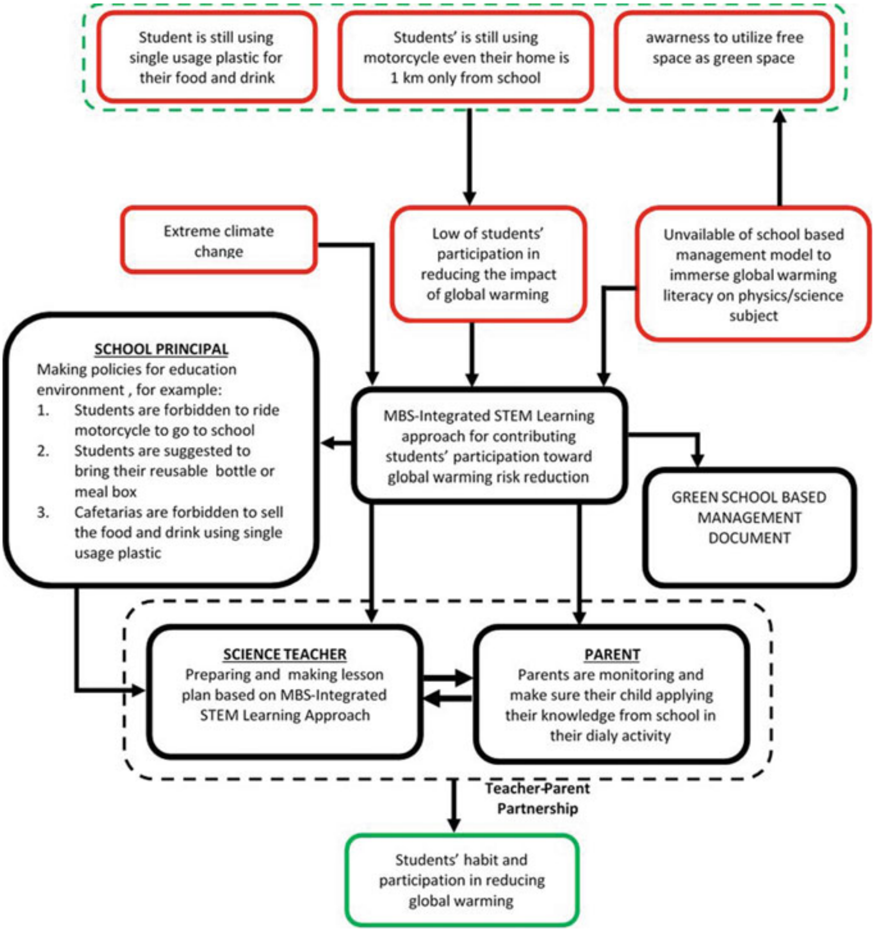


Fig. 6 Green school-based management hypothetical model (reproduced from [82] © Abdurrahman Abdurrahman under the terms of the Creative Commons Attribution 3.0 Licence)

(a) (b)

Fig. 7 Student sustainability project: **a** campaign poster in social media; and **b** scraps green generator prototype

The implementation of the green school model directed students to act daily behavior by orienting the formation of green school characters that can mitigate the climate change impact. During the implementation of the model, many new positive habits emerged gradually. Students go to school on a bicycle or foot, not using plastic accessories, using tumblers for drinks, minimizing electricity and alternating current (AC) usage in schools, unplugging gadgets and laptop chargers when finished filling, wrapping food with paper or leaves, etc. In the classroom, teachers scaffolded and encouraged them to campaign for environment protection and climate change impact mitigation through social media through project assignments such as making posters and creating a water power generator prototype from scraps (Fig. 7).

6 Science Education in the COVID-19 Pandemic: Indonesian Context

The presence of the COVID-19 pandemic not only caused a tremendous panic in the health sector but also had a shocking effect on the education process around the world, where the majority of schools and classes experienced disruption [83, 84]. This condition makes distance learning or online learning a major alternative so that the learning process does not experience disruption. The closure of classes or schools, especially in Indonesia, was previously not the choice of students at the primary and secondary levels due to human resource factors and the availability of an online learning infrastructure that has not been evenly distributed throughout Indonesia. Yet, distance learning has been a new problem for teachers and instructors [85].

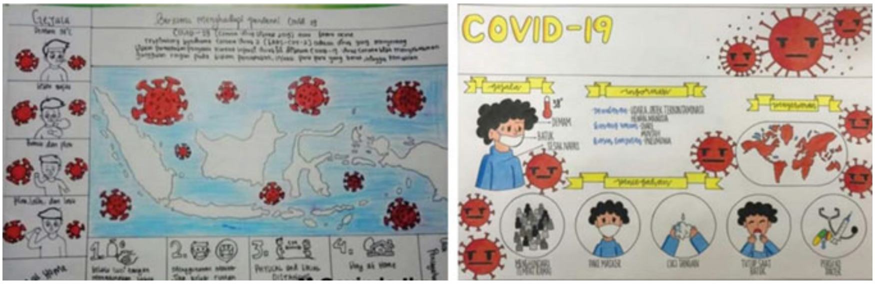


Fig. 8 Students generate visual representations about coronavirus outbreak context

Ichsan et al. [86] and Wargadinata [87] reported that online learning is dominated by various social media such as Whatsapp and Instagram to deliver material or teaching material, and only a few use the learning management system platform. Besides that, the most frequently taught teaching material is in the form of PDF and Video formats provided through Whatsapp. Furthermore, Ichsan et al. [86] also revealed that student responses showed that nearly 35% of students stated online learning was felt to be less effective because of frequent obstacles in the internet network and difficulties in sending assignments or the results of exam answers given by teachers.

On the other hand, especially in science learning, learning at home with various assignments given by the teacher makes students more creative. The free time of accessing material presented by the teacher through an asynchronous online learning platform allows students to do a number of creative thinking processes, especially in exploring the concept of viruses and how to deal with coronavirus outbreaks. The results of observations and interviews with science teachers showed that multimodal representations-based learning was widely applied by science teachers online learning during coronavirus pandemic, especially many students who degenerated visual representations in the form of comics and posters (Fig. 8). This integrated COVID-19 pandemic science learning has been able to trigger the motivation and creativity of the young Indonesian generation in increasing scientific literacy, especially on non-natural disasters such as coronavirus outbreaks. The student can express their literacy of COVID-19 discourses such as social distancing, always using a mask, hand washing, and other preventive behavior through generate-own visual representations.

7 Conclusion

The integrated science curriculum has provided unlimited color in human life for almost four decades. An integrated science curriculum has contributed to the development of science and technology and attitudes and behaviors that are getting better and wiser in managing the universe. The character becomes a guide for integrated science curriculum reforms. Nowadays, humans are faced with the same problems, such as uncontrolled movements, with the use of artificial intelligence (AI). The big challenge is increasing the opportunity for humans will be replaced by AI machines.

In addition, the presence of unpredicted disasters such as COVID-19) also presents a challenge for how an integrated science curriculum is developed and implemented. Massive Open Online Courses (MOOCs) are effective in preparing science learning effectively where classes and schools are disrupted due to epidemics or natural disasters. Moocs-based science learning that reduces human mobility using fossil-fueled vehicles can also be a tool for efforts to maintain the balance of the human environment to continue the balance of the universe in the future. The chapter also highlighted several successful works of science education in solving our daily lives' problems along with some essential aspects that need to be considered in the further development of science education without borders, especially in Indonesia.

Core Messages

- Science curriculum reform must be oriented towards efforts to improve human relations with the universe.
- The major purpose of science education should be to inspire young people to build scientific literacy.
- Learning science should increase the power of creativity and new creations for the benefit of human life sustainability.

References

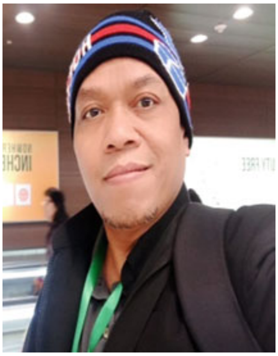
1. Drake S, Reid J (2018) Integrated curriculum as an effective way to teach 21st century capabilities. Asia Pacific J Educ Res 1(1):31–50. https://doi.org/10.30777/apjer.2018.1.1.03
2. Hewitt PG, Lyons S, Suchocki J, Yeh J (2013) Conceptual integrated science. Pearson
3. Moradian N, Ochs HD, Sedikies C, Hamblin MR, Camargo CA, Martinez JA et al (2020) The urgent need for integrated science to fight COVID-19 pandemic and beyond. J Transl Med 18 (1):1–7
4. Harrell PE (2010) Teaching an integrated science curriculum: linking teacher knowledge and teaching assignments. Issues Teac Educ 19(1):145–165
5. Mihaela Drăghicescu L, Gorghiu G, Monica Gorghiu L, Petrescu A-m (2013) Pleading for an integrated curriculum. J Sci Arts Year 13(1):89–95
6. Roberts DA, Bybee RW (2014) Scientific literacy, science literacy, and science education. In: Handbook research on science education, Vol II. Routledge, pp 559–572
7. Roberts DA (2007) Scientific literacy/science literacy. In: Abell ISK, Lederman NG (eds) Handbook of research on science education. Lawrence Erlbaum, Mahwah, NJ, pp 729–780
8. Abd-El-Khalick F (2001) Embedding nature of science instruction in preservice elementary science courses: abandoning scientism. But J Sci Teach Educ 12(3):215–233

9. Klein PD (2006) The challenges of scientific literacy: from the viewpoint of second-generation cognitive science. Int J Sci Educ 28(2–3):143–178
10. McComas WF, Olson JK (1998) The nature of science in international science education standards documents. Springer, pp 41–52
11. Aikenhead GS (1996) Science education: border crossing into the subculture of science. Stud Sci Educ 27(1):1–52. https://doi.org/10.1080/03057269608560077
12. Aikenhead GS, Jegede OJ (1999) Cross-cultural science education: a cognitive explanation of a cultural phenomenon. J Res Sci Teach 36(3):269–287
13. Jidesjö A, Oscarsson M, Karlsson K-G, Strömdahl H (2009) Science for all or science for some: what Swedish students want to learn about in secondary science and technology and their opinions on science lessons. Nordic Stud Sci Educ 5(2):213–229
14. Lee O, Miller EC, Januszyk R (2014) Next generation science standards: all standards, all students. J Sci Teach Educ 25(2):223–233
15. Davies I (2004) Science and citizenship education. Int J Sci Educ 26(14):1751–1763
16. Kolstø SD (2008) Science education for democratic citizenship through the use of the history of science. Sci Educ 17(8–9):977–997
17. Chowdhury MA (2016) The integration of science-technology-society/science-technology-society-environment and socio-scientific-issues for effective science education and science teaching. Electron J Sci Educ 20(5):19–38
18. Sadler TD, Zeidler DL (2009) Scientific literacy, PISA, and socioscientific discourse: assessment for progressive aims of science education. J Res Sci Teach 46(8):909–921. https://doi.org/10.1002/tea.20327
19. Zeidler DL, Sadler TD (2008) Social and ethical issues in science education: a prelude to action. Sci Educ 17(8–9):799–803
20. Sharma A (2012) Global climate change: what has science education got to do with it? Sci Educ 21(1):33–53
21. Bodzin AM, Fu Q (2014) The effectiveness of the geospatial curriculum approach on urban middle-level students' climate change understandings. J Sci Educ Technol 23(4):575–590
22. Zidny R, Sjöström J, Eilks I (2020) A multi-perspective reflection on how indigenous knowledge and related ideas can improve science education for sustainability. Sci Educ 29(1): 145–185
23. Gresch H, Hasselhorn M, Bögeholz S (2017) Enhancing decision-making in STSE education by inducing reflection and self-regulated learning. Res Sci Educ 47(1):95–118
24. Autieri SM, Amirshokoohi A, Kazempour M (2016) The science-technology-society framework for achieving scientific literacy: an overview of the existing literature. Eur J Sci Math Educ 4(1):75–89
25. Zeidler DL (2016) STEM education: a deficit framework for the twenty first century? A sociocultural socioscientific response. Cult Sci Edu 11(1):11–26
26. Oyao SG, Holbrook J, Rannikmäe M, Pagunsan MM (2015) A competence-based science learning framework illustrated through the study of natural hazards and disaster risk reduction. Int J Sci Educ 37(14):2237–2263
27. Mustadi A, Atmojo SE (2020) Student's disaster literation in 'SETS'(science environment technology and society) disaster learning. İlköğretim Online 19(2):667–678
28. Rush JV (2018) The impact of natural disasters on education in Indonesia. Econ Dis Clim Change 2(2):137–158. https://doi.org/10.1007/s41885-017-0022-1
29. Unesco (2008) ICT competence standard for teacher
30. Skryabin M, Zhang J, Liu L, Zhang D (2015) How the ICT development level and usage influence student achievement in reading, mathematics, and science. Comput Educ 85:49–58
31. Development OfEC-oa (2004) Completing the foundation for lifelong learning: an OECD survey of upper secondary schools. OECD Paris
32. Çepni S, Taş E, Köse S (2006) The effects of computer-assisted material on students' cognitive levels, misconceptions and attitudes towards science. Comput Educ 46(2):192–205

33. Takeuchi MA, Sengupta P, Shanahan M-C, Adams JD, Hachem M (2020) Transdisciplinarity in STEM education: a critical review. Stud Sci Educ 00(00):1–41. https://doi.org/10.1080/03057267.2020.1755802
34. Bybee RW (2013) The case for STEM education: Challenges and opportunities. NSTA press
35. McManus C, Nobre CA (2017) Brazilian Scientific Mobility Program-Science without Borders-Preliminary Results and Perspectives. An Acad Bras Ciênc 89(1):773–786
36. Khalili NR, Jacobius TM, Mascarúa JA, Nadal EO (2013) Education without borders: Development of an interdisciplinary project based course between IIT and ITESM. Latin American and Caribbean Journal of Engineering Education 1 (1)
37. Finardi K, Archanjo R (2018) Washback effects of the science without borders, English without Borders and Language without Borders programs in Brazilian language policies and rights. Springer, pp 173–185
38. Abdurrahman AF, Maulina H, Nurulsari N (2019) Design and validation of inquiry-based STEM learning strategy as a powerful alternative solution to facilitate gifted students facing 21st century challenging. J Educ Gift Young Scient 7(1):33–56. https://doi.org/10.17478/jegys.513308
39. Mustafa N (2020) Impact of the 2019–20 coronavirus pandemic on education. Int J Health Pref Res 5(20):31–44. https://doi.org/10.13140/RG.2.2.27946.98245
40. Clark SK, Lott K, Larese-Casanova M, Taggart AM, Judd E (2020) Leveraging integrated science and disciplinary literacy instruction to teach first graders to write like scientists and to explore their perceptions of scientists. Res Sci Educ. https://doi.org/10.1007/s11165-020-09927-9
41. Haggis S, Adey P (1979) A review of integrated science education worldwide. Stud Sci Educ 6(1):69–89. https://doi.org/10.1080/03057267908559869
42. Chisman DG (1990) New trends in integrated science teaching, vol VI. Unesco, Paris
43. Lockard JD (1975) Science and mathematics curricular developments internationally, 1956–1974: the ninth report of the international clearinghouse on science and mathematics curricular developments
44. Millar RH (1981) Science curriculum and social control: a comparison of some recent science curriculum proposals in the United Kingdom and the Federal Republic of Germany. Comp Educ 17(1):23–46
45. Frey K (1989) Integrated science education: 20 years on. Int J Sci Educ 11(1):3–17
46. Weinstein M (2008) Finding science in the school body: reflections on transgressing the boundaries of science education and the social studies of science. Sci Educ 92(3):389–403. https://doi.org/10.1002/sce.20267
47. Collette AT, Chiappetta EL (1984) Science instruction in the middle and secondary schools. ERIC
48. Abd-El-Khalick F, Lederman NG (2000) Improving science teachers' conceptions of nature of science: a critical review of the literature. Int J Sci Educ 22(7):665–701
49. Aaas (1989) Science for all americans: a project 2061 report on literacy goals in science, mathematics, and technology. AAAS publication 89-01S
50. National Research C (2000) Inquiry and the national science education standards: a guide for teaching and learning. National Academies Press
51. Stinson K, Harkness SS, Meyer H, Stallworth J (2009) Mathematics and science integration: models and characterizations. Sch Sci Math 109(3):153–161
52. Roth W-M, Barton AC (2004) Rethinking scientific literacy. Psychology Press
53. Zeidler DL, Sadler TD, Applebaum S, Callahan BE (2009) Advancing reflective judgment through socioscientific issues. J Res Sci Teac Official J Nat Assoc Res Sci Teac 46(1):74–101
54. Development OfEC-oa (2000) Measuring student knowledge and skills: the PISA 2000 assessment of reading, mathematical and scientific literacy. OECD Paris
55. Martin MO, Gregory KD, Stemler SE (2000) TIMSS 1999 technical report. International Study Center Chestnut Hill, MA
56. Schleicher A (2019) PISA 2018: insights and Interpretations. OECD Publishing

57. Ikeda M, Echazarra A (2020) International student assessment: aims, approaches and challenges. Springer, pp 9–20
58. Anderson J, Wilson K, Tully D, Way J (2019) Can we build the wind powered car again? Students' and teachers' responses to a new integrated STEM curriculum. J Res STEM Educ 5(1):20–39
59. Winarno N, Rusdiana D, Riandi R, Susilowati E, Mega R, Afifah A (2020) Implementation of integrated science curriculum: a critical review of the literature Vol 8, pp 723–745
60. Saud U, Johnston M (2006) Cross-cultural influences on teacher education reform: reflections on implementing the integrated curriculum in Indonesia. J Educ Teach 32(1):3–20. https://doi.org/10.1080/02607470500510894
61. Prihantoro CR (2014) The perspective of curriculum in Indonesia on environmental education. Int J Res Stud Educ 4(1):77–83. https://doi.org/10.5861/ijrse.2014.915
62. Thair M, Treagust DF (1999) Teacher training reforms in Indonesian secondary science: the importance of practical work in physics. J Res Sci Teach 36(3):357–371. https://doi.org/10.1002/(SICI)1098-2736(199903)36:3%3c357::AID-TEA8%3e3.0.CO;2-I
63. Walberg HJ (1991) Improving school science in advanced and developing countries. Rev Educ Res 61(1):25–69
64. Kahn M (1990) Paradigm lost: the importance of practical work in school science from a developing country perspective
65. Ueckert CW, Gess-Newsome J (2008) Active learning strategies. Sci Teach 75(9):47–47
66. Mintzes JJ (2006) Handbook of college science teaching. NSTA Press
67. Cassimon D, Essers D, Renard R (2011) An assessment of debt-for-education swaps. Case studies on swap initiatives between Germany and Indonesia and between Spain and El Salvador. Compar Educ 47(2):139–156
68. Cannon R (2017) The sustainability of benefits from educational development projects in Indonesia: What do the Donors Say?
69. BNPB (2016) Potensi dan ancaman bencana. Retrivied from https://www.bnpb.go.id/home/potensi
70. Sasmi AT, Nugraha AD, Muzli M, Widiyantoro S, Zulfakriza Z, Wei S, et al (2020) Hypocenter and magnitude analysis of aftershocks of the 2018 Lombok, Indonesia, earthquakes using local seismographic networks. Seismol Res Lett
71. Nguyen N, Cipta A, Cummins P, Griffin J (2015) Indonesia's historical earthquakes: modelled examples for improving the national hazard map. Geosci Australia
72. Supendi P, Nugraha AD, Puspito NT, Widiyantoro S, Daryono D (2018) Identification of active faults in West Java, Indonesia, based on earthquake hypocenter determination, relocation, and focal mechanism analysis. Geosci Lett 5(1):1–10
73. BMKG (2018) Mitigasi Gempabumi: Kerja bersama untuk Indonesia tangguh. Retrivied from https://www.bmkg.go.id/press-release/?p=mitigasi-gempabumi-kerja-bersama-untuk-indonesia-tangguh
74. Sudrajat A (2019) Integrasi Konsep Kebencanaan Dalam Implementasi Kurikulum 2013 Di Sekolah Dasar. Jurnal Pendidikan Dasar 10(2):118–130
75. Agusdianita N, Karjiyati V, Anggraini D, Dalifa D, Setiono P (2020) Analisis Kebutuhan Pengembangan Model Pembelajaran Tematik Kesiapsiagaan Bencana Banjir Untuk Siswa Sekolah Dasar. Jurnal Gentala Pendidikan Dasar 5(1):19–27
76. Hamisesa RSA, Nataliya FH, Nurdiyanto R, Pujianto P (2018) Analyses of junior high school science competencies in KTSP and integrated-revision of 2013 curriculum: reviewed from the potential of disaster mitigation education for the shaping of a disaster response character. J Sci Educ Res 2(2):85–96
77. Ayub S, Kosim K, Gunada IW, Zuhdi M (2020) Model Pembelajaran Kesiapsiagaan Bencana Gempabumi Di Sekolah Dasar. ORBITA: Jurnal Kajian, Inovasi dan Aplikasi Pendidikan Fisika 5(2):65–72

78. Wardana S, Herdiansyah H, Wicaksono A (2019) Disaster risk management strategy in the environment and disaster mitigation-based school (SWALIBA). IOP Publishing, pp 12090–12090
79. Abdurrahman BK, Diah U, Wini T (2018) Learning community-based model in the context of teacher-parent partnerships: a novel model for preparing post-disaster recovery and resilience for student sin risk disaster areas in Indonesia. Indian J Sci Technol 11(29):1–9. https://doi.org/10.17485/ijst/2018/v11i29/106119
80. Rosidin U, Suyatna A (2017) Teachers and students knowledge about global warming: a study in smoke disaster area of Indonesia. Int J Environ Sci Educ 12(4):777–786
81. Murtilaksono K, Suryana A, Umar I (2011) Secondary and higher education for development of in Indonesia. J Develop Sustain Agric 6(1):35–44
82. Rahman B, Abdurrahman A, Riswandi R, Maulina H (2019) Green school based management model as a powerful alternative solution to overcome global climate change: a need assessment survey analysis of teacher in Lampung, Indonesia. J Phys Conf Ser 1155(1). https://doi.org/10.1088/1742-6596/1155/1/012086
83. Viner RM, Russell SJ, Croker H, Packer J, Ward J, Stansfield C, et al (2020) School closure and management practices during coronavirus outbreaks including COVID-19: a rapid systematic review. The Lancet Child & Adolescent Health
84. Esposito S, Principi N (2020) School closure during the coronavirus disease 2019 (COVID-19) pandemic: an effective intervention at the global level? JAMA pediatrics
85. Zaharah Z, Kirilova GI, Windarti A (2020) Impact of corona virus outbreak towards teaching and learning activities in Indonesia. SALAM: Jurnal Sosial dan Budaya Syar-i 7(3):269–282
86. Ichsan IZ, Rahmayanti H, Purwanto A, Sigit DV, Irwandani I, Ali A, et al (2020) COVID-19 outbreak on environment: profile of Islamic University students in HOTS-AEP-COVID-19 and PEB-COVID-19. Tadris: Jurnal Keguruan dan Ilmu Tarbiyah 5(1):167–178
87. Wargadinata W, Maimunah I, Dewi E, Rofiq Z (2020) Student's responses on learning in the early COVID-19 pandemic. Tadris: Jurnal Keguruan dan Ilmu Tarbiyah 5(1):141–153



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12 Thinking About Emotions in Education: Integrating the Transformation of Learning at School

Macarena-Paz Celume, Lisa Cognard, and Zoé Chamot

> *The emotions, the affective dimension, feelings…? But where are these more or less strange and individual aspects of the human person, of the student, hidden in a school whose legitimacy, whose foundation so often seems to hinder a proper understanding of school knowledge? (…) The school, the public school, the school for all should leave aside the emotional dimensions and devote itself only to the activities of the mind. Certainly, the disciplinary divisions of teaching indicate some places where emotions and their companions are allowed. But in the so-called intellectual disciplines (…) suspicion of emotions remains high.*
>
> *Louise Lafortune, Pierre-André Doudin, Francisco Pons, Dawson R. Hancock 2004 (Les Émotions à l'École, p. 75)*

Some short passages of this chapter are based on sections issued from the doctoral thesis of the first author, Macarena-Paz Celume.

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https://doi.org/10.1007/978-3-031-15963-3_12

Summary

Social and emotional intelligence, which are related to social and emotional learning or socio-emotional competencies or skills, have always been addressed in educational discourses around controversial points of view in which the classic perspectives on education seemed challenged by socio-emotional education promoters. This challenging perspective was not and still is not very appreciated by most conservatives, arguing that those learnings are not fundamental for academic success and even disrupt the child's education. Despite these constraints, many professionals in the educational field and research understand and present evidence stressing how social and emotional education is important for children for their holistic development with positive impacts on academic success. Several studies present school as one of the principal environments where children's social and emotional competencies happen. Within the past ten years, there has been a growing tendency among social and emotional studies to investigate the effects of different interventions on the development of children's emotional regulation, empathy, theory of mind (ToM) abilities, and collaborative behaviors. According to some authors, children's social, emotional, and academic success is intrinsically related to integrating and training emotional intelligence in schools, considering themselves and the school environment.

Graphical Abstract/Art Performance

Emotional connection.
(Acrylic on Canvas Painting by Macarena-Paz Celume).

Keywords

Children · Education · Emotions · School · Social and emotional learning

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

Creativity and social-emotional learning (SEL) are, in today's discourses, more commonly addressed than ever before. Despite this, even if they are considered necessary for policymakers and international organizations in the public discourse, the specific practice of these concepts, such as creativity, are sometimes disregarded at school [1]. According to some authors [2], children's success in social, emotional, and academic aspects is intrinsically related to the integration and training of emotional intelligence in schools, considering not only themselves but the whole school environment. School seems then to be a proper place to develop these competencies because school is the environment where children spend a good part of their time, and also, homes are not the environment typically leading children to learn emotional competencies [3].

Nevertheless, there are still only a few SEL programs that have been meticulously examined [4], and educators do not always put faith in these kinds of programs. Accordingly, creativity researchers [5, 6] insist on explaining creativity to teachers and how to enhance it because this is the only way they will become open to the experience of actually developing creativity among children. In the next section, we will first review the context of creativity and SEL in general school settings. Later, we will focus on the particularity of developing these competencies in French school classrooms.

2 Creativity and SEL in School Contexts

Several studies show evidence of the benefits of creativity and SEL at school [2, 7]. The European Parliament [8] has already highlighted that the ability to express ideas, experiences, and emotions in a creative manner is a key competency to be developed at school. Elias and Arnold [7] describe it as an objective that schools must direct their attention to. They explain that schools worldwide should provide children with the tools they can use not only in their classrooms but all around their environments: "SEL provides many of these tools. It is a way of teaching and organizing classrooms and schools that helps children learn a set of skills needed to successfully manage life tasks such as learning, forming relationships, communicating effectively, being sensitive to others' needs, and getting along with others" [7, p. 5].

Constructing valid SEL training would have a considerable positive impact on school-related outcomes and a series of behaviors related to the child's well-being and, thus, the improvement of school life itself. In this sense, the authors (idem) continue: "When schools implement high-quality SEL programs and approaches effectively, academic achievement of children increases, incidence of problem behaviours decreases, the relationships that surround each child are improved, and the climate of classrooms and schools changes for the better" [13, p. 5].

During the last decade, several authors have provided evidence of the positive impact of SEL interventions [9, 10]. The lack of these competencies, probably derived from a lack of training in the area, has negatively impacted different factors, particularly children's behavior and health [11]. In other words, evidence has shown how SEL not only improves health, well-being, and attitudes in children but also prevents unhealthy behaviors. In this sense, authors insist on how schools are crucial in playing a role in children's health: "by fostering not only their cognitive development but also their social and emotional development" [9, p. 406].

Nevertheless, it is worth mentioning, in the way we measure it, social and emotional aspects include cognitive aspects. For this reason, much school-based training has been created to teach children SEL, based on a vast literature supporting these benefits, which are mostly related to the enhancement of prosocial behavior, improvements in emotional distress, and well-being [10, 12]. A meta-analysis [9] showed that SEL training improved the competencies they were willing to improve. They also showed long-term effects, present for at least six months after the training. This means that SEL interventions not only help children at the moment but also have an influence over time. Researchers also showed that SEL programs positively affect primary schools to middle and high schools with no differences in urban or non-urban settings. In other words, among different SEL interventions included in the analysis, effective interventions could enhance SEL among children from different socio-cultural backgrounds and throughout their time at school. They also found that SEL has to be well structured, as interventions with the clearest structures were the ones with the most positive outcomes.

According to the SEL structure, to develop SE competencies, a previous meta-analysis [13] established four basic steps that training should follow. These steps are explained under the acronym SAFE for *Sequenced, Active, Focused, and Explicit* (Fig. 1):

i. sequenced means skills which need to be learned through a step-by-step process where the main competence to be developed needs to be subdivided into sequential steps that are interconnected;
ii. active means active learning where children actively build their own learning and practice the skills, not only "listen" to the significance of them;
iii. focused is related to a pedagogical position, whereby the pedagogue is willing to give enough time to the learner to process the knowledge; and
iv. finally, explicit is connected to the objectives of the training and sessions: they need to be clear and concise, and they must be communicated to the children if any learning is expected.

In line with this, later reviews [14] corroborate these findings, agreeing that training seems to be more effective when actively engaging learners, such as role-playing or coaching activities. Some authors agree that these skills can be taught and learned through liberal arts training [15, 16], such as drama. Many drama-based pedagogies include the principles of the SAFE methodology and are, by definition, active learning experiences based on improvisation and role-playing activities. Several studies based on drama-based pedagogies have also presented evidence on how their training while being active pedagogies improves SE competencies and creativity outcomes [17–21]. In the same line, other initiatives related to active pedagogies and the study of emotions concerning the development of social and emotional competencies have begun to multiply in some academic environments. Nevertheless, there is still work to do to reach more traditional education systems, where educational policymakers prioritize classical academic knowledge that can be repeated and thus evaluated through standardized tests [22].

In the next part, we will describe some visions for the French school system and how these new policies and ideas around creativity and SEL are being considered, which would lead us to discuss some experiences carried out in France these very last years.

3 Creativity and SEL in the French School Context

Free, public, and secular education in France was born during the third Republic between 1881 and 1882, as a means to educate the people and to avoid fanaticism and ignorance, responding to the values/moto of the Republic "Liberté, Égalité, Fraternité"[1] [23]. Since then, French education has undergone several renewal processes to adjust to the changing social processes.

[1] Liberty, Fraternity, Equality.

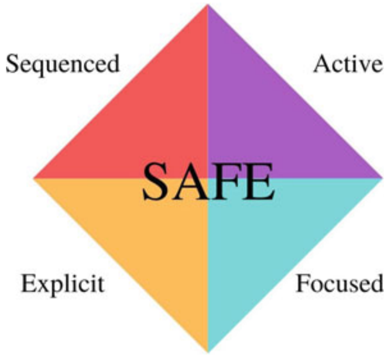

Fig. 1 SAFE structure for interventions on social and emotional learning development (CASEL)

From the beginning of the twenty-first century and a few years before that, a public school in France started living a disillusionment process [24]. According to some authors [23], this *désenchantement*[4] is due to several contradictions within the educational system, which continue to be debated through internal disagreements, but which also relate to the external representations of what the French educational institution is and about the social expectations of the educational system and the objectives that the institution should aim for. In other words, the social expectations of what school should be teaching and how it should be taught are detrimental to re-inventing the French educational system. Yet, bureaucracy inside the institution does not permit this renewal so easily. Nevertheless, new alternative approaches or ways of schooling are not something that arose in our contemporary society. Elsewhere, it is mentioned that "the idea of alternative is not new because the new pedagogical courants from pedagogues such as Célestin Freinet, Maria Montessori, Rudolf Steiner and Ovide Decroly were already present in France since the first half of the XXth century and they had structured themselves as a reaction to the traditional school"[2] [25, p. 4].

These new pedagogies responded to the societal changes which aimed to adjust the French educational institution [23]. According to [26], by the end of the 1970s, the concept of pedagogical differentiation had appeared, whereby the idea of education was based on establishing a flexible frame where learnings are explicit and diverse enough to permit students to work according to their own timing, inside a collective which teaches and responds to the national curriculum. Another author [23] mentions that this perspective implied that social and psychological differences among students were the motor of beneficial social interactions and learning that might impact diverse, motivating, and innovative ways of work. This established a base from which to rethink the educational system, promoting the integration of

[2] Translated from original in French: "L'idée d'alternative n'est pas nouvelle puisque les courants d'éducation nouvelle issus des pédagogues Célestin Freinet, Maria Montessori, Rudolf Steiner et Ovide Decroly sont présents en France depuis la première moitié du XXe siècle et se sont structurés en réaction à l'école traditionnelle.".

different perspectives in education. The opening of widespread public education institutions showed the necessity to adjust learning and teaching experiences to the needs of the multi-cultural population [23]. In this sense, the new paradigms in international education, expecting competencies to be part of educational curricula, increased the pressure for a new adjustment of the French educational institution.

In 1996, it was explained how the French system did not permit the development of competencies such as self-esteem, which were essential for social integration needed regarding the societal changes of the French population (immigration, social mixing, etc.) [27]. The national curriculum[3] establishes that mandatory education should grant each student the necessary means to acquire common knowledge, competencies, and culture. Nevertheless, the French educational system promotes a space where students are still trained under a competitive model that aims at disciplined knowledge acquisition [28] without consideration for creativity or socio-emotional learning as central to the learning process.

In 2017, the National Educational report on research and development into education across the life span [29] proposed ten principal propositions for tomorrow's education in France, towards a "learning society," without clearly considering the development of creative or socio-emotional competencies. The propositions are necessary for a change in French education, certainly. However, they are more focused on research methods in education and on how children should adapt to tomorrow's jobs and digital society than on developing creative or socio-emotional competencies. In summary, they propose to

- apply research methods to children education;
- build educational teams in developing research methods;
- intensify research about education;
- favor cooperation between practitioners and researchers;
- deploy digital collaborations;
- promote open portfolios of learning;
- promote rules for safe data;
- promote ethical rules for research;
- build learning spaces within the communities; and
- create research alliances.

In a more "holistic" approach, an analysis made regarding the so-called "new schools" in France [30] presents a fresh perspective on how the French educational actors perceive the French educational system nowadays. According to them, there are still few but growing alternatives to traditional schools which focus on children's well-being and SEL, without meaning they dismiss academic achievement. They consider social and emotional competencies fundamental for integrating children in today's societies that value autonomy and innovation. Most of these "new schools" arose due to the abovementioned public system.

[3] "Le socle commun de connaissances, de compétences et de culture. Ministère de l'Éducation Nationale et de la Jeunesse.".

Regarding this, the authors explained that these schools did not want to reproduce some of the negative aspects of the public system, such as the excessive detention time at school or the judgments towards students. The authors indicate that these "new directors" insist on the need to let children preserve their desire for learning without letting the children fall into learning for the sake of making their teachers or parents happy. "That's the dream," exclaimed one of the new directors at the end of an interview. Further analysis of interviews carried out by the authors showed how these "new schools" interest is focused on developing so-called 21st-century skills, understanding them as fundamental skills that will be needed for tomorrow's employability.

These alternative "new schools" aim to develop children's well-being and socio-emotional competencies as their educational offer, citing the need for these skills in future societies. In summary, the authors conclude that even though these schools are still a minority and far away from the French traditional educational system, they seem to have an important influence on the public educational discourse as well as educational policies, suggesting that the transformation of education towards a more integral education should be coming soon for the French educational system. In this sense, the authors do not propose that the only solution is to build new schools but to focus more on education in these competencies in school, through the inclusion and development of enrichment activities and a change of the state of mind of school principals and teachers.

According to the National Council for the Evaluation of the School System (CNESCO), the French educational system proposes the development of SEL competencies in preschool, elementary and secondary education. This competency development is proposed to be developed inside the classroom but also through extracurricular activities, with an emphasis on developing well-being at school [31].

Nevertheless, the reality in public education is very different. As we noted in the field during this investigation, the inclusion of these competencies occurs slightly in primary school, and a real inclusion and development that could be made through dramatic interventions still depend on the will of the school principal and teachers. According to the reality we faced when implementing our first studies, most schools refused interventions.

In several of the conversations we had with school principals in the Paris area, they explained that most of the time, they refuse DPT interventions or other artistic or sporting interventions because they are overwhelmed with administration and the curriculum, as the current rules for interventions in schools are vague and complex, without leaving principals the freedom to participate in projects they are interested in, but obliging them to follow a series of bureaucratic paperwork that takes months to get signed and which ends up nowhere. In other words, administrative paperwork seems to block school principals who are sometimes afraid of implementing anything without regional or even national authorization. In line with this, even though there has been progress in implementing drama-based interventions in school, there is still work.

Existing educational programs [32] present drama either as one part of a whole artistic and cultural program that only preschool children might learn at school, or they propose it as an optional subject for a specific group of high-school students or as a subject for primary school children who benefit from special reinforced artistic pedagogy in their schools. Accordingly, this thesis also aims to provide evidence of the benefits of DPT to be considered more seriously in the national educational discourse. DPT could be, for example, included in schools as an extracurricular activity to complement the current offer, or even as a subject within academic time, to enhance the development of SE competencies and creativity of all school-aged children and not only of those who choose the activity.

4 Evidence of the Need of Emotional Learning at School

Regarding the place of emotional learning in schools, we have found a willingness of certain teachers and school principals to develop these competencies among their students. In the same line, researchers in psychology or education show a growing tendency to focus on experimentation with new approaches towards developing these competencies in education. Some of these teachers show a real concern regarding the teaching of these competencies, on the one hand for the personal development of students and teachers, and on the other hand to prevent social and emotional issues that could end up in social misbehaviors or even school drop-out. With the aim of collaboration between researchers, teachers, and school actors, they create and test protocols, programs, and methodologies to enhance and develop these competencies within students through different approaches.

In a recent paper published by a group of researchers [33], they experimented with an intervention in dramatic arts with primary school children, trying to see the impact of this pedagogy (DPT) in the development of socio-cognitive and socio-emotional competencies. They worked with a group of children from fourth and fifth grade from three different schools, conducting a randomized study that lasted eight weeks. This study provided evidence that after the intervention, children who participated in DPT developed socio-cognitive skills such as Theory of Mind (ToM) and socio-emotional competencies, such as collaborative behavior and positive emotions. These results make us wonder about the necessity of replicating these experiences and accompanying children in their emotional development all along with their school life. The outcomes of the teaching and learning social and emotional competencies foster prosocial behaviors and positive emotions. They impact academic success, as brain development is directly influenced by the social and emotional environment [34]. This environment is co-constructed by students and teachers through a collaborative dialogic space [35] that is free of risks and promotes positive emotions. Developing a safe emotional space like this should be one of the principal interests of educational actors and teachers willing to work with emotional learning.

From the perspective of teachers [36], the concept of emotional teaching is proposed to explain the teaching done by the teachers to help the kids develop their emotional competencies and emotional intelligence. It is defined as a capacity to know and control his own emotions and the ones of others [37]. The notion of emotional intelligence was developed in parallel with the notion of SEL. It is positively correlated to academic performance, peer acceptance, school acceptance, and psychological and physical well-being [37–39].

Depending on the teachers, the principal motivations for teaching emotions are different, impacting students' learning. Teachers mainly have three motivations when working on emotions with their classes. The first one is academic success, which positively correlates with emotions' learning [40]. It helps students start learning and face difficulties [41, 42]. Moreover, the capacity to recognize emotions appears to be an important predictor for school satisfaction [43]. The second motivation is kids' fulfillment and especially their well-being. In her master thesis [41], an elementary school teacher specified that her motivation was to help kids deal with their emotions and not be overwhelmed by them. In fact, emotional learning is an efficient way to enhance emotional intelligence, positively associated with psychological well-being [43]. During the interviews, another teachers' motivation to start emotional learning was found: class management. A kindergarten teacher explains it by saying that it is helping her create a peaceful classroom environment and facilitate her life and students' learning. She sees a double benefit in this teaching.

The aim of research carried on with teachers [36] was to understand what are, in France, the effects of emotional teaching on preschool and primary schools' teachers. The data was collected through semi-structured interviews done with fourteen teachers working at different levels on emotions. All the teachers were working in France at the time of the interviews, and 13 of them were teaching in Ile-de-France. Eight teachers were teaching in kindergarten, and six were teaching in an elementary school. The project was a school project for ten teachers, and for four, it was a class project.

In her study, she demonstrated that the relationship between the teacher and his students involved a caring one through emotional teaching. By learning new knowledge on children and on their emotions, teachers analyze and react differently to children's behaviors which lead to a growth of their relationship. Moreover, these pieces of knowledge also guide teachers to question their practices and their vision of the teacher's role. This teaching plays the role of professional development, notably for the teachers that were unhappy with their previous practices. Furthermore, they also became teachers-research who guide their observations in the classroom toward their research objectives. Emotional teaching is also an axis of personal development for some teachers who also question their own emotions in the private and professional sphere. Emotions' teachers are, for some teachers, part of emotional teaching. Nevertheless, emotional teaching is learning done by the kids, which is a long and not always fruitful process.

The first axis of results highlighted developing a caring relationship between the teacher and the students. In this type of relationship, the students feel safe and more competent in the school context, leading to better academic achievement [44]. Teachers' dedication is an important characteristic that might fundamentally impact students' academic achievement [45]. He continues by showing how the relationship quality between the teachers and his students is essential. The development of this caring relationship results from different analyses done by the teachers of kids' behaviors. Some teachers start emotional teaching because they have observed kids with inappropriate behaviors in their classes, and they start to wonder why kids are having these behaviors. Zoé, a kindergarten teacher who participated in one of our studies, did these observations while playing a role in the research. Teachers have new knowledge on kids' development or kids' emotions. This understanding leads to different analyses of kids' behaviors. Once the teachers have this comprehension, they cannot have the same reactions they had.

Nevertheless, all these pieces of knowledge are not enough to understand every child's behavior and react properly. In fact, some children may not reach the expected way. For some kids, expressing their emotions may be important and may lead to frustrations when the teacher decides that it is not the right time to express everyone's emotions. Moreover, for some kids, the problem may be deeper than what the teachers can act on and may need the help of a specialist. More than changing their reactions facing a kid's behavior, teachers also adapt their practices and the tools used in the class. The readjustment of the classroom, by adding specialized corners for well-being or emotions or by doing changes that lead toward students and teacher well-being, is part of the professional development of the teachers. Teachers' new practices have been implemented in the classroom, either punctual sessions or rituals. For some teachers, these new professional discoveries, as sophrology, can become practices that teachers particularly like to create. These changes in the practices used or the analyses of students' behaviors lead to developing a caring and respectful relationship between the teacher and his students. This type of relationship is what some teachers expected before teaching but did not reach. Emotional teaching helps them reach this objective and be closer to their vision of the teacher they want to be.

This vision of the role of the teacher is related to the second axis of results about the evolution of the teacher's role. Emotional teaching conducts a reassessment of their role and of the teaching's way. During the interviews, teachers highlighted that they were evolving as not fruitful for the students or them. They were overwhelmed by their emotions that they could not control. It led them toward reactions they did not want to have because they were not matched with their personal and professional values. All these incoherencies guide teachers during their research toward emotional teaching and add the function of teacher-researcher to their role. A teacher-researcher is a teacher who orients his work with common research practices such as looking for more information on a specific topic, doing observations and experimentations [46]. The experiments done by the teachers are different depending on if the project is a school or a class project and if it is linked or not with a teacher's training. Nevertheless, everyone does not share this vision of the teacher's role in teaching emotional competencies and emotional intelligence. Some teachers do not share this point of view. This disagreement can lead to tensions inside the pedagogical teams, which can be hard to live with for the teachers in favor of emotional teaching. Another impact of this disagreement is that it can be an obstacle to children's emotional learning. The teachers who favor emotional teaching will implement emotions-related practices; they will teach the kids how to react when they feel a specific emotion. The other teachers, especially during break time, will not react the same way. Furthermore, all the parents do not agree that it is part of teachers' role to teach emotional learning. Some can be reticent at first and then see the positive impacts this teaching has on their children. Still, others can be entirely against notably because their opinions on emotions are not the same as those of teachers.

The last axis of results is about teachers' emotions in school and especially in the emotional learning process. School is a social environment where emotions are born and shared from interactions and learning [47]. Teachers are daily facing kids' strong and sometimes contradictory emotions. They also have to deal with their own emotions, which can work for some teachers. As explained by a kindergarten teacher, when they are in a situation of accumulations where different events happen in the classroom, it is hard to be completely available for an event and then be available and react properly to another one. She explains that one day, she was already mad about a conflict that happened between kids, and when another girl came in need of comfort, she was not ready to give her. This example highlights the difficulty teachers may have in class when several emotions are expressed at the same time.

Furthermore, the research teachers have been doing also brings new knowledge of their own emotions in their professional and personal lives. Teachers, as adults, start to reflect on their own emotions and how they want to react while having different emotions. For some of them, it completely changes their relation to some emotions and leads them to reflect on their own children's education. Emotional teaching is, for them, an axis of personal development. Therefore, the place of teachers' emotions also evolved in the classroom. Teachers learn to take emotional distance facing a kid's emotions. As explained by the teachers, it helps them to see the child in his globality and not just as a student and consequently to analyze and react differently to students' behaviors. Teachers also start to expose their emotions in the classroom but with different specific goals. For some teachers, it is important to exchange their emotions with the students to know adults do have emotions and that it is also a learning for them. Speaking about teachers' emotions in the classroom is also a way for teachers to release weight from their chest when they feel an emotion they need to share. Teachers also used their emotions in students' emotional learning. They use the same tools and practices as the ones they proposed to the students in the classroom and start to ask the kids' advice when facing an emotion. Nevertheless, as highlighted by a teacher, emotional teaching is not a "magic trick." In fact, it can still be hard for teachers to deal with all students' emotions and reach the expected way in different situations. It is a learning that needs time and effort to be efficient both on the students' and the teachers' sides.

A study [36] showed that french teachers implicated in emotional teaching are developing themselves professionally and personally. In fact, they learn new practices and tools adapted to the students' emotional learning. This teaching leads teachers to readapt the vision they had on their role and help it match their values. The relationship with the students is important for teachers. Different analyses and reactions to children's behaviors evolved toward a respectful and caring relationship. All these changes help teachers to become the expected teacher. They also learn more about their own emotions and integrate them into their practices. The benefit is double because it helps the teachers with their emotions, and it is also helping students to reflect on someone else's emotions. Teachers as adults also learn to deal with their emotions in personal settings, and some also integrate this learning into their children's education. Nevertheless, emotional learning is a long process that needs constant effort on the side of the teacher and the students and which may not always have the expected effects on the moment.

In another study, [48] she conducted a study which partly revealed the impact of emotional learning, among other educational practices, in students at risk of dropping out, explaining that there was a strong implication of emotions when talking about the decision and prevention of school drop-out.

This study was conducted in a French classroom that hosts children considered at risk of dropping out of school, called "classe relais." This study aimed to identify teachers' pedagogical and educational objectives and practices to put children back to school and re-socialize this public. This facility targets students from middle school who are identified by educational teams as at risk of school drop-out through different indicators such as chronic absenteeism, a low academic achievement due to academic shortcomings, serious or repetitive behavioral issues, or a high lack of motivation for learning for example. This study was carried out thanks to free observations, which allowed a first understanding of the "classe relais" ecosystem and the design of semi-directive interviews with the teachers of the "classe relais" to identify the objectives of the practices initially observed. Through this research, emotional learning appeared to represent a strong place during the process of the "classe relais." It was considered according to the teachers as essential for the success of the program.

School drop-out is considered as people aged from 18 to 24, who have not graduated or, who have at the most the french national diploma Brevet des Collèges (or its equivalent for European figures, that is to say, the certificate delivered at the end of middle school, giving access to high school), and who did not follow any professional training in the past four weeks. It is considered a serious and complex problem for individuals, schools, and society [49]. Complex because of the numerous and diverse risk factors, making the population of children at risk non-homogenous. Risk factors are both internal and external to the school. They have been recently classified by a group of authors [50] in four categories: factors related to family, school, peers, and child. And serious because of its various implications on societal and individual levels.

On an individual level, school drop-out children are in a suffering situation in school, often linked to the lack of valorization of their capacities, and therefore, school drop-out creates an important psychological prejudice in terms of self-esteem; thus, school, which is not managing the valorization and motivation of all the students, is rejected by these children, whom it is not easy to bring back on the school path [51].

On a societal level, the Organisation for Economic Co-operation and Development (OECD) stated that long term social and financial costs of academic failure are important because it generates individuals who do not have the skills to find their place in society, generating higher costs in health, social supports, and childhood care and security [52]. School drop-out represented in 2018, 10 and 6% of the European Union young people aged from 18 to 24 years old, and 8 and 9% in France, a figure that has significantly decreased since 2007 [51]. From an economic perspective, a study commissioned by the French Ministère de l'Éducation Nationale et de la Jeunesse to the Boston Consulting Group in 2012 estimated the lifetime cost of school drop-out for a person at 2,30,000 €. This stake has thus largely influenced public policies and political decisions, especially since the level of education of a country has become an indicator to measure economic development. Thus school drop-out has been recognized as an important stake in Europe, and its rate has been settled as one of the five criteria of European reference that should allow Europe to be the "world's most competitive and dynamic knowledge economy." The European Commission then fixed the objective of reducing the European school drop-out rate to less than 10% in 2020. Different facilities have been set up in France in this line, called "dispositifs relais."

"Dispositifs relais" allow temporary schooling, adapted to students from middle school and who have been identified as at risk of school drop-out. These facilities aim at re-solarizing and re-socializing these students[53]. Among these facilities ("dispositifs relais") stand the "Classes relais," created in 1998, which are a specific program that takes in charge for a limited time, eight weeks, the students described above in specific conditions: small groups—twelve students at maximum—, a tripartite agreement between parents, student and the educative community, an individualized path, specific work on orientation [54].

In this line, this research aimed to understand the specific functioning of a "classe relais" and the specific teaching practices or activities. The study was conducted in a "classe relais" in Paris' suburbs, run by two main teachers, and welcoming three students from three different middle schools. Data were collected thanks to field observations and semi-directed interviews with both teachers and students. The study identified that the main effort of the teachers' practices in this class was the movement from the children's self-perception to a more positive value, enhancing the children's perception of others (their peers and the adult figure) and of learning and school. These dimensions are in line with other authors [55] that explain that positive or negative perceptions of the subject on himself and the other components of the relational situation have to be understood as important energetic sources stimulating or orienting the motivation, or on the contrary, inhibiting or decreasing the accomplishment.

Results on her studies showed that among the teachers' practices, the work on emotions was taking an important place during the "classe relais" program, and it was justified by the teachers as an essential work for the children following this program, given their background and both personal and social issues. Indeed, a common criterion of these children lay in their difficult and unstable familial background. The main characteristics of the children welcomed during this session were relational difficulties, difficulties to affirm oneself, aggressiveness, trying to embarrass the adult, being excluded from the class, and familial difficulties. The teachers also explained that these students and their families have postures that do not correspond to the expectations of adults and the school, which compromises their chances of success in school. In several cases, the teacher also explained that the children welcomed in "classe relais" have very big traumas related to familial or personal drama.

Given these characteristics, the teachers considered it important to shift children's self-perception, mainly through teaching about emotions and emotion management. According to them, the children need to express and share their emotions and experiences to feel better about themselves and enter the learning process, as described below. This can be partly supported by other authors [56], who showed that good emotional regulation abilities strongly predict academic performance.

To do so, the teachers encouraged children to express their emotions and share their histories and feelings. For example, on the very first day of the program, a collective work was a game in which all the participants had to answer questions written on the board game. The questions were related to personal and school experiences. The expression of children's personal history and feelings answers to plural objectives for the teachers, one of them being the understanding of these children's difficulties, in a personal or academic view, as explained by one of the teachers "sometimes they open up and tell us about the problems they have, which sometimes the school has no idea about." The teacher also believed this enabled children to free some mental load and work better. And to encourage the children's sharing and expressing, but also to initiate a trusting relationship between them, teachers "played the game" with children and shared personal emotions or stories themselves.

A typical week in this "classe relais" included academic and non-academic learning [48]. One teacher mentioned: a successful week is a week when students "learn stuff in history, in English, stuffs on life, on your emotions, on your feelings, etc." According to the teachers, working on emotions enables both the development of empathy and decreasing the feeling of being different. In this line, the program included a weekly workshop on emotions, animated by an intern student in psychology studies. During these workshops, the children were trained to recognize peers' emotions, name the emotions, the gestures usually associated with these emotions, how to answer them, and how to manage a negative emotion. Also, the teachers tried to work at the same time academic disciplines and the needs of the children, including work on emotions, where children and teachers talk about emotions, each time different ones, and the children were asked to write something, or to tell something, to train and practice in the meantime oral expression or written expression, and emotion understanding and management. For another example, the teachers also adapted drama workshops to the emotion's workshops, dedicating one of the drama workshops to emotions, aiming at developing children's empathy.

The teachers also attempted to provide the children with tools to manage their emotions. First, during the first day, while providing school supplies to the children, the teachers also offered a notebook as a reference to the book they were to follow during the program: "Anne Frank and her Kitty." The tool was introduced to them as a notebook that every child entering the "classe relais" is offered, in which they can write whatever they want, and in which they can express themselves when they feel sad or angry, for example. This notebook appeared to be frequent and appreciated by the children. Second, when children were angry, frustrated, or had trouble concentrating, the teachers provided play-dough. The children got easily used to this practice. They were allowed to use it whenever they wanted, and it appeared to reduce their negative emotions and enhance their attention during lessons.

The main idea behind all these activities was to develop emotional competencies to understand the different emotions and manage and cope with unpleasant emotions. This way, within the frame of "classe relais," these activities developed positive emotions in children, helped them have a more positive-value self-representation, and helped them keep on learnings and were focused on preventing children from becoming school drop-outs.

5 Conclusion

The different studies that we have been carrying out in the past years present consistent evidence that social and emotional competencies crucially contribute to the holistic development of children. That school is an exceptional place that helps children develop social and emotional competencies. Teaching and learning social and emotional competencies in a school environment positively impacts children and adolescents' cognitive and social development and favors positive emotions. We also presented evidence that social and emotional learning can be done through active pedagogies such as drama pedagogies. Learning about social and emotional competencies can enhance positive emotions in children. In this line, social and emotional learning activities are fundamental in the methodologies of schools that tackle the prevention of school drop-out. Moreover, we could see that teachers use emotional teaching to reach their pedagogical goals, like students' academic achievement. That also helps them reach their professional expectations. In other words, emotional teaching also leads to the professional and personal development of the teachers.

The different evidence that we presented above shows how developing social and emotional competencies and focusing on students' emotions within the learning environment is directly related to children's cognitive and social development, influencing processes that permit them healthy development. A healthy development, through the respect of their learning processes and own emotions, seems to be the key to developing a more just and peaceful society, and to achieve the learning challenges of the twenty-first century, developing, on the one hand, positive emotions in students and teachers, and preventing, on the other hand, school drop-out.

Core Messages

- Social and emotional competencies contribute to socio-cognitive child development.
- Emotional teaching leads to the professional and personal development of teachers.
- Social and emotional learning and socio-cognitive competencies can be taught and learned through drama pedagogy.
- Learning social and emotional competencies enhance children's positive emotions.
- Emotional learning activities are fundamental for preventing school drop-out.

References

1. Beghetto RA, Plucker JA (2006) The relationship among schooling, learning, and creativity: "all roads lead to creativity" or "you can't get there from here"? In: Kaufman JC, Baer J (eds) Creativity and reason in cognitive development. Cambridge University Press, Cambridge, pp 316–332
2. Brackett M, Patti J, Stern R, Rivers S, Elbertson NP, Chisholm C, Salovey P (2009) A sustainable, skill-based model to building emotionally literate schools. In: Thompson R, Hughes M, JBT (eds) Handbook of developing emotional and social intelligence: best practices, case studies, and tools. John Wiley & Sons Inc, New York, pp 329–358
3. Torrente C, Rivers S, Brackett M (2016) Teaching emotional intelligence in schools: an evidence-based approach. Springer, Cham, pp 325–346
4. Lopes PN, Salovey P (2004) Toward a broader education. In: Walberg HJ, Wang MC, Zins RJE, PW (eds) Building school success on social and emotional learning. Teachers College Press, New York, pp 79–93
5. Kaufman JC, Beghetto RA (2014) Creativity in the schools: renewed interest and promising new directions. Handbook of positive psychology in the schools. Routledge, New York, pp 165–175
6. Beghetto RA, Kaufman JC (2013) Fundamentals of creativity. Educ Leadernsh 70:10–15
7. Elias MJ, Arnold H (2006) The connection between academic and social-emotional learning. In: Elias MJ, Arnold H (eds) The educator's guide to emotional intelligence and academic achievement. Corwin Press, Thousand Oaks
8. European Parliament (2006) Recommendation of the European Parliament and of the Council of 18 December 2006 on key competences for lifelong learning. Off J Eur Union

9. Durlak JA, Weissberg RP, Dymnicki AB, Taylor RD, Schellinger KB (2011) The impact of enhancing students' social and emotional learning: a meta-analysis of school-based universal interventions. Child Dev 82:405–432. https://doi.org/10.1111/j.1467-8624.2010.01564.x
10. Taylor RD, Oberle E, Durlak JA, Weissberg RP (2017) Promoting positive youth development through school-based social and emotional learning interventions: a meta-analysis of follow-up effects. Child Dev 88:1156–1171. https://doi.org/10.1111/cdev.12864
11. Blum RW, Libbey HP (2004) School connectedness—strengthening health and education outcomes for teenagers. J Sch Health 74:229–299. https://doi.org/10.1111/j.1746-1561.2004.tb08278.x
12. Greenberg MT, Weissberg RP, O'Brien MU, Zins JE, Fredericks L, Resnik H, Elias MJ (2003) Enhancing school-based prevention and youth development through coordinated social, emotional, and academic learning. Am Psychol 58:466–474
13. Durlak JA, Weissberg RP, Pachan M (2010) A meta-analysis of after-school programs that seek to promote personal and social skills in children and adolescents. Am J Comm Psychol 45:294–309. https://doi.org/10.1007/s10464-010-9300-6
14. DuBois DL, Holloway BE, Valentine JC, Cooper H (2002) Effectiveness of mentoring programs for youth: a meta-analytic review. Am J Comm Psychol 30:157–197. https://doi.org/10.1023/A:1014628810714
15. Goldenberg EN (2001) Teaching key competencies in liberal arts education. New Dir Teach Learn 2001:15–23. https://doi.org/10.1002/tl.2
16. Zeidner M, Roberts RD, Matthews G (2002) Can emotional intelligence be schooled? A critical review. Educ Psychol 37:215–231. https://doi.org/10.1207/S15326985EP3704_2
17. Garaigordobil M (2003) Programa Juego. Juegos cooperativos y creativos para grupos de niños de 8 a 10 años. Ediciones Pirámide, Madrid
18. Garaigordobil M (2006) EPC Escala de Personalidad Creadora: Evaluación de conductas y rasgos de la personalidad creativa infantil. In: Verónica Violant S de la T (ed) Comprender y evaluar la creatividad. Aljibe, pp 324–332
19. Goldstein T, Lerner M (2018) Dramatic pretend play games uniquely improve emotional control in young children. Dev Sci 21:e12603. https://doi.org/10.1111/desc.12603
20. Goldstein T, Winner E (2012) Enhancing empathy and theory of mind. J Cogn Dev 13:19–37. https://doi.org/10.1080/15248372.2011.573514
21. Moore M, Russ SW (2008) Follow-up of a pretend play intervention: effects on play, creativity, and emotional processes in children. Creat Res J 20:427–436. https://doi.org/10.1080/10400410802391892
22. Sahlberg P (2011) Creativity and innovation through lifelong learning. Lifelong Learn Eur 16:53–60
23. Clerc F (2008) L'école française au xxie siècle: une mutation difficile. Enfances Psy 40:71. https://doi.org/10.3917/ep.040.0071
24. Baubérot J (2004) Laïcité. 1905–2005, entre passion et raison. Le Seuil, Paris
25. Wagnon S (2018) Les pédagogies alternatives en France aujourd'hui : essai de cartographie et de définition. Tréma Rev Int en Sci l'Éducation Didact 50. https://doi.org/10.4000/trema.4174
26. Przesmycki H, de Peretti A (2008) La pédagogie différenciée. Hachette, Paris
27. Bruner J (1996) The culture of education. Harvard University Press, New York
28. Taddei F (2009) Former des constructeurs de savoirs collaboratifs et créatifs: Un défi majeur pour l'éducation du 21e siècle. https://www.cri-paris.org/en/shared-documents/WEBSITE-CRI_PDF-oecd-Training-creative-collaborative-fr2009.pdf. Accessed 13 Jul 2019
29. Bechetti-Bizot C, Houzel G, Taddei F (2017) Vers une société apprenante: rapport sur la recherche et développement de l'éducation tout au long de la vie
30. Legavre A, van Zanten A (2018) Analyse de discours: Le Projet des Nouvelles Écoles. L'école des Parents 40–43
31. Florin A, Guimard P (2017) Qualité de Vie à l'École
32. DGESCO (2016) EDUSCOL. Programmes d'enseignement du théâtre. https://eduscol.education.fr/theatre/sinformer/textes-officiels-programmes

33. Celume MP, Goldstein T, Besançon M, Zenasni F (2020) Developing children's socio-emotional competencies through drama pedagogy training. An experimental study on theory of mind and collaborative behavior. Eur J Psychol
34. Farah M (2017) The neuroscience of socioeconomic status: correlates, causes, and consequences. Neuron 96:56–71
35. Celume M-P, Besançon M, Zenasni F (2019) How a dialogic space can impact children's creativity and mood valence in drama pedagogy training: study with a French 4th grade sample. Think Ski Creat 33:100576. https://doi.org/10.1016/j.tsc.2019.100576
36. Cognard L (2020) Emotional learning as a lever for professional and personal development of teachers: a qualitative study. [Master thesis]. Université de Paris
37. Mayer J, Roberts R, Barsade S (2008) Human abilities: emotional intelligence. Annu Rev Psychol 59:507–536
38. Voltmer K, von Salisch M (2017) Three meta-analyses of children's emotion knowledge and their school success. Learn Individ Differ 59:107–118
39. Constans S, Florin A, Guimard P, Guirimand N, Nocus I, Sovet L, Celume MP, Encinar PE, Humeau C, Jacquin J (2019) Ce que les enfants pensent de leur bien-être en France. Nantes
40. Richard S, Clerc-Georgy A, Gay P (2019) Évaluation d'un entraînement basé sur le jeu de faire semblant destiné à favoriser le développement des compétences socio-émotionnelles chez les enfants de cinq ans : étude exploratoire. L'Année Psychol 119:291–332
41. Concédieu C (2017) Les émotions dans la classe [Master thesis]
42. Crahay M, Dutrévis M (2010) Psychologie des apprentissages scolaires. De Boeck Supérieur, Bruxelles
43. Shankland R (2019) La psychologie positive, 3rd edn. Dunod, Paris
44. Hamre BK, Pianta RC (2006) Student–teacher relationships. In: Minke GGB, KM (edd) Children's needs III: development, prevention, and intervention. National Association of School Psychologists, Washington, DC, pp 59–71
45. Hattie J (2012) Visible learning for teachers: maximizing impact on learning. Routledge, London/New York
46. Leong Y, Chick H, Moss J (2007) Classroom research as teacher-researcher. Math Educ 10:1–26
47. Weissberg RP (2000) Emotion and learning. Train Dev 54:45–54
48. Chamot Z (2020) Teachers' practices for school hang-up with children at risk of school drop-out. A case-study of a "classe relais" in Antony, France. [Master Thesis]
49. McCaul E, Donaldson G, Coladarci T, Davis W (1992) Consequences of dropping out of school : findings from high school and beyond. J Educ Res 85:198–207
50. Gubbels J, van der Put CE, Assink M (2019) Risk factors for school absenteeism and dropout: a meta-analytic review. J Youth Adolesc 48:1637–1667
51. Ministère de l'Éducation Nationale et de la Jeunesse La lutte contre le décrochage scolaire
52. Field S, Kuczera M, Pont B (2007) Politiques d'éducation et de formation En finir avec l'échec scolaire Dix Mesures Pour Une Éducation Équitable
53. Éduscol Lutte contre le décrochage scolaire. Mission de lutte contre le décrochage
54. Ministère de l'Éducation Nationale et de la Jeunesse Dispositif Relais. https://www.education.gouv.fr/bo/14/Hebdo14/REDE1406108C.htm. Accessed 14 Jun 2020
55. Ruel P (2009) La problématique de l'adaptation scolaire et la motivation. Rev des Sci l'éducation 10:247–260
56. Djambazova-Popordanoska S (2016) Implications of emotion regulation on young children's emotional well-being and educational achievement. Educ Rev 68:497–515

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13 Surprise and Story in Thinking and Learning and Their Absence from Mathematics Education

George Gadanidis and Rosa Cendros

Children begin their lives as eager and competent learners. They have to learn to have trouble with learning in general and mathematics in particular.

Papert, 1980 (Mindstorms: Children, computers, and powerful ideas, p. 40)

Summary

This chapter explores how the concepts of surprise and story appear in recent educational research and how they are portrayed and translated into curriculum documents. We answer the questions: how are the concepts of surprise and story addressed in recent educational research? And how are the concepts of surprise and story considered in curriculum documents? This review is based on studies conducted over the past ten years that contained the term mathematics and one of the following terms in title or abstract: "surprise," "wonder," "aesthetics," "beauty," "insight," or "story." We also analyzed the same terms in mathematics curriculum documents from over 24 jurisdictions in Canada, the United States of America, Australia, and England. We found that the concept of surprise is not commonplace in mathematics education research or curriculum documents, while the term story appears numerous times, both in research and in curriculum

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N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_13

documents. We conclude that more research is necessary to connect the use of surprise and story to mathematics education experiences—to students' mathematical thinking and learning—that can truly spark a sense of enjoyment and wonder around mathematical ideas. Similarly, curriculum documents should offer a more explicit linkage between eliciting these aesthetic experiences and the study of mathematics in K-12 education.

Graphical Abstract/Art Performance

Math surprise—a research performance.

Keywords

Curriculum · Education · Mathematics · Story · Surprise · Thinking

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

For a long time, there has been an accepted consensus that there is a close relationship between aesthetic experiences and doing mathematics [1–4]. Similarly, many studies on mathematics education have reached an agreement in suggesting an aesthetic appreciation of mathematics in students' learning experiences [1, 5–8]. We refer to an aesthetic appreciation that can come in many forms, whether it is the creative and artistic expressions derived from mathematics visualizations [9], the beauty of a simple and elegant mathematical proof [2], the surprising unexpectedness of mathematical ideas and solutions [10], or the enjoyment of a well-crafted mathematics story [11].

However, how has this long-standing consensus been taken in current mathematics education research, and ultimately, how has it been translated to curriculum documents which directly influence how mathematical ideas are approached in the classrooms? This paper will look at two concepts closely related to aesthetics in mathematics—surprise and story—and how they are portrayed in education. We chose to focus on these concepts because we consider them as aesthetic factors and human necessities.

On the one hand, stories are essential for humans to grasp the complexities of their surroundings and communicate that understanding to others. Neuroscience research has shown that stories are the basis of our thinking; the human brain automatically makes sense of information and experience in story terms.

> It's not that we can use story thinking. It's that we MUST. We automatically do. We can't not do it [12].

Rose [13] wrote

> just as the brain detects patterns in the visual forms of nature and in sound, so, too, it detects patterns in information. Stories are recognizable patterns, and in those patterns we find meaning […] They are the signal within the noise [13].

Surprises, on the other hand, help humans understand puzzling and difficult events. Humans are compelled to resolve and explain surprising events because that is how we learn new things about the world and, therefore, are better prepared to face such events in the future [14]. Adler [15] proposes that a surprise is a valuable tool for learning. When students encounter surprising information, they are urged organically to correct the content and understand what makes it so interesting. Researchers have also found that it is possible to enhance the retention of information through surprise [14], perhaps because surprise can make learning more interesting and pleasant [16].

The collaborative work of the first author, in research classrooms in Ontario, Canada, and in Brazil, over the last 15 years [17–19], has developed a simple test that incorporates both surprise and story: When students are asked, "What did you do in math today?," are they able to share a story that offers mathematical surprise and insight? For example, for the topic of area representations of fractions in grade 3, we engage students in shading square grids to represent the fractions 1/2, 1/4, 1/8, 1/16, and 1/32 (Fig. 1). They then cut out the shaded parts. We ask: if you kept doing this forever, shading more and more fractions in this way, cutting out the shaded parts, how big would the new shape be if the shaded parts were put together? Students realize that the infinite set of fractions fits inside a single square. They then share at home that it is possible to hold infinity in their hands (Fig. 2) and help adults better understand the connection between infinity and limit and that infinite series can have finite sums, which is at the heart of calculus.

As another example, for the topic of growing patterns in Grade 1, students build odd numbers using linking cubes (as shown in Fig. 3) and realize that “Odd numbers hide in squares!” (as shown in Fig. 3). They also build even numbers and see that they “hide” in rectangles whose dimensions differ by 1 (Fig. 4). The grade 1 students then share their surprises and insights with their grade 8 buddy class, who, in turn, use these representations to develop formulas for the sums of odd, even, and natural numbers (Fig. 5). A research performance based on the above ideas, including a music video based on scripts grade 3 students authored of how they might share their learning at home, is available at the QR code related to Graphical Abstract (Fig. 6).

Such experiences of mathematical surprise, insight, and storytelling add humanity to the mathematics learning experience:

> story makes us human and adds humanity to mathematics. Boyd notes that good storytelling involves solving artistic puzzles of how to create situations where the audience experiences the pleasure of surprise and insight. Solving such artistic puzzles may not be commonplace in mathematics pedagogy and it may not always be easy, but the mathematical beauty that results gives so much pleasure [17].

Over six decades ago, Snow [20] expressed sorrow about the dividing line between science and art. Root-Bernstein [21] suggests that historically, science and art are

> very similar, certainly complimentary, and sometimes even overlapping ways of understanding the world

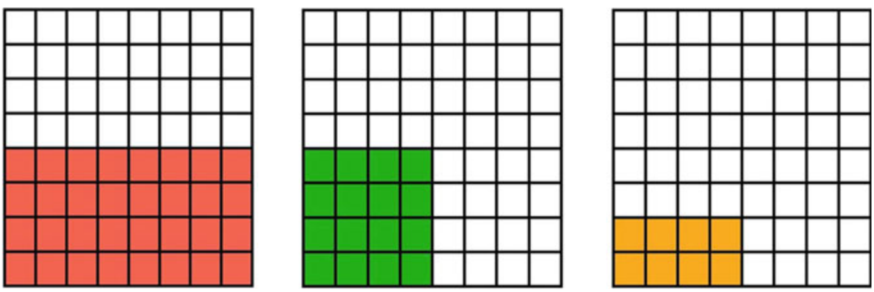

Fig. 1 Area representations of fractions

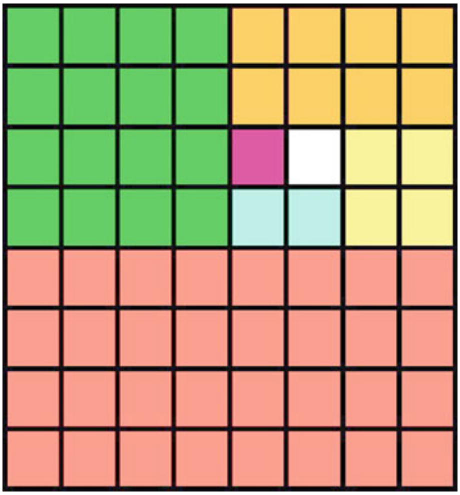

Fig. 2 An infinite number of fractions fit in a single square

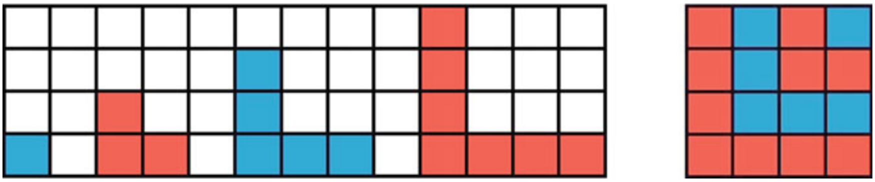

Fig. 3 Odd numbers hide in squares!

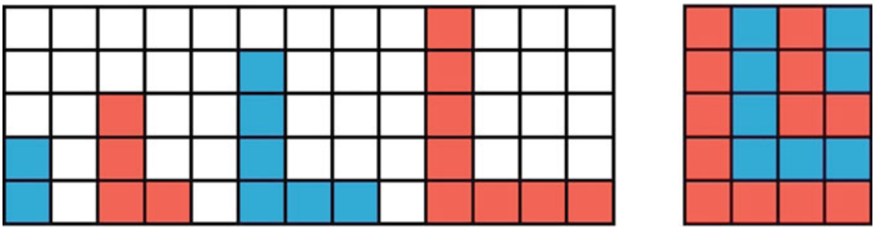

Fig. 4 Even numbers hide in rectangles!

even though it has been generalized in recent times that art is

"subjective, emotional, and based on intuition," while science is "objective, analytical, and rational."

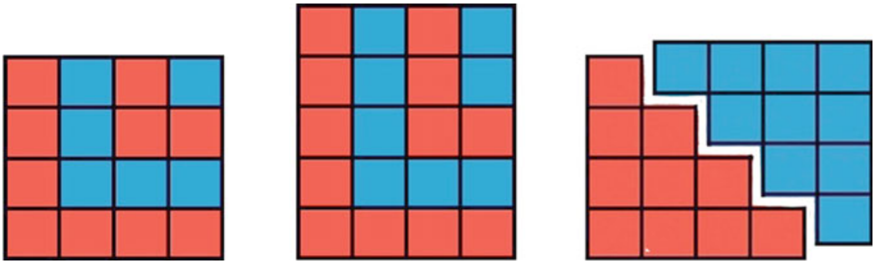

Fig. 5 Sum of odds = N^2, sum of evens = N(N + 1), sum of naturals = N(N + 1)/2

Fig. 6 A research performance

This paper will explore how the concepts of surprise and story appear in recent educational research and how they are portrayed and translated into curriculum documents. We answer two questions:

i. How are the concepts of surprise and story addressed in recent educational research?; and
ii. How are the concepts of surprise and story considered in curriculum documents?

2 Review of Research on Surprise, Aesthetics, and Story in Mathematics Education

To conduct this review, we initially searched in two educational databases (ProQuest Education and ERIC) for literature published in 2010–2020 containing the term mathematics and one of the following terms in title or abstract: surprise, wonder, aesthetics, beauty, insight, story. Twelve papers provided salient findings for this review.

2.1 Surprise in Mathematics Education Research

Out of the 12 identified sources, only four papers provided research regarding surprise in mathematics education. One of them related to surprise and aesthetic experiences, one related to eliciting a sense of wonder through creative expression, and the other two about building anticipation and surprise as part of a narrative, one in gaming and the other in storytelling.

First, in relationship to surprise and aesthetic experiences, Koichu, Katz, and Berman [22] found that surprise could influence students' perception of the beauty of mathematics. They interviewed middle school students, and two similar geometry problems were presented to them, each with a different degree of surprise associated with its solution. Students were then asked to evaluate the beauty of each problem, and ultimately, the problem was rated as more beautiful when it had a more surprising solution. This result shows that an aesthetic response can be introduced in mathematics learning by manipulating the extent of surprise.

Second, in relationship with eliciting a sense of wonder through creative expression, Waite [23] documented mathematics creativity in young children and found that discovery and 'aha!' moments allowed learners to view mathematics as something to be awed and excited about. In her study, she also found that planning for mathematics creativity requires consideration of relationship, relevance, and rigor. Maintaining a culture of not knowing is crucial to implementing this process and boosting students' confidence. She suggests that

> creativity in mathematics is possible if students use dialogue and reflection to explain how their thinking is changing, or what new things they are discovering about mathematics [23].

Finally, two studies in our review focused on surprising events within a narrative introduced for mathematics learning. First, Wouters et al. [16] examined the effects of surprising events in a serious game on mathematical learning. They found that students who were exposed to surprise learned more than their counterparts who were not. Hence, game-based learning and mathematics learning can benefit from surprise as a narrative device. Ryan and Dietiker [24] interpreted mathematical lessons as stories along the same lines. They found that they can build anticipation and create surprise, which constitutes a stimulating approach to teaching elementary mathematics. They developed a framework that allows teachers to unfold mathematics

> in a way that enhances students' aesthetic experience (such as gasping in surprise) while expanding their mathematical knowledge [24].

2.2 Stories in Mathematics Education Research

Story and storytelling were dominant topics in our review, with ten pieces of directly related literature. Two of those pieces were also related to surprise and were included in that section [16, 24].

First, to elaborate on how stories increased mathematics learning, two studies were experiments that controlled the inclusion of interactive stories [25, 26]. Both studies found positive results. Gunbas [25] compared the learning outcomes of i, students who used computer stories to solve problems; ii, students who used a paper story instead; and iii, students who were taught with no stories (isolated word problems). Compared with the second and third groups, students in the first group achieved significantly higher scores. Furthermore, even the non-story treatment on a computer was significantly less effective than the story treatment. Similarly, Hassinger-Das et al. [26] compared mathematics vocabulary measures between students who received an interactive storybook treatment and students who received traditional instruction. There was an advantage for the storybook intervention group on measures of mathematics vocabulary, both for words that were relevant to it as well as those that were not. However, in that study, the researchers suggested teaching the mathematics vocabulary along with other instructional approaches due to the fact that they did not find an effect of the storybook intervention on general mathematics learning.

Two studies in our review about teachers' perceptions introduced a form of storytelling as a teaching strategy to teachers and teacher trainers [27, 28]. Perceptions in both studies were positive. Yuksekyalcin et al. [27] conducted their study integrating digital story creation with drama and found that there were mostly positive opinions regarding this approach from science and math teachers. In addition, the teachers indicated that they prefer using creative drama in their classrooms to attract students' attention or make them think of the content they are teaching. On the other hand, Mercat et al. [28] applied the C-book software with teachers and teacher trainers. C-book is.

> "an electronic book aimed at promoting creative mathematical thinking" that helps its users blend "hyper-text, images and widgets of diverse origins into a single interactive narrative."

In this study, the interactive narrative revolved around *op-art* pieces, art based on patterns and colors that create optical illusions. They found that

> technology, far from hindering the creative process actually can be used to help putting it on firm grounds, […] by giving means to objectify the description and creation of the artwork itself and making explicit the choices made, allowing for the creative exploration of new original ways: 'what if…' [28].

According to two studies in our review, creating stories can also help teachers assess understandings and misconceptions. McCormick and Essex [29] asked children to write and illustrate multiplication and division stories. Researchers found that many of the students who wrote correct stories had adequately conceptualized unitizing, which is fundamental to place value, multiplication, and division. Children were able to relate multiplication and division and did not find one harder than the other. Their findings suggest a story writing assessment can reveal students' understanding and misunderstanding of operations in a way traditional tests cannot. Similarly, Karaoglan Yilmaz et al. [30] found stories to address previously identified misconceptions and mistakes about fractions.

Finally, but perhaps most importantly, stories foster an inclusive atmosphere in mathematics classrooms, according to two studies in our review. Corp [31] used stories that are culturally responsive in a third-grade mathematics class. In this study, Black students (the target audience of the culturally responsive intervention) regarded African American stories as highly engaging and enjoyable. Consequently, because engaged students are more likely to grasp mathematics, the stories contributed to their understanding to varying degrees. On the other hand, Green et al. [32] designed an intervention for children with disabilities that integrated mathematics and children's literature. Children who received the intervention had significantly higher scores on two standardized tests than the control group in total math abilities, one-to-one correspondence counting, quantity comparison, and oral counting.

To summarize, stories in mathematics:

- increase learning outcomes [25, 26];
- are positively evaluated by teachers and teacher trainers [27, 28];
- have a higher impact when delivered through or combined with computers [25, 28];
- are helpful to reveal understandings and misconceptions when being developed by students [29, 30]; and
- foster the inclusion of culturally and cognitively diverse learners [26, 31, 32].

3 Exploring the Concepts of Surprise and Story in Mathematics Curriculum Documents

To conduct this review, we focused on Canada, the United States of America, Australia, and England, and we limited our scope to jurisdictions with at least one curriculum document published in 2010–2020.

3.1 Surprise in Mathematics Curriculum Documents

The term surprise does not appear in any revised documents or its stemmed words. However, to deepen our search, we included terms that are related, or in some contexts, synonyms. These terms were wonder, insight, and aesthetics (including stemmed words). While there were more references to the mentioned additional terms, there were still few mentions of the topics. All of them were included as part of curriculum frameworks or descriptions but never as a part of the outcomes or standards for any revised curriculum documents.

In most cases, the terms wonder, insight, and aesthetics appear described merely as a medium to achieve understanding. For example, in the Alberta K-9 Curriculum

[33], seven mathematical processes are defined, and the fifth process, reasoning, is paired with developing a sense of wonder about mathematics.

The term insight is often paired with the construct of problem-solving in the reviewed documents. In the Indiana Academic Standards [34], insight is achieved in a problem-solving process when students consider similar problems or problems in a simpler form. Similarly, in the Colorado Curriculum, insight results from sustained reasoning during problem-solving [35]. In the South Carolina High School Curriculum [36], students gain insight when applying their mathematics knowledge and skills in varied contexts. Also, the curriculum for Knowledge and Employability Mathematics in Alberta [37] relates insight to creative thinking and unique connections among ideas to be applied to problem-solving.

Only two documents in this review present ideas more related to creating a sense of wonder in mathematics just for the pleasure of the experience. In the new Colorado Academic Standards [35], three distinct purposes for mathematics are described. One of them is to *Experience Wonder, Joy, and Beauty*. According to this document:

> Just as human forms and movement can be beautiful in dance, or sounds can make beautiful music, the patterns, shapes, and reasoning of mathematics can also be beautiful. On a personal level, mathematical problem solving can be an authentic act of individual creativity, while on a societal level, mathematics both informs and is informed by the culture of those who use and develop it, just as art or language is used and developed [35].

Similarly, in the England Mathematics Curriculum, the purpose of studying mathematics is also related to enjoyment and beauty, in addition to understanding the world. According to the document:

> A high-quality mathematics education, therefore, provides a foundation for understanding the world, the ability to reason mathematically, an appreciation of the beauty and power of mathematics, and a sense of enjoyment and curiosity about the subject [38].

In this curriculum review, we also looked at the term aesthetics and its stemmed words to find references to students developing aesthetic experiences and appreciating the beauty of mathematical proofs [10]. However, the term aesthetics in curriculum documents always appears related to the visual and artistic appreciation of the world. Furthermore, this appreciation for aesthetics is only included in two documents at the secondary level (both from Quebec), and the term is absent from elementary curriculum documents.

The Quebec secondary curriculum includes the term aesthetic in the description and context of its programs, where the discovery of mathematics and its history is seen as a vehicle to

> develop an informed, aesthetic or critical view of the world [39].

This aesthetic view is also applied to the judgment of the media and the quality of a message, as expressed in the following quote:

> Mathematical competencies can contribute to the development of critical, ethical and aesthetic judgment with respect to the media… [students'] spatial sense and knowledge of

> shapes, geometric figures and proportions can also help them develop criteria for assessing media representations in terms of image and movement and for evaluating the aesthetic quality of a message [39].

3.2 Stories in Mathematics Curriculum Documents

Compared to the term surprise, the term story appears significantly more in curriculum documents. Most of the documents in our review include the term at least once, and some of them include it several times in outcomes or achievement indicators. Most of the time, the term is used in reference to story problems or story context for mathematics problems. Using story problems, whether listening to them or creating them (orally, pictorially, and in writing), is mentioned numerous times in the revised documents. Below are some prominent examples.

Manitoba's Grade 1 Curriculum mentions story problems across several achievement indicators. For example, for the Number strand, one of the specific learning outcomes (1.N.9) states that students are expected to

> demonstrate an understanding of addition of numbers with answers to 20 and their corresponding subtraction facts, concretely, pictorially, and symbolically [40].

Some of the suggested ways students can demonstrate this understanding (achievement indicators) are by acting out a story problem, indicating whether a story represents addition or subtraction, and representing story problems pictorially.

Similarly, other provinces in Canada include story problems in several outcomes and performance indicators. Story problems are included in number or numeracy strands to represent or create a context for number sentences in all cases. For example, by Newfoundland and Labrador curriculum guide [41], students are expected to represent a given story problem with visuals or manipulatives, then translate it into a number sentence. The opposite process (creating a story or problem based on a given number sentence) is present in the Nova Scotia curriculum [42]. The same indicators and some suggested activities appear in the curriculum documents of New Brunswick [43], Alberta [33], and Prince Edward Island [44].

Also, the US Common Core Standards include the story as a context of learning and provide it as an example in several outcomes, so, for example, students should "create a story context for $4 \div (1/5)$, and use a visual fraction model to show the quotient" [45]. This is included in all revised documents from states that adhere to the Common Core Standards [35, 46] and other states that still have not followed the standards, such as Florida [47].

However, there are a few instances where stories in mathematics are not directly associated with numeracy. First, in the British Columbia Mathematics curriculum [48], a story is included in one of the curricular competencies in relation to indigenous perspectives and other cultures. The document states that students should

> engage in problem solving experiences that are connected to place, story, cultural practices, and perspectives relevant to local First Peoples communities, the local community, and other cultures [48].

Also, the New York curriculum gives a special connotation to the use of stories in mathematics learning. This document uses the metaphor of a story to guide the mathematics curriculum, which is

> based on the principle that mathematics is most effectively taught as a logical, engaging story [49].

Therefore, the curricular structure is a dynamic, unfolding tale devoted to one character: The Unit (as in a unit of *5 apples* or just *5*) for grades K-5 [46], The Ratio for grades 6–8 [50], and The Function for grades 9–12 [51]. The story is used as a framework to sequence mathematics curriculum, as it is described in a support document:

> At the elementary level, the story's main character is the basic building block of arithmetic, or the unit. Themes like measurement, place value, and fractions run throughout the storyline, and each is given the amount of time proportionate to its role in the overall story. The story climaxes when students learn to add, subtract, multiply, and divide fractions; and solve multistep word problems with multiplicative and additive comparisons [49].

This means that by understanding the unit as the main character in a story, the curriculum encourages relating, manipulating, and converting that basic building block. Based on the unit, the progression for K-5 starts with the initial structures of addition and subtraction, followed with place value and multiplication, and ending with operations with fractions, all of which should be understood by the students as unit-based procedures, which enables them to transfer skills and build upon previous knowledge.

4 Conclusion

Our review found that the concept of surprise is not commonplace in mathematics education research or curriculum documents. Only four studies in the past ten years (apart from work done by the first author of this paper) provided research regarding surprise in mathematics education. One of them related to surprise and aesthetic experiences; another related to eliciting a sense of wonder through creative expression; and the last two were about building anticipation and surprise as part of a narrative (in gaming and storytelling, respectively). This lack of research on the topic is reflected in curriculum documents, where the term surprise is never considered in mathematics standards or curriculum frameworks and descriptions. Only related terms such as wonder, insight, or aesthetic were present. All of them were included as part of curriculum frameworks or descriptions but never as a part of the outcomes or standards for any revised curriculum documents.

In most cases, the terms wonder, insight, and aesthetics appear described merely as a medium to achieve understanding. The term insight is often paired with the construct of problem-solving in the reviewed documents. Only two curriculum documents in this review present ideas more related to creating a sense of wonder in mathematics just for the pleasure of the experience. On the other hand, the term aesthetic always appears related to the visual and artistic appreciation of the world. Furthermore, this appreciation for aesthetics is only included in two documents at the secondary level, and the term is absent from elementary curriculum documents.

In contrast, the term story appears numerous times, both in research and curriculum documents. The identified benefits of stories in mathematics education include:

i. increasing learning outcomes;
ii. revealing understandings and misconceptions when developed by students;
iii. fostering the inclusion of culturally and cognitively diverse learners; and
iv. offering the possibility to integrate technology to increase its impact.

All these benefits, except for the last one, are matched in curriculum documents, where stories (whether listening to them or creating them) are included not only in frameworks and descriptions, as is the case for surprise, but also across several achievement indicators most often related to numeracy and in one case associated with deep understanding (matching benefits i and ii above). In one document, the story is included in one of the curricular competencies in relation to indigenous perspectives and other cultures (matching benefit iii above). And finally, in one document, a story is used as a metaphor to describe the learning progression in the curriculum.

The exploration conducted in this review shows that more research is necessary to connect the use of surprise and story to mathematics thinking and learning in educational settings, which can truly spark a sense of enjoyment and wonder around mathematical ideas. Similarly, curriculum documents should offer a clearer linkage between eliciting such aesthetic experiences and the doing and learning of mathematics in K-12 education. More ideas should be presented to teachers, not only on how to apply surprise and story as a medium but also as a goal of learning mathematics.

Having worked extensively with the ideas of surprise and story for 15 years in classrooms in Ontario and Brazil, we caution that education reform should be inclusive of various methods and approaches and value existing teacher and system knowledge. We noted in Gadanidis, Borba, Hughes, and Lacerda [18]:

> although reform is typically associated with change on a grand, pervasive scale, our model is much less intrusive pedagogically. We are not seeking a revolution in mathematics education, but a strategic focus on mathematics worthy of attention, worthy of conversation, worthy of children's incredible minds, which thirst for knowledge and for opportunities to explore, question, flex their imagination, discover, discuss and share their learning. We believe that occasional, well-designed aesthetic mathematics experiences "that are immersive, infused with meaning, and felt as coherent and complete," and the associated experience of complex, surprising, emotionally engaging, and viscerally pleasing

mathematics, can serve as “a process of enculturation” with lasting impact on students’ (and teachers’) dispositions, living fruitfully in future experiences, by raising expectation and anticipation of what mathematics can offer, and what the intellectual, emotional and visceral rewards might be when quenching a thirst for mathematics.

Core Messages

- Thinking is logical as well as emotional and aesthetic.
- The human brain is wired to enjoy, create, share, and learn from surprising experiences. Humans are storytellers, and the pleasures of good stories are surprise and insight.
- Mathematics curriculum documents typically ignore surprise and story.
- Surprise and story can raise students’ and teachers’ expectations of what mathematics can do.

References

1. Smith DE (1927) Esthetics and mathematics. Math Teach 20:419–428
2. Hardy GH, Snow C (1967) A mathematician’s apology, 1st edn. Cambridge University Press, London
3. Davis P, Hersh R (1981) The mathematical experience. Birkhauser, Boston
4. Dreyfus T, Eisenberg T (1986) On the aesthetic of mathematical thought. Learn Math 6:2–10
5. Krutetskii VA (1976) The psychology of mathematical abilities in schoolchildren. University of Chicago Press, Chicago
6. Papert S (1980) Mindstorms: children, computers, and powerful ideas. Basic Books, Inc.
7. Silver EA, Metzger W (1989) Aesthetic influences on expert mathematical problem solving. In: McLeod D, Adams V (eds) Affect and mathematical problem solving. Springer-Verlag, New York, NY, pp 59–74
8. Sriraman B (2009) The characteristics of mathematical creativity. ZDM- Int J Math Educ 41:13–27
9. Malina F (1979) Visual art, mathematics and computers. Pergamon Press, Oxford
10. Ernest P (2015) Mathematics and beauty, pp 23–27
11. Trakulphadetkrai NV, Aerila J-A, Yrjänäinen S (2019) Bringing mathematics alive through stories. Story in children’s lives: contributions of the narrative mode to early childhood development, literacy, and learning. Springer, Cham, Switzerland AG, pp 199–225
12. Haven K (2014) Story smart: using the science of story to persuade, influence, inspire, and teach. Libraries Unlimited, Santa Barbara, CA
13. Rose F (2011) The art of immersion: how the digital generation is remaking Hollywood, Madison Avenue, and the way we tell stories. W.W. Norton and Co
14. Foster MI, Keane MT (2019) The role of surprise in learning: different surprising outcomes affect memorability differentially. Top Cogn Sci 11:75–87. https://doi.org/10.1111/tops.12392
15. Adler JE (2008) Surprise. Educ Theory 58:149–173. https://doi.org/10.1111/j.1741-5446.2008.00282.x
16. Wouters P, van Oostendorp H, ter Vrugte J et al (2017) The effect of surprising events in a serious game on learning mathematics. Br J Educ Technol 48:860–877. https://doi.org/10.1111/bjet.12458

17. Gadanidis G (2012) Why can't I be a mathematician? Learn Math 32:20–26
18. Gadanidis G, Borba M, Hughes J, Lacerda HD (2016) Designing aesthetic experiences for young mathematicians: a model for mathematics education reform. Int J Math Educ Reform 6:225–244
19. Gadanidis G, Clements E, Yiu C, Group theory, computational thinking, and young mathematicians. Math Think Learn
20. Snow CP (2013) The Two cultures. In: New Statesman. http://www.newstatesman.com/cultural-capital/2013/01/c-p-snow-two-cultures. Accessed 10 Jul 2015
21. Root-Bernstein R (1996) The sciences and arts share a common creative aesthetic. The elusive synthesis: aesthetics and science. Kluwer Academic Publishers, Netherlands, pp 49–82
22. Koichu B, Katz E, Berman A (2017) Stimulating student aesthetic response to mathematical problems by means of manipulating the extent of surprise. J Math Behav 46:42–57. https://doi.org/10.1016/j.jmathb.2017.02.005
23. Waite LA (2013) Re-awakening wonder: creativity in elementary mathematics. University of Letherbridge
24. Ryan LE, Dietiker L (2018) Using plot twists to engage learners. Teach Child Math 24:316–323. https://doi.org/10.5951/teacchilmath.24.5.0316
25. Gunbas N (2015) Students' mathematics word problem-solving achievement in a computer-based story. J Comput Assist Learn 31:78–95. https://doi.org/10.1111/jcal.12067
26. Hassinger-Das B, Jordan NC, Dyson N (2015) Reading stories to learn math: mathematics vocabulary instruction for children with early numeracy difficulties. Elem Sch J 116:242–264
27. Yuksekyalcin G, Tanriseven I, Sancar-Tokmak H (2016) Mathematics and science teachers' perceptions about using drama during the digital story creation process. EMI Educ Media Int 53:216–227. https://doi.org/10.1080/09523987.2016.1236970
28. Mercat C, Filho PL, El-Demerdash M (2017) Creativity and technology in mathematics: from story telling to algorithmic with op'art. Acta Didact Napocensia 10:63–70
29. McCormick KK, Essex NK (2017) Capturing children's multiplication and division stories. Teach Child Math 24:40–47
30. Karaoglan Yilmaz FG, Özdemir BG, Yasar Z (2018) Using digital stories to reduce misconceptions and mistakes about fractions: an action study. Int J Math Educ Sci Technol 49:867–898. https://doi.org/10.1080/0020739X.2017.1418919
31. Corp A (2017) Using culturally responsive stories in mathematics: responses from the target audience. Sch Sci Math 117:295–306. https://doi.org/10.1111/ssm.12247
32. Green KB, Gallagher PA, Hart L (2018) Integrating mathematics and children's literature for young children with disabilities. J Early Interv 40:3–19. https://doi.org/10.1177/1053815117737339
33. Alberta Ministry of Education (2016) Mathematics kindergarten to grade 9 program of studies
34. Indiana Department of Education (2014) Mathematics K-12 standards. https://www.doe.in.gov/standards/mathematics. Accessed 18 Feb 2020
35. Colorado Department of Education (2020) Mathematics academic standards
36. South Carolina Department of Education (2015) College and career-ready standards for mathematics K-12
37. Alberta Ministry of Education (2008) Mathematics grades 10–12
38. England Department for Education (2014) National curriculum in England: mathematics programmes of study. https://www.gov.uk/government/publications/national-curriculum-in-england-mathematics-programmes-of-study/national-curriculum-in-england-mathematics-programmes-of-study. Accessed 18 Feb 2020
39. Gouvernement du Québec (2016) Secondary mathematics program cycle 2
40. Manitoba Education (2013) Kindergarten to grade 8 mathematics manitoba curriculum framework of outcomes
41. Government of Newfoundland and Labrador (2018) Mathematics—K-12 English programs curriculum guides. https://www.gov.nl.ca/eecd/k12/curriculum/guides/mathematics/. Accessed 16 Feb 2020

42. Government of Nova Scotia (2016) Mathematics curriculum documents P–12. https://sapps.ednet.ns.ca/Cart/items.php?CA=12andUID=MTZGZWIyMDIwMjMzNjQ5MTk4LjIuOTQuNTk=
43. Government of New Brunswick (2010) K-9 mathematics curriculum. https://www2.gnb.ca/content/gnb/en/departments/education/k12/content/anglophone_sector/curriculum_anglophone.html
44. Government of Prince Edward Island (2015) Mathematics curriculum grades 1–12. https://www.princeedwardisland.ca/en/information/education-and-lifelong-learning/mathematics-curriculum. Accessed 16 Feb 2020
45. Common Core State Standards Initiative (2010) Common core state standards for mathematics
46. New York State Common Core (2013) A story of units: a curriculum overview for grades P-5
47. Florida Department of Education (2014) Mathematics K-12 Florida standards
48. British Columbia Ministry of Education (2016) Mathematics curriculum K-9
49. New York State Common Core (2013) How to implement a story of units
50. New York State Common Core (2013a) A story of ratios: curriculum map and overview for grades 6–8
51. New York State Common Core (2013b) A story of functions curriculum map and overview for grades 9–12

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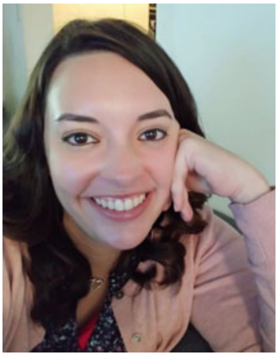

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14 Storytelling: The Ancient Tool of Using Stories to Communicate Knowledge for a Sustainable Future

Maria Hofman-Bergholm

The Saami's are our teachers and we will learn from them. Then we will be happier and healthier in every way.

Carl von Linnaeus after his trip to Lapland, 1732

Summary

As humanity faces alarming global problems and sustainable development is a well-known concept by now, it seems obvious that we might need to do something more to change the negative trend of disasters that humanity is facing. There are already good thoughts, research, and science regarding sustainability, but perhaps we need to add something more. One of the problems why climate change escalates and not enough action seems to be taken might be that there is a disconnection between science, culture, and traditional knowledge. We know the facts produced by research and highlighted by population groups possessing traditional knowledge. But we still do not seem to know how to act on these facts in a proper way. This will be a theoretical chapter discussing some possible ways in our work forward towards sustainability. Is there a way to reconnect science, culture, and traditional knowledge? Could it be done through education, or should we broaden the perspective to also include informal education through,

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N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_14

for example, transformative tourism? This chapter will discuss the possibilities traditional knowledge with its history of storytelling could provide in the struggle to reconnect important systems in our society. Could we use storytelling and systems thinking as a method and means to understand and approach the complexity of the concept of sustainability?

Graphical Abstract/Art Performance

Grandmother and granddaughter.
(Painting by Sophie Skagersten).

Keywords

Indigenous knowledge · Nature entrepreneur · Nature guide · Storytelling · Sustainability · Traditional knowledge

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

Humanity is facing alarming global problems of overpopulation, an insecure food system, and an increasing shortage of clean water and sanitation. Even though sustainable development has been a familiar concept for more than 30 years now, deforestation continues, air pollution and biodiversity loss increase [1]. The last decade has brought the climate debate to the front. Devastating hurricanes, floods, droughts, earthquakes, and tsunamis have become a recurring feature in people´s everyday lives through worldwide news reports. Discussions are raised around climate change and whether it is human actions or inactions that have affected nature and pushed these disasters forward.

In this context, Kakoty [2] raises an important question; if we agree that human actions directly contribute to climate change, why is no action taken to correct it? One possible answer to this question is probably to be found in the systems created by mankind, political and economic systems with a focus on a constant growth cycle and with one purpose: an ever-growing consumption and production. Nowadays, the main focus of all societies seems to be consumerism, which is declared as a requirement to achieving happiness [3, 4]. The politics and economic forces have convinced us that our happiness is dependent on growth and consumption [5]. This, in turn, has led to the fact that prosperity is identified with consumption and wealth [6].

If we put this in relation to Kakotys [2] reasoning around the economic system developed by mankind based on a model of raising growth from ever-increasing consumption, we must now understand that an ever-increasing consumption requires an ever-increasing production of wares which is why we now start to face the limited supply of natural resources. This and the fact that some recent studies indicate that an increase in income per capita does not correlate with levels of happiness after reaching a certain point in income per capita should be a wake-up call [5, 6]. An adapted system thinking could facilitate the understanding of this. Plain and simple, more money does not mean more happiness after reaching a certain level of income; instead, there is research indicating that our habits of overconsumption are pushing us in the opposite direction towards illness, our habits seem to alienate us from our social relations that are important for our well-being [5]. These insights put in touch with the understanding that our overconsumption depletes our natural resources call for a new way of thinking. More and more, it now appears that *social relations* (living with) and active participation in the society where you *do things for others* are equally or more important to our well-being than economic values [7]. Then it should be obvious that there is a need for a new way of thinking, considering that our current, unsustainable lifestyle does not give us the benefits we think it does. We may need to be reunited with the idea that the meaning of life is not consumption; instead, we should look for what makes our own life feel meaningful. That means we need to change our current mindset and adopt a new view of our relationship to and interaction with nature [8].

For a long time, Western science has been highlighted as the leading science with a hegemonic dominance, which has caused a kind of marginalization and dismissal of indigenous and aboriginal perspectives [9]. In 2015 the United Nations (UN) members agreed on 17 sustainable development goals (SDGs) where the importance of traditional indigenous knowledge is highlighted as important to reach a truly sustainable development [10]. Research shows the importance of integrating traditional knowledge with Western science for a sustainable future; however, very little is mentioned about how to proceed. Some opportunities will be discussed here on how we could possibly integrate science from different fields with culture. But first, the concept of sustainability needs to be discussed.

2 The Western and the Indigenous Concept of Sustainability

Sustainability is a complex concept. The scientific community has commonly accepted that there are four dimensions interrelating in the concept of sustainable development, i.e., the economic, social, ecological, and social dimensions. But there are also different aspects of the dimensions included, which are complexly interrelated, and that is why sustainability and sustainable development is perceived as very intricate [11].

Broadly speaking, the Western view of the concept of sustainability and the indigenous differ in some areas. The Western concept of sustainability differs a bit from the indigenous concept; Throsby and Petetskaya [12] note that the two approaches share some common concerns, but there are also differences between the Western and the indigenous view of the concept. Both the Western and the indigenous views of sustainability consist of a worldview based on the thought that the world is built by holistic systems where everything is interconnected in different ways, and nothing exists in isolation, but the way the holistic systems are characterized differs a lot between the approaches. In the Western concept, the connections consist between major areas as macroeconomy, the natural capital stock, climate system, and society. In the indigenous perspective, the holistic systems and interconnections are more comprehensive, encompassing other areas as kinship, language, country, and ceremonies. The indigenous perspective embraces the cultural perspective in a completely other way than the Western [12].

Some researchers [13] argue that it would be possible to integrate local and indigenous knowledge systems with science to develop effective cooperation and facilitate the exchange of knowledge between the different knowledge systems. However, to achieve such kind of collaboration requires a change in how we approach the local, traditional or indigenous knowledge system. It is not to be "scientific studies about" or "scientific studies into," it should be a collaboration with equitable engagement for supporting investigations into our shared environmental challenges [13]. Also, Mazzocchi [14] argues about the importance for the two different approaches of knowledge systems to come together and see the value in learning from each other.

Herman [15], Tulloch [16], and Wolff [17], among others, argue that Christianity and the scientific revolution have developed a philosophy of knowledge that dominates our Western thinking today. Nature has become an object of control through technology. This development has resulted in a disconnection between science, culture, and traditional knowledge, which is one of the major problems today as science gives us tools, but it is the culture that determines what we do with the tools. If science and culture are disconnected, we might develop scientific tools that, in the long term, are useless if we cannot understand how to use them in a proper way. This disconnection is also why Herman [15] deduce climate change to be a social and behavioral issue.

To reconnect man with nature and science with culture and traditional knowledge, it seems urgent to integrate systems thinking in all levels of education, as suggested by Hofman-Bergholm [1]. Systems thinking provides a holistic way of thinking about all parts of society and nature as interconnected and is probably a prerequisite for a sustainable future. Systems thinking both could and should be integrated both in formal and informal education to speed up the urgent change that is needed in our way of thinking. UNESCO (the United Nations Educational, Scientific, and Cultural Organization) has also raised the importance of changing the way people think and act for a sustainable future in their Global Action Program on Education for Sustainable Development—Future Forward [18]:

> Long-term sustainable development can be achieved only if individuals and societies change the way they think and act. Education is key to achieving this transformation [18].

But in this reasoning, one should remember that this is a paradox. For example, the well-known UN document from 1992, Agenda 21, pays the greatest attention to education. Education is emphasized as a key to a sustainable future, but it is education as it is formed today that has brought us to the point where we stand now, in an unsustainable situation. Christianity, Dualism, and education are three possible factors that have influenced societal development to this stage. The development of education has, over time, led to education being disconnected from the social or societal context. As long as humanism focuses on human development, the gap between man and nature will remain. However, education may not be the only tool for creating a good and functioning society; this is not the task of education. The task of education is to discuss what a good life consists of, not to create and develop it [17]. This reconnects to Herman's [15] thoughts on the disconnection between our different systems in society today.

Beckford et al. [9] argue that if we want a new ecological ethos, we need to start with education, not education as it appears today, but an education that has realized the value of indigenous knowledge, which could generate sustainability and stewardship. But as the change in educational systems is known to be very time-consuming [1], a way to accelerate the needed change in people's attitudes could be possible through greater investment in, for example, transformative tourism and other kinds of informal education. More reading about integrating systems thinking in formal education could be found in [1]. This chapter will now focus on traditional knowledge, sustainability, and transformative tourism as a way to affect societal development towards sustainability.

3 Traditional Knowledge and Indigenous Knowledge

There is no universal definition or word for the knowledge of indigenous people. Traditional knowledge, indigenous knowledge, and local knowledge can be seen as different terms with similar meanings. It refers to cultural, non-material knowledge transmitted from generation to generation and from individual to individual in local, aboriginal, or indigenous societies [12, 14]. Blewitt [8] use the term "traditional ecological knowledge: the wisdom of the elders," meaning ecological traditions transmitted from generation to generation. According to Mazzocchi [14],

> traditional ecological knowledge is interpreted as a cumulative body of knowledge, practices and representations that describes the relationships of living beings with one another and with their physical environment, which evolved by adaptive processes and has been handed down through generations by cultural transmission.

In the pre-modern society, it was general for common people to have extensive species knowledge about plants and animals. Marks and rules, clues, sayings, and rhymes were used to store and remember the knowledge of nature. This was a condition for survival in a society where nature was a major resource. Folk poetry was a tool for predicting weather at a time when survival depended on weather, wind, drought, rain, heat, and cold. Tradition and storytelling conveyed knowledge about how to read the signs in nature. Even today, there are known statements about how to read nature, e.g., "when the swallows fly low, it will be rain," but nowadays, people have greater confidence in the weather service's forecasts and consider such claims to be oddly curious claims from the past [19].

But what happens to such valuable knowledge when the older generation can no longer tell about it, and most of the younger generations have switched to gainful employment from agriculture? Children and youths seem to alienate more and more from nature, which has negative consequences such as the fact that they assimilate little or no knowledge of nature, which at a later stage leads to ecological illiteracy. This, in turn, affects the attitude towards nature in adulthood, which can have a negative impact on the planet's long-term health as you have to get to know nature to care about it [20].

4 Traces of the Sustainability Concept in Aboriginal Cultures

One can trace the sustainability concept a long way back in aboriginal cultures through studying the old languages of different tribes and peoples. For example, in northern Scandinavia, the Saami people, an arctic indigenous population group living in interaction with nature, have a tradition of transferring their knowledge about their living environment and local traditions to the next generation by storytelling. And they have a special word for this Saami traditional knowledge, "árbediehtu," embracing the conditions of nature and man in its context. It is a holistic view which means that man and the environment must be considered and treated as a whole. "Árbediehtu" is seen as a collective knowledge the Saami carry with them, and it consists of knowledge about heritage, traditions, customs, and ways of life. The Saami believe that biodiversity is a prerequisite for all life on earth and forms the base for the ecosystem services necessary for human existence and well-being [21].

This can be seen as an example of that indigenous people have a holistic worldview and live in interaction with nature. They understand the interconnected systems needed for a sustainable future. This probably applies to every different aboriginal culture as it seems like indigenous groups embrace this kind of worldview. Another example can be found in New Zeeland, where the word "kaitiaki" is a Māori who has a duty to pass the environment to future generations in good condition according to the Cambridge dictionary [22]. An article [23] published in 2017 on the New Zeeland science learning hub develops and explains in a little more detail what the worldview of the Mãori looks like. Beyond "kaitiaki," the Māori people also have a responsibility to maintain the viability, *mauri*, which permeates everything and binds together the spiritual and the physical world. The Maori term for this assignment is *"Kaitiakitanga"* which means patronage, stewardship, or care and must be interpreted in the right context of the Maori who have a holistic relationship to the world around them. *"Kaitiakitanga"* means reciprocity; nature needs to give the people who take care of it *"kaitiaki"* what they need to meet their needs, both physical and spiritual. *"Kaitiaki"* are responsible for ensuring that nature retains its ability to do so in the future, that it retains its *"mauri,"* its vitality.

4.1 Sustainable Development, Traditional Knowledge, and Biodiversity—How Are They Connected?

Primarily we need to remember and understand that the basis for all life is actually nature. If there were no nature, there would not exist any economics, culture, or social life. This is the reason why sustainability, in the beginning, was linked to biology and was perceived as some form of nature conservation. Now, within the era of the climate crisis, we can see that our whole society is dependent on well-functioning ecosystems, and ecosystems are dependent on biodiversity [11];

> Biodiversity is the name given to the variety of ecosystems (natural capital), species and genes in the world or in a particular habitat. It is essential to human well-being, as it delivers services that sustain our economies and societies [24].

This is how the European Environment Agency defines the word biodiversity. The economic values of the European culture are obvious. Sustainable development, biodiversity, and ecosystems are interconnected to the macroeconomy exactly as Throsby and Petetskaya [12] suggest in the discussion on the Western concept of sustainability earlier in the chapter. The ecosystems on earth are seen as a capital stock that provides humans with a variety of goods such as food, wood, fuel, carbon dioxide absorbers, water purifiers, and recreation, goods that form the basis of human social and economic well-being [25, 26]. In addition to providing humans with these products, ecosystems also help to prevent the spread of disease through biological control. The ecosystems in the world also provide humans with genetic and medical resources for the prevention or cure of diseases [26]. This together constitutes ecosystem services and biodiversity–a service from nature to mankind. But it can only thrive and survive if we take care of it in a proper way based on a worldview with its origin in traditional knowledge. One could say that the future of mankind lies in the hands of mother nature or Pachamama (the Inka Earth mother).

We depend on nature to survive, but during the last years, indigenous groups in, for instance, South America have raised their environmental concerns, which are based on ancient beliefs. They emphasize that our current problems derive from our abuse of the sources of Pachamama [27, 28]. It feels frustrating that aboriginal people with their worldview bear less responsibility for climate change, but they will probably suffer the most of the climate change and its negative effects as they are dependent on the ecological system [29]. The Sami Parliament [21] in Sweden defines the term biodiversity as a prerequisite for all life on earth, and it forms the basis for the ecosystem services that are necessary for the existence and well-being of mankind.

Already in the early 90 s, it was recognized internationally that traditional knowledge played an important role both in the protection of biodiversity and in achieving sustainable development [30]. Article 8 of the Convention on Biological Diversity urges us to:

> …respect, preserve and maintain knowledge, innovations and practices of indigenous and local communities embodying traditional lifestyles relevant for the conservation and sustainable use of biological diversity…. [31].

Gadgil et al. [30] argued already in 1993 that traditional or indigenous knowledge has great potential and was rediscovered to be a model for how to live in healthy interaction with the environment, but Campbell [10] states that it is just recently we started to understand the real importance of the traditional knowledge system. Indigenous cultures manage about 28% of the world's land surface, and they serve as guardians for most of the animal and plant species in the world. Calculations count to 80% of global biodiversity that indigenous cultures preserve and guard. All over the world, we are all dependent on nature and the food system that nature provides us with. Yet we have kept on denying the indigenous people's battle against the extensive deforestation, the degradation of land, and the consequences of climate change until lately when international organizations have started to recognize the importance of this fight and global advocacy of indigenous peoples is lifted to the front [10].

In Canada, researchers have worked with the Canadian mainstream curricula to implement indigenous perspectives. They claim that our modern society has lost track of its connection to the environment. They also highlight the rights Canadian students have to learn about indigenous knowledge, perspectives, and epistemologies and to learn the indigenous way of living in interaction with nature that could help mainstream people in Canada to reconnect with nature [9].

Beckford et al. [9] has conducted research through interviews with officials of the Walpole Island Heritage Center to examine different cultural aspects of environmental stewardship and sustainability in their work, looking for lessons for teaching ecological education in classrooms in Canada. One of the older female respondents stated:

> We are totally dependent on our land. Without the river we would have no fish, without the marshes we would have no ducks, without the mishkodi we would have no medicines, without the beauty of nature we would have no peace. The land is our soul [9, p. 244].

This quote alone could answer the question about how sustainable development, traditional knowledge, and biodiversity are connected. Nature is something more than just for our material survival. Take time to read and ponder the quote. It occurs very simply and is an example of systems thinking that would be quite easy to teach even small children to understand and could help develop a more wide and deep form of systems thinking. That is why storytelling for traditional knowledge transformation could be very valuable to offer, from kindergarten to adult education and also in transformative tourism. Storytelling can make facts more easily accessible and understandable.

According to for instance the Arctic Centre at University of Lapland [32], storytelling has been used throughout centuries to communicate traditional knowledge.

5 Storytelling

> Storytelling is a two-way interaction, written or oral, between someone telling a story and one or more listeners. It is a well-known and powerful means of communicating messages and engaging audiences [33].

Storytelling can be seen as the ancient tool of communicating knowledge through telling stories, and it has the potential to engage and motivate the listener in a completely different way than traditional logical-scientific communication of knowledge [33]. To communicate evidence and place the knowledge in a context through storytelling makes it easier to understand and process the knowledge for the audience, and it is shown to increase the willingness to act upon the knowledge [33]. That makes storytelling a powerful tool in changing human actions and is a possible tool to use within the area of transformative tourism to enable change. This is as storytelling is shown to engage the listener, and engagement is in a key position in the process of change.

One of the reasons why climate change seems to continue without people reacting very much is the cause of a common psychological reaction when we face environmental problems or concerns. This common psychological reaction is denial or apathy, which are a kind of defense mechanism that our species has evolved to continue affecting and harming nature in bad ways, even though we all know it is wrong or have bad consequences [34]. But imagine if these defense mechanisms could be affected by emotional connections when facing facts through storytelling as, according to Sundin et al. [33] turns out that if a person feels emotionally involved and engaged, he or she is more likely to act upon new information or knowledge.

Also, the UN has highlighted storytelling as a possible tool to use to make the SDGs more concrete and tangible for the public. Digital storytelling through videos and documentaries is one way to move forward according to sustainability projects within the UN. In a UNESCO [35] publication, storytelling is highlighted as an effective ESD (education for sustainable development) pedagogy because traditional stories that contain the wisdom of the elders reflect values that develop respect for the environment and cultural heritage. Or as Bird Miller [36, p. 15] states.

> Story-telling may provide a bridge between "once upon a time" and today, somewhere else and right here, as well as traditional and Western scientific knowledge.

6 Transformative Tourism: A Possible Pathway Forward with the Guidance of Skilled Nature Entrepreneurs

According to research on the subject, transformative tourism simply means tourism that affects the tourist in such a way that a change in attitude and possibly a change in lifestyle occurs, see for instance [37–39].

Transformative tourism strives for a changed attitude towards nature and is also expected to turn customers into important messengers to change the interest in and protection of nature, among others. Sustainable tourism is often described as the opposite of mass tourism, and it also includes respecting the indigenous peoples and the areas that are important to them. Some researchers use the term sustainable tourism, other use transformative tourism, but it seems like the fundamental value of sustainability constitute a common basis for both views, or perhaps you can say it is different terms used for activities with the same desired results, namely to transform tourism towards a profound form of sustainability [37–39]. Walker and Moscardo [37] describe sustainable tourism as local activities providing insights and a sense of the local place and destination, which, according to the theory, promotes the development of responsibility within the tourist to take care of the place or destination and preserve it. To preserve, interpret and reproduce aboriginal cultures and lifestyles for tourists are often suggested as tools to achieve the insights and sense of place needed to develop the sense of responsibility [37].

There is a lot more to transformative tourism than attitude change, but in the end, striving for a sustainable future and sustainability is the main underlying focus of transformative tourism. From the literature on transformative tourism, one can find descriptions like cross-cultural understanding, global citizenship, positive change in values and attitudes, and changes in lifestyle [38].

As a result of their conceptual model, Pung et al. [38] propose that:

> tourist transformation is facilitated by contextual stimuli which strike the tourists and lead to reflecting and integrating new knowledge, skills and beliefs, which ultimately enhance the tourists' existential authenticity and increase the tourists' cross-cultural understanding and pro-environmental awareness, with potential consequences on long-term behavior [38, p. 2].

Kirillova et al. [39] suggest that the tourism industry's representatives who endorse life changes among tourists need to convince the tourists to act upon their own inner existential courage and selfhood. To reach a person's sense of selfhood, emotions need to be involved. To infuse for example moral values within younger generations, storytelling has been used for generations [35].

7 The Nature Entrepreneur: A Link Between Modern Man and Nature

Research emphasizes that people need to get to know nature and develop an understanding of it to nurture it in a proper way [40]. As a result of urbanization, less and less people know nature in a deeper sense. Children of today do not develop any deeper contact with nature, both children in the countryside and in the cities spend a lot of time indoors, and their relationship with nature is abstract rather than concrete [41].

We perceive the outside world in two different ways, spontaneous attention and directed attention. When we stay in nature, spontaneous attention is switched on, and the brain registers impressions from the outside world without much effort. Nature provides a kind of free zone from the high-tech society that constantly makes demands, where performance is a key, and the directed attention is used. Nature is perceived as unpretentious. The need to be alone and the need to disappear from demands is common. Being alone in nature gives man a feeling of avoiding competition with other people for a while [42–44]. Urbanization took off around the turn of the last century, and since 2008, more than half of the world's population lives in cities. This has led to lost contact with nature, but not only in the cities. Also, children (and adults, the author's addition) in the countryside has largely developed an "urban" relationship with nature because life in the countryside has changed dramatically in the last 40 years [41].

The lost nature contact is not good for any of us. In Scandinavia, nature entrepreneurs have understood this, and there are nowadays nature companies that offer various services to customers that need the peace nature can bring them. That modern man recovers and feels good in nature despite the fact that most of us are not very close to nature in everyday life has its origins in the childhood of mankind. Living in nature is the normal state of the human species; it is the home of the human species with a deeply human experience of a life in close contact with nature [45].

There is research indicating the importance of forest visits for people's mental well-being and how staying in the forest affects heart rate and blood pressure. The research suggests that the forest may be a suitable environment for the rehabilitation of workers who are on sick leave due to stress [46]. Our bodies are adapted to moving and physical activity. This is how we have lived since time immemorial, except now very recently when most people sit still most of their waking time. This also applies to the inside, which is adapted to nature's different sensory impressions, but nowadays, most people live in nature-poor environments with other sensory impressions. Living habits have changed so that most of us live under constant stress and mental health suffers. It is obvious that humans can handle a lot of stress and a high-tech life, but only if we in between make sure to take a break and let the body return to an inner state of rest. The timeless inner self needs real breaks with nature's presence to cope with the stressful everyday life we live today [45].

The reasoning so far seems to indicate quite clearly that mankind needs something more than money, goods, and consumption for their welfare. Man needs to be reunited with the meaning of life, and for this to be possible, a change is required in the current way of thinking about consumption, status, and one's relationship to nature. The relationship with nature needs to change towards a living in interaction with nature which is something the aboriginal groups often do. To change man's relationship with nature, transformative tourism and storytelling could play an important role. And the occupational group that could be highlighted to play an important role in the work towards sustainability are nature entrepreneurs and nature guides. They could serve as ambassadors for sustainability, both ecological and cultural, and at the same time be a link between modern man and nature.

Being a nature entrepreneur often involves multifaced tasks, varying working days, and many different types of challenges. Most nature entrepreneurs are consciously or unconsciously ambassadors for sustainability. In a nature company led by a nature entrepreneur, nature forms the basis for the entire business. Quite typical of a nature company is that the business often varies depending on the season. Nature companies also include companies that engage in various forms of nature tourism [47].

Some nature tourism companies also have niched in on taking care of the cultural heritage. The Swedish National Heritage Board in Sweden [48] has written a report very worth reading on how cultural heritage can support sustainable societal development. They state that:

> Cultural heritage helps to create belonging and understanding of our places in the times. This is expressed by cultural heritage saying something about how we are and what we have been, where we are and where we are going.

As a reconnection to both nature and culture has been lifted forward by many researchers as required for a sustainable future, it is of great importance that nature entrepreneurs and nature guides also in the continuation are encouraged and appreciated for their work within this area. They have the opportunity to, in addition to formal education, teach people the importance of biodiversity, ecosystems, nature contact, traditional knowledge, and cultural heritage for a good life in the future.

8 Discussion

To help us reconnect to nature and culture, education is an important cornerstone, but not the education that has taken us to where we are today but a changed education. As educational change is shown to be very time-consuming, we also need to find change agents in other areas of informal education. Here I suggest that nature entrepreneurs and nature guides can play a major role through working and offering services within transformative tourism and informal education. Nature guides and nature entrepreneurs can be seen as a very important professional group to make the modern man more interested in nature and culture and develop the necessary understanding of biodiversity and the interconnected systems in nature that we have to take care of so that nature can continue to take care of us.

Aboriginal people often possess traditional knowledge, but we sadly have a history of not treating the indigenous people of the world very well. Can we expect them to be willing to tell us their stories? We might need to take ourselves by the collar and get away from the static we-them thinking and make sure we, in a respectful way, could exchange stories and experiences before it is too late. This could be a dimension within the area of transformative tourism to take hold of and develop in a respectful way. My suggestion is that nature entrepreneurs and nature guides could act as a link between locals/aboriginal people and tourists to keep the stories alive and transfer the important traditional knowledge to the future. In other words, the professional group of nature guides and nature entrepreneurs could be highlighted and lifted forward as an important cornerstone in the society to reconnect man with nature and for a sustainable future to thrive.

9 Conclusion

From the discussions in previous paragraphs, it turns out quite clearly that native people have a different approach to nature and its resources than non-aboriginal people. But here, we who are adjusted by the Western way of thinking should take a step back, look at ourselves and our Western preconceptions and critically review it. The power of change is in our hands. We could change our mindset and not make this a "we and them" discussion, we could adopt a cross-cultural approach and all come together and learn from each other's cultural and traditional stories. Because in the end, there is no "we and them," we are all dependent on the natural resources that we sooner or later are running out of if we do not take the necessary steps towards change in our mindset.

It is a bit interesting that almost everyone thinks about changing the world, but very few think about changing themselves. We seem to have forgotten that we all are a part of the world. The change needs to start within yourself. Listen to the stories of old and wise people, take the stories to your heart and let the change begin from there.

Core Messages

- Science, culture, and traditional knowledge need to be reconnected for a sustainable future.
- Traditional knowledge and cultural heritage are indispensable to reconnect the modern human with nature.
- Storytelling with the potential to influence change in mindset could be a suitable tool to transfer traditional knowledge.
- Nature entrepreneurs and nature guides could be important cornerstones in transferring traditional knowledge.

References

1. Hofman-Bergholm M (2018) Could education for sustainable development benefit from a systems thinking approach? Systems 6:43. https://doi.org/10.3390/systems6040043
2. Kakoty S (2018) Ecology, sustainability and traditional wisdom. J Clean Prod 172:3215–3224
3. Assadourian E (2013) Re-engineering cultures to create a sustainable civilization. State of the world 2013: is sustainability still possible? Worldwatch Institute; Island Press, Washington, DC, USA, pp 113–125
4. Bauman Z (2007) Consuming life. Polity Press, Cambridge, UK
5. Salonen OA, Konkka J (2015) An ecosocial approach to well-being: a solution to the wicked problems in the era of anthropocene. Foro Educ 13:19–34
6. Andersson JO, Eriksson R (2010) Elements of ecological economics. Routledge, New York, NY, USA
7. Helliwell JF (2014) Social norms, happiness, and the environment: closing the circle. Sustain Sci Pract Policy 10:78–84
8. Blewitt J (2008) Understanding sustainable development. London, UK, Earthscan
9. Beckford C, Jacobs C, Williams N, Nahdee R (2010) Aboriginal environmental wisdom, stewardship, and sustainability: lessons from the Walpole Island first nations, Ontario, Canada. J Environ Educ 41(4):239–248
10. Campbell J (2019) No sustainable development without indigenous people. (online) https://sdg.iisd.org/commentary/guest-articles/no-sustainable-development-without-indigenous-peoples/
11. Wolff L-A, Sjöblom P, Hofman-Bergholm M, Palmberg I (2017) High performance education fails in sustainability?—a reflection on finnish primary teacher education. Educ Sci 7:32
12. Throsby T, Petetskaya E (2016) Sustainability concepts in indigenous and non-indigenous cultures. Int J Cult Prop 23(2):119–140
13. Tengö M, Hill R, Malmer P, Raymond C, Spierenburg M, Danielsen F, Elmqvist T, Folke C (2017) Weaving knowledge systems in IPBES, CBD and beyond—lessons learned for sustainability. Curr Opin Environ Sustain 26–27:17–25
14. Mazzocchi F (2006) Western science and traditional knowledge: despite their variations, different forms of knowledge can learn from each other. EMBO Rep 2006 7(5):463–466. https://doi.org/10.1038/sj.embor.7400693
15. Herman RDK (2016) Traditional knowledge in a time of crisis: climate change, culture and communication. Sustain Sci 11:163–176. https://doi.org/10.1007/s11625-015-0305-9
16. Tulloch L (2015) Is Emile in the garden of Eden? Western ideologies of nature. Policy Futures Educ 13(1):20–41. https://doi.org/10.1177/1478210314566729
17. Wolff L-A (2011) Nature and sustainability. An educational study with Rousseau and Foucault. Diss. LAP Lambert Academic Publishing GmbH & Co, Saarbrücken
18. UNESCO (2017) Complimentary additional programme 37 C/5—CAP education for sustainable development. Available online: https://fr.unesco.org/system/files/Education%20for%20Sustainable%20Development%20-%20Future%20Forward.pdf. Accessed 19 Aug 2020
19. Stattin J (2014) När naturen talar. Ingår i Midholm & Saltzman (eds): Naturen för mig. Nutida röster och kulturella perspektiv [When nature speaks. In: Nature to me. Contemporary voices and cultural perspectives.] (Author translation). Institutet för språk och folkminnen i samarbete med Folklivsarkivet, Lunds universitet, Göteborg
20. Wells N, Jimeneze F, Mårtensson F (2018) Children and nature. In: van den Bosch, Bird (eds) Oxford textbook of nature and public health: the role of nature in improving the health of a population. Oxford University Press. https://doi.org/10.1093/med/9780198725916.001.0001
21. Sami Parliament webpage https://www.sametinget.se/109396. Accessed 26 Aug 2020
22. Cambridge dictionary (online 2020) https://dictionary.cambridge.org/dictionary/english/kaitiaki

23. New Zeeland Science Learning Hub (2017) https://www.sciencelearn.org.nz/resources/2544-understanding-kaitiakitanga. Accessed 25 Aug 2020
24. European Environment Agency (2020) https://www.eea.europa.eu/themes/biodiversity/intro. Accessed 25 Aug 2020
25. Zurlini G, Jones KB, Li L, Petrosillo I. Potentials of ecosystem service accounting at multiple scales. Encyclopedia of Earth. https://editors.eol.org/eoearth/wiki/Potentials_of_ecosystem_service_accounting_at_multiple_scales. Accessed online 25 Aug 2020
26. Sala OE, Meyerson LA, Parmesan C (red) (2009) Biodiversity change and human health. From ecosystem services to spread of disease. Scientific committee on problems of the environment, vol 69. Island Press, Covelo
27. Hill M (2008) Inca of the blood, inca of the soul. J Am Acad Relig 76(2):251–279. https://doi.org/10.1093/jaarel/lfn007
28. Dransart P (1992) Pachamama: the inka earth mother of the long sweeping garment. In: Barnes R, Eicher JB (eds) Dress and gender: making and meaning. Berg, New York/Oxford, pp 145–63. Print
29. Jaakkola J, Juntunen S, Näkkäläjärvi K (2018) The holistic effects of climate change on the culture, well-being, and health of the Saami, the only indigenous people in the European Union. Curr Environ Health Rep
30. Gadgil M, Berkes F, Folke C (1993) Indigenous knowledge for biodiversity conservation. J Human Environ 22:151–156
31. United Nations (1992) Convention on biological diversity (with Annexes). No 30619. United Nations, Rio de Janeiro, Brazil
32. Arctic Centre, University of Lapland Traditional Knowledge (arcticcentre.org) https://www.arcticcentre.org/EN/arcticregion/Arctic-Indigenous-Peoples/Traditional-knowledge
33. Sundin A, Andersson K, Watt R (2018) Rethinking communication: integrating storytelling for increased stakeholder engagement in environmental evidence synthesis. Environ Evid 7:6. https://doi.org/10.1186/s13750-018-0116-4
34. Koger S, Winter D (2010) The psychology of environmental problems: psychology for sustainability. New York, NY, USA, Tylor and Francis Group
35. UNESCO (2012) Education for sustainable development. Sourcebook. Available online: https://sustainabledevelopment.un.org/index.php?page=view&type=400&nr=926&menu=1515. Accessed 25 Aug 2020
36. Bird Miller M (2010) Storytelling for sustainability. Ometeca 14(15):2010
37. Walker K, Moscardo G (2016) Moving beyond sense of place to care of place: the role of Indigenous values and interpretation in promoting transformative change in tourists' place images and personal values. J Sustain Tour 24(8–9):1243–1261. https://doi.org/10.1080/09669582.2016.1177064
38. Pung JM, Gnoth J, Del Chiappa G (2020) Tourist transformation: towards a conceptual model. Ann Tourism Res 81. https://doi.org/10.1016/j.annals.2020.102885
39. Kirillova K, Lehto X, Cai L (2017) What triggers transformative tourism experiences? Turism Recreation Res 42(4):498–511. https://doi.org/10.1080/0250281.2017.1342349
40. Gruenewald DA (2003) The best of both worlds: a critical pedagogy of place. Educ Res 32 (4):3–12
41. Mårtensson F, Lisberg Jensen E, Söderström M, Öhman J (2011) Den nyttiga utevistelsen? Forskningsperspektiv på naturkontaktens betydelse för barns hälsa och miljöengagemang (in Swedish) [The wholesom outdoor stay? Research perspectives on nature contact importance for children's health and environmental commitment]. The Swedish Environmental Protection Agency, Stockholm
42. Ottosson ÅM (2006) Naturkraft – om naturens lugnande, stärkande och läkande effekter (in Swedish) [Power of nature—about the calming, strengthening and healing effects of nature (author translation). Wahlström & Widstrand, Stockholm
43. Korpela K, Staats H (2014) The restorative qualities of being alone with nature. In: Coplan, Bowker JC (eds) The handbook of solitude: psychological perspectives on social isolation,

social withdrawal, and being alone (pp.351–367) Publisher: Wiley. https://doi.org/10.1002/9781118427378
44. Bodman G (2019) Leva ett med naturen (in Swedish). [Live one with nature] (author translation). Diss. Åbo Akademis förlag: Åbo
45. Ottosson Å, Ottosson M, Magnusson R (2020) Närmare naturen (in Swedish) [Closer to nature] (author translation). Bonnier Fakta
46. Lundell Y, Dolling A, Nordström E-M, Skärbäck E, Stoltz J, van den Bosch M, Grahn P (2015) Rehabiliteringsskog och virkesproduktion. Går de att kombinera? (In Swedish). [Rehabilitation forest and timber production. Can they be combined?] (author translation). Fakta skog. Rön från Sveriges lantbruksuniversitet. (6)
47. Kanckos M (2009) Yrke: naturföretagare. Ett jobb i och med naturen! (In Swedish) [Occupation: nature entrepreneur. To work in and with nature] (author translation). Finlands Natur 1 (2009)
48. Swedish National Heritage Board in Sweden (2017) Räkna med kulturarvet. Kulturarvets bidrag till en hållbar samhällsutveckling. (In swedish). [Count on the cultural heritage. The cultural heritage's contribution to a sustainable society development.] (Authors translation). Riksantikvarieämbetet

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Unshackling Learning

15

Horace Crogman and Maury Jackson

Let us tell them that they are all the more truly what they do not think they are because they do not know it; for they do not know the penalty of injustice, which above all things they ought to know- not stripes and death, as they suppose, which evil-doers often escape, but a penalty which cannot be escaped.

Socrates

Summary

This chapter analyzes the relationship between thinking and learning. It employs the philosophical method; that is, it questions accepted beliefs about the nature of thinking and its relationship to reality, e.g., whether it reflects reality or constructs reality. A brief review of influential philosophical voices sets the broader context for framing the problem, leaving us with a bigger problem to resolve. We are left to explore what is necessary for our exercises in thinking to bring about long-term cultural change. To explain and explore this topic, we offer flow diagrams to model the neuron processes that organically reinforce a

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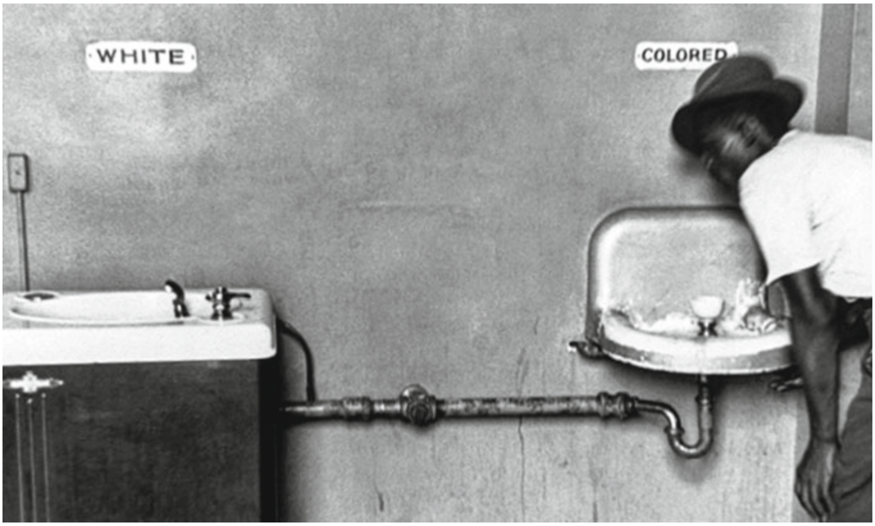
N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_15

relationship between thinking and learning. The dynamics between thinking and learning, under sensory stimuli and through the perceptual frames employed, impact social norms and behaviors, thereby warranting educational visions that intentionally reform thinking and learning through backward and forward feeds, respectively. This transformative sketch is proposed to better understand how to unshackle learning from the societal disparities that reinforce inequalities that directly affect gender and racial groups.

Graphical Abstract/Art Performance



The long Road to Racial Equally. Based on actual data from 1981 to 2007, it will take 140 years for the black percentage of full-time faculty to reach the current percentage of blacks in the United States population.

(Reproduced with permission from [1]).

Keywords

Conceptual conflict · Curiosity · Learning · Perceptual learning · Thinking

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

Since Descartes published his famous *Meditations* [2] in 1641, much has been said about the subject of thinking. Some argue (though not among those who subscribe to Freudian notions of subconscious drives) that we become our thoughts. This means that our actions and character formation occur due to thinking. Philosophers, educators, and others have long sought conceptual demarcations to establish the foundation for an adequate definition of what it means to "think." An adequate definition of thinking offers the necessary and sufficient conditions for some related tasks, i.e., delivering instruction and discovering clear and precise notions (both of which shape our beliefs and spirituality). All of this involves a better understanding of the brain and its relation to many dimensions of our human nature.

On the one hand, for example, as a rationalist, Descartes relates thinking to existence. Although he never put it exactly in the language of "I think therefore I am," this phrase aptly summarizes his investigative findings. With his thought experiment, Descartes reasoned from thinking to existence. Some go beyond merely showing that existence is implied in the act of thinking. They suggest that mental processes allow humans to shape the world into their image, that is, according to their goals, plans, ends, and desires. We form our thoughts, decision-making, and problem-solving through mental manipulation of information. Thinking results from information manipulation. On the other hand, as a skeptical empiricist, Hume [3] believed that ideas are born from experiences. According to his thinking, there is a direct link between our thinking and experience-generated ideas. Here we move in the opposite direction from Descartes, not with thinking shaping reality, but with the notion that experience influences and even creates human thought processes. The rational and empirical notions of the origin and power of thought and its relationship to (and interaction with) the world lead us, consequently, to relate thinking to learning. The tension between the disputed rational and empirical basis of thinking has been captured with clarity in the book by Mortimer J. Adler entitled *Intellect: Mind Over Matter*. Adler offers a philosophical description of human consciousness (cognitive, conative/appetitive, and affective dimensions). From this field of consciousness, the mental powers emerge as intellectual, cognitive, appetitive, and sensitive powers. This broad yet detailed analysis reframes the discussion regarding the objects of the mind, i.e., percepts, memories, images, and concepts. In one sense, they can all be loosely called objects of thought. And this is where the more recent challenge occurs; namely, will our future understanding of thinking grow from studying the phenomena as an empiriometric science or through metaphysical reflections? [4]. In reflecting on thinking, we make connections to learning. By participating in any task, the circle of learning requires that a person necessarily move beyond the theoretical abstraction of mere ideas into a concrete realm and back.

This chapter will tackle the obvious and less obvious connections between thinking and learning, that is, how they influence each other. We elucidate how flawed thinking leads to disastrous consequences and further show how better thinking feeds into better learning. The interaction between learning and thinking is also beneficial for the larger human community. At this point, a number of questions converge, particularly, what role does language and culture play in forming and informing our thinking? This question has been investigated to understand the nature of language [5], its influence on scientific thought [5, 6], and its impact on structural education [7]. As with all things, there are also downsides, which come as a result of lacking informed feedback into the thinking-learning interaction. A cycle of misconception is perpetuated as students learn incomplete and half-truths (i.e., in introductory courses or their own personal construction of reality) without the benefit of a challenge or confrontation. These same persons stand before future students as professors with half-truths that keep faulty thinking alive [8]. Here we see the impact of language on thinking within different forms of life as, Wittgenstein perceived it. Thinking is advanced by debunking what had previously been thought to be true.

Humankinds' thinking intrinsically drives the learning process. Eventually, this led social communities to create educational systems that were intended to bring about human progress through guiding and structuring learning: often called "traditioning." Throughout human history, the ability to course-correct these traditions or "schools of thought" came through a complex dance between thinking and learning [9]. And what followed came conflicts of interests that led to inevitable groupings. These "schools" shackle the human thought process by creating cultural frames that, in too many instances, slow human progress and promote alienation [10].

Throughout human history, superstition provided the raw material that formed the scientific development of important concepts known today. Humans once believed the earth was flat, an idea that was confirmed by an ordinary approach to what they perceived every day as they looked toward the horizon. This looking was connected to survival instincts. It caused people to postulate the danger that awaits one who sails too far out on the ocean: fear they would fall off the edge. Nevertheless, the developments in science have left us with ambivalent results, i.e., either freeing or shackling human thought and knowledge shaping a new reinforced belief. Throughout history, individuals arose who elevated society from the ashes of the cultural norms that the masses followed. These exceptional individuals caused gigantic shifts in thinking and belief. The pre-Socratic thinkers' ideas were less celebrated in their time [11]. Yet, it is important to note that a number of these individuals, throughout history, were slaves, priests, women, scientists, second-class citizens, children, great and small. This testifies that thinking is that property and ability accessible to all and that elevates humanity toward its next discovery.

While there remains a philosophical dispute over whether language is discovered or invented, it is beyond dispute that natural human languages have been shown to move in novel ways. This demonstrates the innate creativity of the users. In addition, there is little dispute that language systematically shapes human thought in ways that push us beyond the signification systems of the lower animal kingdom and their development and adaptation. The human language-creating capacity allows us to ask questions that drive human exploration and constantly reshape our thought. This led us along with the silk road evolution of history through trial and error: paving paths forward for the human cognitive power to develop and aid in performing remarkable feats.

Diverse circles of society influence thinking in different ways, such as theological and religious guilds. Indeed, what would Western civilization be without Christianity's philosophical thought? Christian thought is infected with a doctrine of resistance. In this way, it has done more to reform and liberate the thinking of humans than any theological thought before it. Thinking is power, and this can implode on itself. Christian faith compelled its initial devotees to read for themselves (e.g., the Bereans). This inevitably generates the persons' thinking abilities, which, in turn, unshackles the minds once locked up in figurative and literal chains [12]. Christian formation repurposed education by not only centering on the elite's learning but also directing its energies toward the peasants. Increasing a population's literacy also empowers them to shape their newly acquired information into indigenous cultural thought. So, while it is true that these religious circles have, at times, been culpable of shackling the mind of humanity, they have also sparked some of the single most important movements to reform human thinking. This reform in thinking was generated by the juxtaposition of reigning ideas with novel ideas recently encountered. This juxtaposition posed challenges to current beliefs and initiated a conceptual conflict.

Society, in some sense, has forgotten how we got to where we are. Many want to replace theological thoughts with scientific ones. Yet, this may be another shackle on human thinking that could just as well lead to humanity's own destruction. Whenever ethical boundaries are unreflectively shredded and theological principles pushed aside, in the fervor of exciting new knowledge, unforeseen problems emerge. Besides educational advances, many Christian movements also contended for gender and human rights. For example, in his shaping of Christian philosophy

[13], Paul contests the notion that women are second-class citizens and that slavery was an acceptable institutional practice for economic wealth building [14]. Christianity denounced the barbarity seen in Roman Gladiator games and secured its eventual overthrow [14]. Unlike many philosophies before it, Christianity demanded freedom, love, and education for all, slave and free, women and men.

Thus, the educational system within Western societies was shaped by Christianity [15–17]. Nevertheless, given all of its inherent potential for good, Europe's civic societies used this faith tradition to shackle the poor during the Dark Ages and African societies during their time of colonial expansion [18]. Yet, because of its inherent proclivities to resist oppression, Christian devotees inevitably rise to break these bonds, to open freedom and education to all. How Christian ideas relate to thought and learning shapes the outcome of humanity.

At the forefront of "thinking" is the question of how humans learn. Ideas about learning were constructed by the likes of Piaget, Vygotsky, and Chomsky. For recent generations, teaching children how to read was built directly on Chomsky's Whole-Word theory: a theory that goes back to Horace Mann in the 1800s. Though quite revolutionary for their time, these ideas also caused a shackling of our current education system and may have resulted in the diagnosis of some reading disabilities [19]. Who or what shackles our learning (both within our educational system and in our thinking beyond formal schooling)? What role does formal education play in opening minds to free humans from their cultural prejudices and languages? Is scientific "truth" a sufficient criterion for overriding those misconceptions that have now crystallized in our thinking and continue to influence our behavior? Feyerabend [20] believes that science, itself, is an ideology that inhibits freedom of thought, such that we are obligated to oppose it: "Any ideology that breaks the hold a comprehensive system of thought has on the minds of men contributes to the liberation of man." What are the essential elements that will unshackle learning and enlighten human thinking potential? We will proceed to better understand how humans acquire their thinking abilities, how thinking is connected to learning, and how the interaction between them impacts societal norms and behaviors.

2 How Thinking Occurs Within the Brain

Over time, the concepts regarding how we think about our reality were shaped by thinkers such as Heidegger, Piaget, Vygotsky, Merleau-Ponty, Chomsky, and Dewey. Progress from these thinkers led to the development of neuroscience and cognitive psychology. These fields contribute greatly to our understanding of thinking in our time. By defining thinking, cognitive psychologists have encouraged great debates. There are the socio-biologists, behavioral geneticists, biophysicists, and computer scientists who all contribute to (and muddied the waters for) an agreed-upon definition of "thinking." And depending upon their metaphysical commitments, those definitions might imply reductive materialism between the brain and the mind or imply an instrumentalist/functionalism position, which relates mental activity to brain activity without reducing them to the same identity. For our purpose, thinking is defined as an intellectual exercise aimed to find answers to questions, which means that it will engage all the language process centers of the brain.

From functional magnetic resonance imaging (fMRI) studies, neuroscientists found that, as a task gets progressively harder, the neural activities, particularly the prefrontal cortex, increase, which suggests an increase in mental processing. Mental process engagement is associated with a neuronal activity that we can correlate to thinking [20–23]. Thinking about where our thoughts come from is helped by the analog of electron activity. Electrons move in random directions inside a metal, or similarly, the random direction of magnetic domains in magnetic materials captures a comparable image. When an electric field is applied to the metal, the electrons all align along the field. This is the same process that applies to the concept of magnetic domains. The claim asserted here is that in a similar way, "thinking" happens involuntarily in the brain as neurons randomly fire. Here, sensory stimuli combined with memory recollection occur like the electric field, and the random firing of the brain's neurons occurs like electrons' movements in the metal. This picture captures what is meant by "Thinking." The senses capture the stimuli, which bring the neuron firings into focus or alignment, resulting in new thinking. For instance, if the eye captures something interesting, curiosity is aroused, and whatever was occupying the attention before has now shifted to what the eye sees, this whole process describes how thinking emerges. All thoughts are now focused in a particular direction, which causes questions to arise in the mind about what is being seen. For this reason, while it is ordinary to hear of a person multi-tasking, this, nevertheless, is not possible. Suppose there is a very loud noise taking place outside, as you sit, by a window; this sensory stimuli combined with your memory recollection takes the opportunity of the potential to shift thoughts into focus by directing neuronic pathways to the visual centers of the brain to align with what is happening in the auditory peripheral. Your attention is now directed to the noise as questions arise.

Figure 1 is a flow diagram that models the connections between thinking and language. Here we see a basic process where sensory input brings information into the brain from the environment to show how learning may then be achieved. How we perceive a stimulus will be strongly influenced by our language [24]. The thinking at the center of Fig. 1 is engaged with sensory information. There are two paths illustrated by Fig. 1 as they apply to the thinking process:

i. as the brain engages with an incoming stimulus, the first path compares incoming information through memory recall with its storage knowledge. If this knowledge exists in some incomplete form, new questions may arise, or further thinking may result. If the stimulus is nothing new nor stimulating enough, then interest is lost, and all thinking stops (Fig. 1); and
ii. the second path is the result of an unknown object or situation and which bypasses the comparison phases. This instantly piques our curiosity.

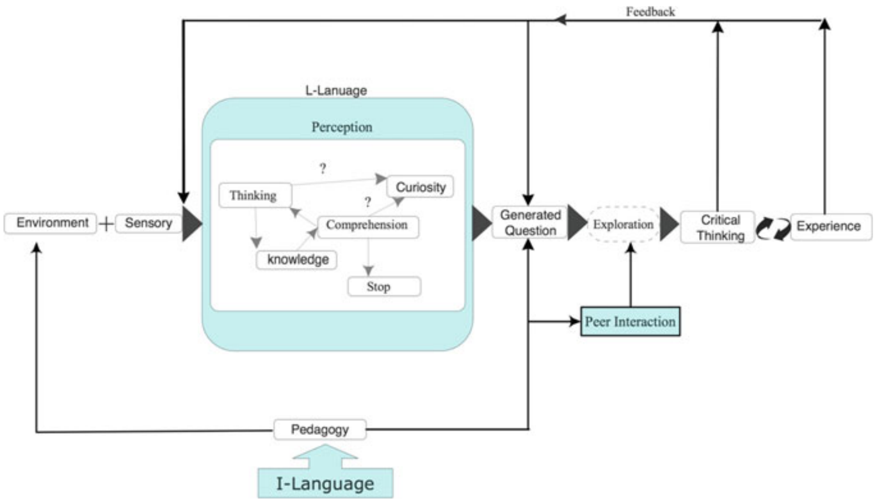


Fig. 1 Generated questions learning model showing the dynamics at play around (1) question asking, (2) the student, and (3) the instructor in a learning environment. *(Adapted from* [25] *under a Creative Commons Attribution (CC-BY) 4.0 license)*

Whenever our curiosity is engaged, by either path i or path ii, it will generate questions that drive our focus and exploration. However, note that the questions we generate depends on the environment and whom or what exists there. Figure 1 illustrates this thought in the pedagogy element. Notice two types of languages involved:

i. I-Language: the trained language (instructor); and
ii. L-Language: the untrained language (learner), steeped in cultural norms, develops through cultural experiences.

The L-Language influences thinking the most, and this is what must be challenged to bring about learning.

3 The Dance Between Thinking and Learning

Learning is the acquisition of knowledge or skills through experience, observation, change in behavior, or instruction [24, 26]. Learning functions like the concept of work in physics. For work to be done, it requires a change in position or condition. So too, the process of learning happens when our belief practices change behaviors or orientation due to changes to our thinking. Thinking is truly a dynamic system in that it changes with time. Thinking and learning have a correlated relationship that makes it difficult to show any causal relationship. This means they are connected as a feedback system. By feedback, we mean any two dynamical systems connected together such that each system impacts the other. Thinking and learning are (in most instances) strongly coupled together. The interplay between thinking and learning helps us become more conscious about our surroundings.

Figure 2 attempts to create a mathematical representation of the relation between thinking and learning. In some later work, we will provide more details on how to model this relationship. In Fig. 2, the inputs are sensory (sight, sound, taste, touch, and smell), each of which focuses on thinking. Thinking initially occurs in L-language (perception framed by cultural biases, misconceptions, prior experiences, and noise) with the crude output of learning that generates organic feedback. Thinking at this stage is more instinctual and may lead primarily to forming and reinforcing stereotypes, following impressions and superstitions. Left unchecked, it can lead to internalized racism and prejudice that conditions the cultural makeup of L-Language. This language informs our learning before the I-Language affects our thinking. However, I-Language's forward and backward feeds engage higher-order thinking and learning, which transforms the L-Language into R-Language (restructured language). With this process, the thinking of the learner is reformed. The learner is now able to achieve critical or deep thinking.

In order to foster the learning process, it is the purpose of instruction to bring about struggle, or dissonance, in the learner's mind. This requires learners to restructure thoughts or compare them against (or even abandon) prior schemes and knowledge in the face of empirical facts and new inferences of reasoning. This mental struggle between the new concept and the learner’s acquired concept is called conceptual conflict [27]. Thus, conceptual conflict results from differences or changes in position, which, in turn, bring about learning. Conceptual conflict solicits and stimulates the curiosity of learners, which causes the thinking to flourish as the brain generates the necessary questions that promote the learning event. The resulting end product of thinking is learning. In other terms, learning is an outcome

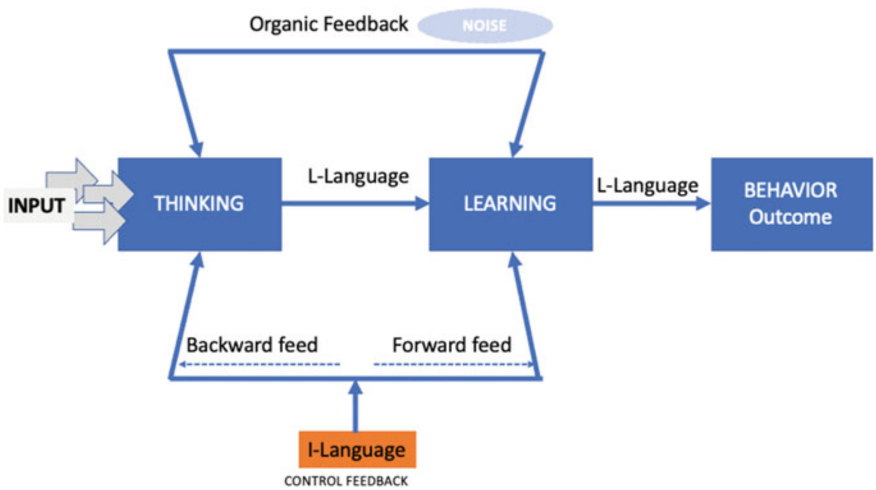


Fig. 2 The interaction between thinking and learning through language

of thinking. In physics or any other subject, every student starts with a deep-rooted system of commonsense attitudes on how the physical world works [28]. This springs from personal experience that develops over many years, a primitive practicing science form. When these experiences do not match the scientific *truths,* students have misconceptions or misunderstandings.

Learning does not create thinking, but it helps our thought be better positioned for deep-level thinking. Moreover, thinking drives exploration, which, in turn, tasks the learning conditions to reshape thinking in a hermeneutical circle. A goal of teaching is to inform, but teaching is only truly effective when it intentionally creates targeted conceptual conflict [29]. Thinking and learning is the way the brain refines itself.

How can instruction maintain and continually enrich this dance between learning and thinking? Instruction uses sensory stimuli as a way to solicit the learner's curiosity. Curiosity motivates learning, exploration, or a fantasy-fulfillment. Malone [30] believes that "[T]he way to engage learners' curiosity is to present just enough information to make their existing knowledge seem incomplete, inconsistent, or unparismonious;" this emerges whenever one is faced with conceptual conflict. Sensory input is like the selected frequencies that bring thinking into focus, creating the potential to awaken the learner's curiosity (Fig. 3). Malone designates as *sensory* that which maintains "interest" in the senses (a cat playing relentlessly with a ball or newborn consumed by a fireplace). Berlyne [31], on the other hand, designates these same instances as a function of perception, which stems from motivating visual and sensory-inspection, as well as the attentiveness to novel perceptual stimulation. What is true in both the newborns' and cats' reactions to the stimuli presented is the same engaged response.

Nonetheless, the human brain is wired for language, which is why children learn the language without being taught, and it is the language that differentiates humans from all other animals [24, 32, 33]. At its early stage, the child has a language

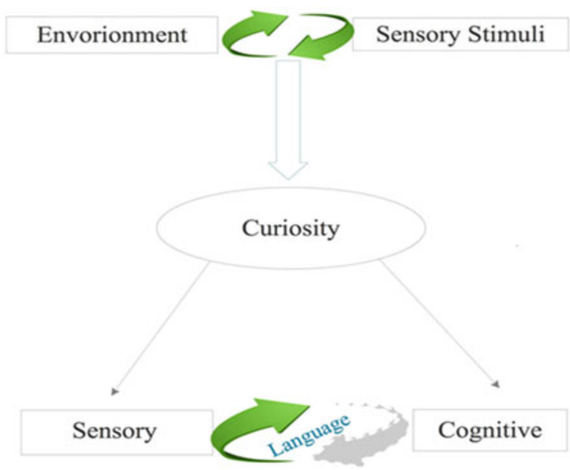


Fig. 3 The connection between language and curiosity. *(Adapted from* [24] *Creative Commons Attribution License (CC BY))*

deficit; it functions in its surroundings without systematic-purposeful intent. Yet, a child's brain is wired to slowly acquire language and gradually transition beyond random playfulness toward systematic, purposeful learning. Language brings to the human brain cognition, which further embeds the language into the structure and feedback loops that guide sensory interpretation (Fig. 3). Crogman [24] unifies Malone's sensory curiosity and Berlyne's perceptual curiosity into what he terms "base curiosity" (Fig. 4). By combining these differing insights, he offers a perspective that shows the broader composition of learning related to curiosity. The distinction is that perceptual curiosity is language feedback onto sensory curiosity. Moreover, perceptual curiosity is when the difference between human and animal curiosity commences. Curiosity is of two kinds:

i. base that is instinctual; and
ii. cognitive that is educated and structured [24].

This unity comes in the form of feedback between the base and cognitive constituents of the primary and raw structures of thinking, and on which cognitive curiosity is developed further through the evolution of language.

A good stimulus provides something new for (or teases out something interesting from) the learner. The unfamiliarity or reflection about prior knowledge catalyzes the learner into a state of thinking. The time response and question-asking signify a clear indicator of the learner's thought. When conceptual conflict is created, the mind is flooded with questions, which instruction must nurture. Questions are the result of thinking deeply about something interesting to the mind. In this framework, instructors use demos, describe situations, or ask questions to stimulate—these tools model for the learner how to probe their question-asking behavior.

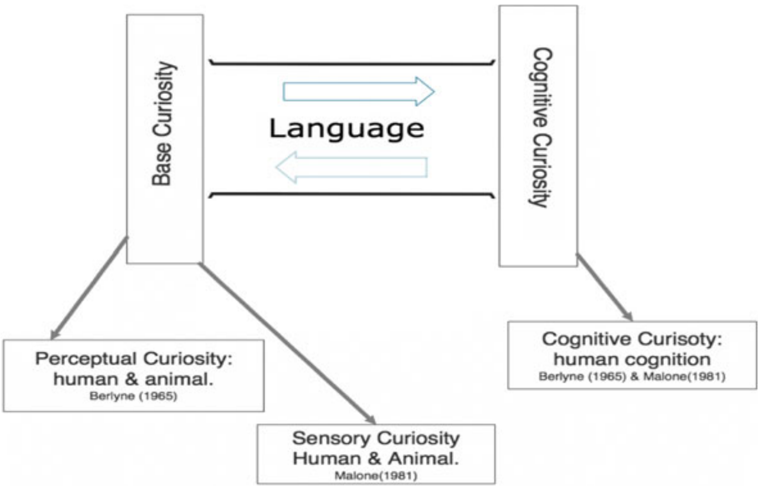


Fig. 4 Interplay of language between the base and cognitive curiosity, and their subcategories. *(Adapted from* [25] *under a Creative Commons Attribution (CC-BY) 4.0 license)*

Instructors can query learners' questions by:

- putting forward a question to work on and modeling exploration for the learners to emulate;
- soliciting from students to produce their question and then perform inquiry;
- unraveling student's misconceptions by inquiring directly or through media; or
- creating discussions to inspire learners' new questions [24, 26].

3.1 Language and Thinking

Language is the device that human beings use to code their thinking or communicate it. Our language is shaped by culture, which may positively or negatively impact outside the cultural boundaries. The Sapir-Whorf hypothesis [34, 35] states that the structure of a language regulates the modes of thinking and behavioral attributes of the cultures in which it is articulated. However, we may replace the word "conditions" with "determines." Some researchers suggest no empirical evidence supports that language determines thought [36]. Unexpected grammatical novelties or changes affect how humans perceive the world based on their language and thinking differences [37, 38].

The interaction between language and thinking can be coupled in a way analogous to atomic interactions. When the electronic transition happens much faster than the vibrational motion, we use the Born–Oppenheimer approximation to separate the electronic motion from the vibrational motion [39]. So too, changes in our thinking can be influenced by every sensory stimulus we may encounter. These changes happen in rapid succession; however, their influence on language happens much slower. Therefore, language cannot be a determining factor of our thinking since thinking can be decoupled from language; however, "habitual uses of language can influence our habit of thought and action" [40]. In the long run, our thought changes the language itself.

Language plays a fundamental role in the human brain, from the processing of color to making moral judgments. We express the way we think through the language we speak. Vygotsky says that the merging of thought and speech in children climaxes at about age 2, at which point their language transitions into internal thought and rationalizes their cognition [41]. It is the stage at which we argue that the language feedback transforms into based curiosity (Figs. 3 and 4). Language does not occur in a vacuum, but culture is the vehicle in which it is created, shaped, and grown. As culture changes, language shifts. For instance, Mandarin speakers are faster to recognize temporal relationships than English speakers [42], which may suggest that language habits help shape the habits of thinking. Cultures with pronoun-drops tend to be more loyal to the collective values, whereas cultures with non-pronoun drop languages, such as English, tend to bring about individualism [43]. Our understanding of the world is whittled through language. For Piaget, children can use language to construct complex environment structures, transforming low-level conceptual models into high-level ones [44].

Cultures are the habits we develop through experiences. We use our cultural experience to construct our language, which, in turn, impacts the way we think. Think of Russian speakers who master color recognition better than English speakers, and how Japanese speakers classify objects by material instead of shape, unlike English speakers [38]. What we perceive as colors is influenced by what we see and what we call them. In some communities, space is defined relative to the observer, so if the speaker does not stay focused on space constantly, they will not convey their meaning adequately [24]. Gaby [45] noted that the Kuuk Thaayorre language lacks active spatial metaphors when describing time, for example [45]. Using absolute frames mean that the description is always independent of the observer's orientation. They are not plagued with such confusing use of language as in English, where someone has to clarify, "No, I meant my right, not your right!" Thus, how individuals in totally different societies locate themselves in space or handle color informs their thought about the environment and vice versa.

3.2 Cultural Stereotypes Go Wrong

The words of famous Marcus Garvey exclaim, "We are going to emancipate ourselves from mental slavery because whilst others might free the body, none but ourselves can free the mind. Mind is your only ruler, sovereign. The man who is not able to develop and use his mind is bound to be the slave of the other men who use his mind." Misunderstanding and misinterpretation emerge from unsuccessful connections between past presuppositions and newly acquired information [46, 47]. Misconceptions shackle learning and form stereotypes that propagate ideologies like racism, sexism, and classism. Those broken educational systems reinforce these dangerous ideologies.

Take, for example, *the ideology of racism*. The biological family of a woman named Rachel Dolezal uniformly identified as white; nevertheless, she chooses to identify as a black woman. Ms. Dolezal recognized that race is not a biological fact; it is a social construct. Among many in Africa, the notion of "Black" people is not taken seriously, and in Europe, identities are not reduced to "White" people. Black and White are constructs of superiority and inferiority, much like in India: evidence of America's own caste structure. This is a shackle that continues to impact what we think and learn. This enslavement of the mind evolved and grew in American society. During the period commonly known as the era of Jim Crow Laws, in-depth segregation in the American society formed the White/Black binary. At what table counters did those folk eat, who were neither Black nor White or what doors did they enter through?

Racial stereotypes have destructive thinking and learning outcomes in society. The Jim Crow ethos trickled down into the systemic barriers that victimize Black people today. Black people were largely responsible for the gains made through the Civil Rights Movement, but due to structural racism, they often experience the least of its benefits. In reaction to these inequities, some unexpected changes in thinking found ways of transforming the narrative employing the rhetorical phrase "people of color." This new designation refers to an array of groups who did not suffer from the levels of injustices and marginalization. Today the term "people of color" socially forms a new class for anyone of the marginalized non-White groups. The unintended consequence further the obstacles of social uplift for Black Americans. An anti-black racist often uses the "people of color" category to reinforce America's historical injustices against Black people: filling job vacancies with non-black persons-of-color. Consider how Asian Americans are designated people of color, yet they are overrepresented in economic and educational success outcomes [48, 49]. This does not suggest that racial stereotypes for Asian Americans do not exist. One stereotype labels them as very intelligent, which works toward their favor in the educational system and workplace. However, this creates unreasonably high expectations of young Asian American children, leading to unhealthy levels of anxiety [50]. This is not unlike the challenge many of the children face in the countries from which their parents have immigrated [51].

Again, these racial constructs often harm thinking and learning. The stereotypes shape persons to advocate for social norms that propagate structural racism. This effect is observed at the intersection of the educational and prison industries. Moody [52], in studying the reading skill of Texas prisoners (253 prisoners from 130,000 randomly chosen), reported that roughly 80% of the jail detainees were practically illiterate. Forty-eight percent of prisoners were dyslexic, while two-thirds struggled with reading comprehension. Another study by the Bureau of Justice Statistics, in its Special Report on the Educational and Correctional Populations, published that among state prison inmates who have not completed a high school degree or obtained their General Educational Development certificate, 66% have a learning disability, and 59% a speech disability (possibly a symptom of dyslexia). Based on these data types, the correlation between literacy and crime is forged. In 2020, the Federal Bureau of Prisons reported that African Americans make up 38.2% of the prison population. Black people are only 13% of the total United States population. This demographic itself conditions thinking beyond the prison population and into the larger society (i.e., Black people are more likely to commit a crime). The incarceration rate of Black people at least triples the rates for Hispanic people and White people in every American state [53]. Nellie points out that the disparity within the prison system in the United States is a result of racialized discrimination [53]. Apparently, we are building a society that marginalizes individuals of color and causes them to drop out or fall behind in school. Thus, the inequality gap is larger for such individuals. Black males already experience both overrepresentations in special education programs and racial discrimination, and their difficulties are compounded further as dyslexia is added to their plight.

Furthermore, they are often misdiagnosed and placed in programs for behavioral or cognitive disorders instead of being in programs for remediation of their dyslexia [54, 55]. This contributes significantly to a reading gap. There is no evidence that people commit crimes because they cannot read, and these correlations are coincidental, while the real culprit is the inequality gap in society. Marginalization is directly responsible for poor economic and educational outcomes.

Another example to consider, as an illustration of the effect of thinking and learning, is *the ideology of sexism*. Gender stereotypes involve the beliefs held about the place that females and males hold in society (to say nothing about those who resist the gender binary). These beliefs have a negative impact that affects the career choices of young individuals, bolstering gender stereotypes and widening the gender gaps in certain careers [56]. In considering the push to encourage Science, technology, engineering, and mathematics (STEM) programs, many in America believe that boys are superior at math to girls. And in fact, we could point to some outcomes where this seems true. There is, however, a clear failure to understand how society, over time, creates and shapes this reality. Consider the following: in 2013, nearly 6 out of 10 women in the United States received undergraduate diplomas in all fields and half of the fundamental and applied science diplomas. However, these percentages gloss over hidden disparities, once broken down by fields, which cause concern. Women earned less than 20% of computer science and engineering credentials and slightly more than a third of the degrees received in physics and math. These statistics worsen when ethnic identities break down the set. In 2012, minority women received less than 10% of the undergraduate degrees awarded in the field of engineering, physics, math, computer, and biological sciences. This number improves to nearly 15% when social science disciplines are added [57]. Women represent half of the United States college-educated labor force, yet in the workforce are just 29% of the STEM. Again, this ratio worsens for minority women, representing less than 1 in 10 researchers and engineers [58]. A recent study of 350,000 participants across 66 countries shows that in countries with a high enrollment of female students in tertiary science education, gender stereotypes are weaker. Ironically, stereotypes about women were strongly gendered in those countries with supposedly high overall gender equity [59].

In some Middle Eastern and African countries, it is believed that girls should not go to school. We saw how this played out in the life of Noble Prize winner Malala Yousafzai, who was shot by the Taliban [60] for advocating for girls' education. Traditionally, this was true in Western nations not too long ago. Reading and writing positively impact the development of language (we have already noted the relationship of language to thinking and learning). It also helps to provide a historical record of past and present events. Reading and writing help to imagine future possibilities as it structures the future language and reimagines lost connections from the past. In turn, this helps the people in those cultures think more critically about recording those events.

In considering how these shackling ideologies take root in social thinking and behavior, we must also reconsider *ideology's role as the shackling tool of propaganda*. Propaganda has been used effectively to shape people's thinking as it remains the rhetorical tool for society's stereotypes. The Nazis regime in Germany used language to appeal to and manipulate the masses. It is reported that the German Minister of Propaganda said in 1934, "We must speak the language which folk understand, whoever wants to speak to folk must, as Luther says, pay heed to folk speech" [61]. Hitler understood this and made a similar pronouncement a year earlier: "I must not measure the speech of a statesman to his people by the impression which it leaves in a university professor, but by the effect it exerts on the people" [62]. Hitler also wrote that "All propaganda must be popular and its intellectual level must be adjusted to the most limited intelligence among those it is addressed to. Consequently, the greater the mass it is intended to reach, the lower its purely intellectual level will have to be" [63]. Language has an ordinary usage that must be challenged or confronted by new ideas to overcome the tools of propaganda's shackles. Daly and Trofimov [62] argue that the interest in what the common mass thought and said became an important datum to discredit the Jewish people. Thus quotes, slogans, phrases, and proverbs that were anti-Semitic became a daily message. Today negative stereotypes about Jewish people still plague Western societies.

Many fear that former United States President Trump and his Republican political opposition research allies employ the propaganda tool or the dog whistle of *fake news*. This is sounded to reshape a large part of American political thinking regarding the commonly accepted reliable sources. This plays to the impulses of the low information voter like giving them the license to dismiss the dangers of the COVID-19 pandemic in 2020. They tune in to the president as he reiterates the ineffectiveness of masks and touts Hydroxychloroquine as a cure for the COVID-19. This rhetorical echo convinced some of "the most limited intelligence among those" Americans to refuse wearing masks and take an unrecommended drug. Herman Cain, a Black Republican presidential candidate who aligned himself with the Trump regime, died from the COVID-19 after advocating for people not to wear masks [64]. This is a clear indicator of how thinking shapes behavior even in the most so-called educated and rational minds. The thinking of these supporters is shackled to a political ideology that causes them to ignore the warnings of the organization that was put in place to handle these sorts of crises.

The negative impact of language stereotypes felt by Black people worldwide primarily comes from American White supremacist cultural stereotypes. Because of America's global footprint in foreign policy, its rhetorical tropes condition the world's thinking/behaving in ways that lock in culturally marginalized modes of structural racism. This also influences deep suspicion of Western attempts to "develop" or "aid" other nations around the globe. On the African continent, where Ebola is prevalent, many health workers are attacked because of a belief that Western nations create fake diseases to take advantage of them (villagers believe that Ebola "is nothing more than an invention of white people to kill black people" [65]). A similar situation occurs in Black American communities vis-a-vis the healthcare system. A series of broken trust with institutions fuel Black peoples suspicions:

i. insurance companies used various algorithms to calculate Black people's risk scores prior to COVID [66];
ii. among Black children, the educational system is less effective, with a higher rate of fourth-grade failure [67]; and

iii. the criminal justice system's disparities and the failed trust.

There are more law enforcement stops and questions for Black people than for Whites, and 60% believe they cannot get a fair trial in the court system, compared to 25% of White people [68, 69]. These aspects are compounded by a general distrust of the government due to historical experiences of abuse from these institutions. These examples testify to the power of thinking and illustrate the deep need to unshackle our thoughts for actual learning and change to occur.

4 Can Education Systems Unshackle Learning?

In academia, which is supposed to be the place where the oppressive structural phenomena should have no place, the true shackling actually flourishes. Take physics, for instance; nationally, more than half of African American physics faculty are employed at Historical Black Colleges and Universities, HBCUs. The remaining African American physics faculty work at just 23 out of 746 departments. Thus, most physics students will never interface with a Black faculty member in their discipline [70]. This might be one of the principal reasons why only 4% of the bachelor's degrees awarded in physics are earned by African American students. LatinX faculty do not fare much better. The number of LatinX physics faculty is only 1.5 greater than African American faculty, and half of all LatinX faculty are in 46 departments (with the largest number in Puerto Rico and Texas). This reflects an intrinsic lack of support for these professionals. As reported by observers of the field, "underrepresented minorities are brought in as assistant professors, sometimes through special programs that aim to improve diversity, only to leave shortly thereafter" [71]. In large urban universities, the faculty will not reflect the community they serve. How will they fulfill the goal to create diversity? In California, the UC and CSU tertiary educational systems lack Hispanic and African American faculty in the STEM fields. Very little is done by the administration in these institutions to ensure the success of Hispanic and Black faculty members. We constantly hear of the need for more "people of color" in the faculty in academia; however, this has not led to equity in hiring across the board but to the increased hiring of non-White people. This means that for Black communities, the same systemic problem remains.

There also remains the problem of gender discrimination in academic STEM programs. Table 1 shows the need for gender equity in STEM [72]. Male faculty are up to four times more likely to be hired and develop a STEM career than female faculty. This has a very negative impact on young girls who receive career counseling in these fields. This is worse when ethnicity is taken into account. Research has demonstrated a tendency for people to hire people who look like them, and this would not bode well for either Black people, Hispanic people, or females in the field. Women among the faculty were considered an underrepresented group, which was true in the 1990s. However, the university actually became more diverse with respect to gender, though not with respect to race and ethnicity. Figure 5 shows that

Table 1 Percentage of faculty diversity by field and US population diversity

	US population	Biology	Chemistry	Economics	Educationleadership policy	English	Sociology
Racial/ethnic shares							
Asian	4.7	12.9	14.4	20.9	8.5	5.6	8.4
Black	12.2	0.7	1.4	2.9	15.1	8.8	8.9
Hispanic	16.3	3.0	2.5	5.1	7.8	4.2	5.9
White	63.7	83.3	81.7	70.9	68.7	79.8	76.6
Other/Unknown	3.1	0.1	0.0	0.2	0.0		0.21.6
Gender shares							
Female	50.8	31.1	18.1	19.7	53.2	48.7	47.1
Male	49.2	68.9	81.9	80.3	46.8	51.2	52.9
Unknown							
N(Faculty)		1,325	529	554	284	888	427

Reproduced (from [72])

53% of college faculty are male while 46% are female. This is an improvement given that the university was historically a male-dominated institution—the influx of women into the American workforce in the 1980s accounts for this change. Moreover, the gain was also influenced by the Civil Rights Movement. Looking at the data closely in Fig. 5, 41% of university faculty are White males and 35% White females. This is near gender equity. While equity has been approximated in gender, it has not been the case with race. White women are twice as likely to be hired as their other racial counterparts in all ethnic groups combined. Thus, the real problem is not just diversity but actual ethnic diversity. Black women fare the worse, followed by Black men. If universities' hiring outcomes became more ethnically diverse, the gains in gender equity would remain intact. It is still true that women overall fare less than White and Asian men in STEM, but Black men and women fare the worse. The university institution has improved ethnic and racial diversity in their student body, but their faculty remain largely undiversified. It is a truism that achieving racial equity involves those most impacted by structural racial inequity as a program for creating and implementing institutional practices and policies that affect them.

What impact does this lack of diversity have on the mind of the learner? Our thinking is shaped in part by what we experience. Education creates conceptual changes that enhance examination, exploration, and deep thinking [26]. Conceptual challenges require students to see the necessity for a change in their concepts [28, 74]. On the off chance that they do not recognize a conceptual change requirement, misconceptions might emerge in their minds. When it reflects the stories of conflict in STEM educational outcomes, the instructors' language can be a catalyst for a

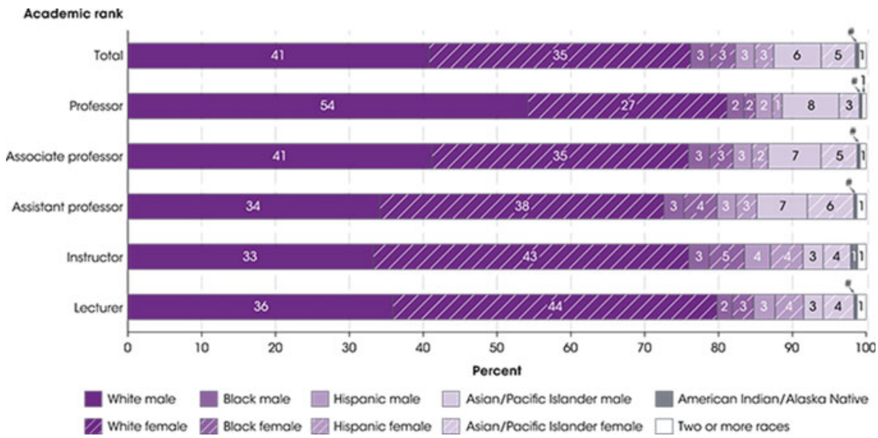


Fig. 5 The percentage distribution of full-time faculty for academic rank in degree-granting postsecondary institutions, by race/ethnicity and sex: Fall 2017. (*Reproduced from the U.S. Department of Education, Institute of Education Sciences, National Center for Education Evaluation and Regional Assistance (NCES)* [73])

conceptual change in all students. Research shows that people respond better when the entities and communities they work and study in are more diverse.

When one of the author's nieces was in high school, her Asian math teacher constantly pointed to the contribution of Asians to education and expressed his thought that Black people are not good at science. The mental toll on this author's niece was devastating. She was bullied by students of other ethnic groups. His niece would constantly find herself in contention with the teacher over her work. Yet, when her work was examined, it showed her to be oftentimes correct. Reading some of the students' remarks was disheartening, as they often reported to her how the teacher had remarked on the superiority of Asian people over other people groups. His niece only found courage because she lived with a STEM expert. When there was an intervention with the instructor to correct perceptions and establish facts, his niece dramatically improved and graduated top of her class. She later went on to finish a double degree in STEM. The point here is that this young female's learning suffered because the teacher was shackled in their own thinking and beliefs and thus also attempted to shackle the student's own thinking, becoming an obstacle to her progress and potential. Too many students of color suffer this disparity because of a system in which learning suffers from conceptual shackles.

5 The Opened Mind

Questions are the key to unshackling learning. Human resilience is witnessed in the struggle implied in the questions posed, and those questions compound when curiosity is engaged. As we have shown before, thinking is unraveled when instruction creates conceptual conflict. These conflicts can be awakened by using clever tools that engage thinking and result in positive learning outcomes. In environments designed for learning, i.e., educational institutions, research has shown that pedagogies that engage the learners through a sense of randomness and fun (through the sensory) encourage the learner to own greater autonomy in their thinking and learning. Active learning strategies that make ample use of the sensory capacities keep the learner's attention and inquiry engaged throughout the whole learning task (for more information, see [26] that shows the effect of sensory stimuli in generating learners' questions). When students can generate their own questions and move onto exploration quests, they become unshackled learners.

An active pedagogy must create changes in the sensory system to provoke the learner to reflect on past experience and examine prior knowledge against the new concepts. This is referred to as perceptual learning, by which all learning must be defined. Learning brings about changes in behavior that are measurable. Research has demonstrated that human behavior is molded in the early years. Because human perceptual systems are very mutable through thinking, it stands to reason that instruction must utilize the right stimuli to shape the thinking as ways to improve societal norms. Further, illiteracy is no excuse for marginalizing populations when the outcome of thinking and learning can affect changes to advance the lives of the citizens equitably. It is important that good educational pedagogy grounds itself in social justice actions, which by nature are designed to expose the wrongs of society while endeavoring to solve inequities. It is irresponsible of any educational system to cripple thinking by creating formulaic aspects of thinking procedures, such as scientific thinking. Education aims to provide learners with the tools to reform and improve their thinking. These tools must not contain harmful social biases such as gender/racial/class and other stereotypes; they need to be effective for learning that improves thinking.

Educational equity has promised that training strongly influences individuals' life quality. This seems true in specific instances. Yet, because of racial, gender, and other discrimination practices, an inequality gap largely affects Black people more than any other population. For example, universities provide mechanisms to negotiate one's salary. Still, Black people often find themselves unable to succeed in the negotiations compared to their White counterparts, be it women or men. In STEM, physics education research has helped shape and improve educational practices. Yet, a recent study shows that there are still large implicit biases in selecting research participants and making general claims based on findings that do not reflect the general population [75]. A large portion of the people responsible for inequalities actually knows what is wrong in the system and how to fix it. This rings true in the society at large; why have educational institutions failed to break this shackle of thinking? Unfortunately, our response is not to acknowledge that educational institutions have failed. Here again, people prove too afraid to give up power and comfortable positions for the sake of rectifying these imbalances.

How do we solve this problem, and how can our society reach race and gender equity? Education seems powerless to overcome group prejudice because the learning cohort is short-term. As we pointed out earlier, the educational system's gender equity in higher education overshadowed racial inequity in America. Graphical Abstract illustrates the percentage of Black faculty as it correlates to the percentage of the Black population in America; if the trends continue along these lines, it will take 140 years for representation to reach equity [1]. Without political and social intervention, this will continue to grow and become an improbable problem to solve. Population growth does not automatically mean the growth of Black faculty in part due to systemic racism [76]. Governments exist to make the life of their citizens better, yet, political systems often remain in an unhealthy partisan state, poorly affecting their citizens. Therefore, the systemic pressures causing suboptimal health, grave educational disparities, and criminalizing Black communities deserve an equally matched systemic solution. This change should involve positive trends driven by socially targeted developmental programs, economic, educational investments, participation of those impacted in policy- and decision-making, and expansion of access to all levels of society [77].

Nevertheless, the light shone on racial injustice and gender inequity through the Civil Rights Movement has caused school systems worldwide to rethink the knowledge and abilities understudies require for success; and the instructive procedures and framework required for all children to realize them. Thus, higher education must play a crucial role in preparing students for the workforce in a dynamic, fair, and aware citizenry, both nationally and internationally. This means that race equality must be embedded in teaching and learning: in order to ensure that institutions acknowledge the experiences of those marginalized groups within and around them and value all students, including ethnic minorities and international students.

6 Conclusion

We have established that thinking fosters learning. Thus when thinking is shackled, learning is adversely affected. The thinking that boys are smarter than girls or boys are better than girls in STEM results in many girls self-steering away from STEM programs. If teachers and administrators concede to departmental cultures that reflect the outcomes of such beliefs, then we can assume that implicit biases will find their way into policies and decisions that will continue to discourage women, transitioning them away from STEM programs. Unshackling learning creates an education paradigm where the learner's thinking is unbounded. This is possible when a diversity of people says "No" to structural racial inequity and actively involve themselves in creating and implementing equitable institutional practices. California Governor Gavin Newsom said, "students respond better to professors that look like them." To unshackle learning means creating learning environments that have done away with structural inequity. We must create new pipelines that address these issues from kindergarten through grade 12. We must be intentional as a society. Human beings are often slaves to their thinking, which, in turn, influences learning and future decision-making and policy development in society. Experience helps us build prior knowledge claims, which we rely on to weigh against new knowledge proposals, generate new ideas, or create more knowledge [24, 26]. The knowledge we generate can shackle our thinking if new confrontational questions are not encouraged in the learning process. Randomness and humor, when used appropriately, can promote an environment optimally complex. Together, this engages learners' curiosity and sets the stage for novel Socratic questioning to fuel the thinking-learning-rethinking-relearning hermeneutical educational circle.

Core Messages

- The sensation-perception-convention feedback thinking reinforces current ideas in an oppressive social system.
- A thoughtful hermeneutical circle offers a social impact that forms learning and reforms society to next-level thinking.
- Racial-gender-class disparities condition learning contexts that quash the creative dimensions necessary for thinking.

References

1. Slater RB (2007) The snail like progress of Blacks in faculty ranks in higher education. J Blacks High Educ
2. Descartes R (2013) René descartes: meditations on first philosophy: with selections from the objections and replies. Cambridge University Press
3. Parker AM (2004) An inquiry concerning human understanding. Ploughshares 30(1):125–127
4. Adler M (1990) Intellect: mind over matter. Macmillan Publishing Company, New York, p 103
5. Wittgenstein L (2009) Philosophical investigations. Wiley
6. Kuhn TS (2012) The structure of scientific revolutions. University of Chicago press
7. Woodson CG (2006) The mis-education of the Negro. Book Tree
8. Winfrey J (2020) We need to rethink lower-division physics teaching. PhT 73(4):10–11
9. Dolnick E (2011) The clockwork universe: Isaac Newton, Royal society, and the birth of the modern world. Harper Collins
10. Feyerabend PK (1975) Against method. New Left Books, London
11. McKirahan RD (2011) Philosophy before Socrates: an introduction with texts and commentary. Hackett Publishing
12. Jackson M, Crogman H (2019) The twisted fate of the king james version and the black religious experience in America. Cult Religious Stud 490
13. Crogman, Jackson (2015) A simple exegesis on the faith in James' eye glasses JBT 16(15)
14. Jackson M, Crogman H (2016) Shepherding public discourse practices: homiletic form aligned to the logic operative in racial rhetoric and public theological discourse for secular liberal democracies. Cult Religious Stud, Sept 2016 4(9):576–588. https://doi.org/10.17265/2328-2177/2016.09.004
15. Gilley S (2006) The cambridge history of christianity: volume 8, World Christianities c. 1815–c. 1914. Brian Stanley. Cambridge University Press, p 16
16. Johnson E (2009) Foundations for soul care: a Christian psychology proposal. InterVarsity Press
17. Steane A (2014) Faithful to science: the role of science in religion. OUP Oxford
18. Tamez E (2006) The Bible and the five hundred years of conquest. Voices from the margin: interpreting the bible in the third world, pp 13–26
19. Feyerabend P (1988) How to defend society against science. In: Klemke ED et al (eds) Introductory readings in the philosophy of science. Prometheus Books, Buffalo, New York
20. Crick F (1996) The astonishing hypothesis: the scientific search for the soul. J Nerv Ment Dis 184(6):384
21. Kuhl PK (2010) Brain mechanisms in early language acquisition. Neuron 67(5):713–727
22. Nani A, Manuello J, Mancuso L, Liloia D, Costa T, Cauda F (2019) The neural correlates of consciousness and attention: two sister processes of the brain. Front Neurosci 13:1169
23. Pagnoni G, Cekic M, Guo Y (2008) Thinking about not-thinking: neural correlates of conceptual processing during Zen meditation. PLoS ONE 3(9):e3083
24. Crogman H (2017) Language and thinking in learning theories: grasping the interplay between the verbal cultural diversity and critical thinking, and their consequences for African American Education. In: Frontiers in education, vol 2. Frontiers, p 64
25. Crogman H, Trebeau Crogman M (2016) Generated questions learning model (GQLM): beyond learning styles. Cogent Educ 3:1202460. https://doi.org/10.1080/2331186X.2016.1202460
26. Crogman H, Peters R, TrebeauCrogman M (2018) Probing students misconceptions results from concept inventory and their understanding in science learning. Eur J Phys Educ 9(1):23–44
27. Liang S (2016) Teaching the concept of limit by using conceptual conflict strategy and desmos graphing calculator. Int J Res Educ Sci 2(1):35–48

28. Fadaei AS, Mora C (2015) An investigation about misconceptions in force and motion in high school. US-China Educ Rev 5(1):38–45
29. Crogman H (2019) Students' misconceptions are falsely measured by concept inventory tests while lack of prior knowledge is ignored. J Contemp Educ Res 3(2)
30. Berlyne DE (1965) Structure and direction in thinking. Wiley, New York, NY
31. Malone TW (1981) Toward a theory of intrinsically motivating instruction. Cogn Sci 5(333–369):1. https://doi.org/10.1207/s15516709cog0504_
32. Hermer-Vazquez L, Moffet A, Munkholm P (2001) Language, space, and the development of cognitive flexibility in humans: the case of two spatial memory tasks. Cognition 79:263–299. https://doi.org/10.1016/S0010-0277(00)00120-7
33. Spelke ES, Hermer L (1996) Early cognitive development: objects and space, perceptual and cognitive development. In Gelman R, Kit-Fong T (eds), Academic Press, San Diego, pp 71–114
34. Kay P, Kempton W (1984) What is the Sapir-Whorf-hypothesis? Am Anthropol 86:65–79. https://doi.org/10.1525/aa.1984.86.1.02a00050
35. Whorf BL (1956) Language, thought and reality. MIT Press, Cambridge, MA
36. Boroditsky L (2003) Linguistic relativity. In: Nadel L (ed) Encyclopedia of cognitive science. MacMillan, London, pp 917–921
37. Levinson SC, Wilkins DP (eds) (2006) Grammars of space: explorations in cognitive diversity, vol 6. Cambridge University Press, New York
38. Weiler N (2015) Speaking a second language may change how you see the world. Sci Mag. Available at: http://www.sciencemag.org/news/2015/03/speaking-second-language-may-change-how-you-see-world
39. Crogman HT, Harter WG (2004) Frame transformation relations for fluxional symmetric rotor dimers. J Chem Phys 121(19):9297–9312
40. Kashima Y (2020) Language and language use. In: Biswas-Diener R, Diener E (eds) Noba textbook series: psychology. DEF publishers, Champaign, IL. Retrieved from http://noba.to/gq62cpam
41. Vygotsky LS (1978) Mind in society: the development of higher psychological processes. Harvard University Press, Cambridge, MA
42. Boroditsky L (2001) Does language shape think? Mandarin and English speakers' conceptions of time. Cogn Psychol 43:1–22. https://doi.org/10.1006/cogp.2001.0748
43. Kashima E, Kashima Y (1998) Culture and language: the case of cultural dimensions and personal pronoun use. J Cross Cult Psychol 29:461–486
44. Inhelder B (1978) Language and thought: some remarks on Chomsky and Piaget. J Psycholinguist Res 7:263–268. https://doi.org/10.1007/BF01068109
45. Gaby A (2012) The Thaayorre think of time like they talk of space. Front Psychol 3:300
46. Meyer DK (1993) Recognizing and changing students' misconceptions: an instructional perspective. Coll Teach 41(3):104–108
47. Shepherd M. Dallas 'whites only' water fountain now fountain of knowledge, Dallas news. Retrieved from https://cw33.com/news/whites-only-water-fountain-shares-civil-rights-story/
48. Joo N, Reeves RV, Rodrigue E (2016) Asian–American success and the pitfalls of generalization. Brookings Long Memos (20)
49. Lee ES, Rong XL (1988) The educational and economic achievement of Asian–Americans. Elem Sch J 88(5):545–560
50. Crogman TH, Trebeau Crogman AM, Warner L, Mustafa A, Peters R (2015) Developing a new teaching paradigm for the 21st century learners in the context of Socratic methodologies. Br J Educ Soc Behav Sci 9:62–95. https://doi.org/10.9734/BJESBS/2015/17825
51. An SM, Pak CH, Kang HW (1992) Chongsonyon uiski tae chosa (A largescale investigation of adolescents' consciousness). Uri Kyoyuk 11:40–72
52. Moody KC, Roman MJ, Paulsen KA, Freeman DH, Haynes M, James TN (2000)
53. Nellie A (2016) The color of justice: Racial and ethnic disparity in state prisons. The Sentencing Project, Washington, DC

54. Gardner R III, Hsin Y (2008) Reading and children with emotional/behavioral disorders. Balanced Reading Instr 15(2):25–40
55. Robinson SA (2013) Educating black males with dyslexia. Interdisc J Teach Learn 3(3): 159–174
56. Nosek BA, Smyth FL, Sriram N, Lindner NM, Devos T, Ayala A et al (2009) National differences in gender-science stereotypes predict national sex differences in science and math achievement. Proc Natl Acad Sci USA 106:10593–10597. https://doi.org/10.1073/pnas.0809921106
57. National Science Board, National Science Foundation, & National Center for Science and Engineering Statistics. (n.d.). S&E indicators 2016: NSF—national science foundation. Retrieved from https://nsf.gov/statistics/2016/nsb20161/#/
58. National Girls Collaborative Project (2015) Statistics. Retrieved from https://ngcproject.org/statistics
59. Miller DI, Eagly AH, Linn MC (2015) Women's representation in science predicts national gender-science stereotypes: evidence from 66 nations. J Educ Psychol 107:631–644. https://doi.org/10.1037/edu0000005
60. Husain M (2013) Malala: the girl who was shot for going to school. BBC News Magazine, vol 7
61. Woodbury M (1998) Media stereotypes of Jews: From JAPs to MDs. Cultural diversity and the US media, pp 99–109
62. Daly J, Trofimov L (2017) The Russian revolution and its global impact: a short history with documents. Hackett Publishing
63. Hitler A (1951) Hitler on propaganda
64. Edelman A (30 July 2020) Former GOP presidential candidate Herman Cain dies of COVID-19. NBC News. Retrieved 9 Aug 2020. https://www.nbcnews.com/politics/politics-news/former-gop-presidential-candidate-herman-cain-dead-coronavirus-n1235312
65. Robyn D (2014) Eight reported dead in attack on Ebola workers in Guinea. Los Angeles times. Retrieved 9 Aug 2020. https://www.latimes.com/world/africa/la-fg-attack-ebola-guinea-outreach-20140918-story.html
66. Ledford H (2019) Millions of black people affected by racial bias in healthcare algorithms. Natur 574(7780):608–609
67. Cokley KO (2016) What it means to be black in the American educational system, the conversation. Retrieved 9 Aug 2020. https://theconversation.com/what-it-means-to-be-black-in-the-american-educational-system-63576
68. Cannon MF (2013) Distrust of justice system also affects black Americans' views on public health measures, CATO institute. Retrieved 9 Aug 2020. https://www.cato.org/blog/suspicion-criminal-justice-system-also-affects-african-americans-views-public-health-measures
69. Schrantz D, McElroy J (2000) Reducing racial disparity in the criminal justice system: a manual for practitioners and policy makers. Sentencing Project, Washington, DC
70. Ivie R, Anderson G, White S (2020) African Americans and hispanics among physics and astronomy faculty. App.org. Available at: https://www.aip.org/sites/default/files/statistics/faculty/africanhisp-fac-pa-123.pdf. Accessed 5 Jan 2020
71. Academic diversity (2007) Nature 447:753–754. https://doi.org/10.1038/447753b https://www.nature.com/articles/447753b#citeas
72. Li D, Koedel C (2017) Representation and salary gaps by race-ethnicity and gender at selective public universities. Educ Res 46(7):343–354
73. U.S. Department of Education, National Center for Education Statistics (NCES) (2019) The condition of education 2019 (NCES 2019–144), Characteristics of Postsecondary Faculty
74. Merenluoto K, Lehtinen E (2000) Do theories of conceptual change explain the difficulties of enlarging the number concept in mathematics learning? Paper presented at the annual meeting of the American educational research association. New Orleans, LA

75. Kanim S, Cid XC (2020) Demographics of physics education research. Phys Rev Phys Educ Res 16(2):020106
76. Rouse C, Hoover GA (2017) Report: committee on the status of minority groups in the economics profession (CSMGEP). Am Econ Rev 107(5):777–791
77. Noonan AS, Velasco-Mondragon HE, Wagner FA (2016) Improving the health of African Americans in the USA: an overdue opportunity for social justice. Public Health Rev 37(1):1–20

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16 Relevant Social Problems, Socially Alive Questions, and Gender in Social Science Teaching: A Conceptual and Methodological Review for the Development of Social Thinking Skills

Delfín Ortega-Sánchez

The main educational value of the History education consists in providing children and young people with the knowledge and skills necessary to situate themselves in their world, to understand what is happening in it, to have theoretical instruments to be able to interpret and value what is happening, its background and its consequences, and, in short, to commit them to building their personal and social future.

Joan Pagès

Summary

Included in the curriculum, relevant social problems (a concept attributed to the Anglo-Saxon tradition), socially alive questions for citizenship (a concept attributed to the French-speaking tradition), or controversial topics are one of the most prominent research concerns of social science didactics. The connection of historical and geographical knowledge with contemporary social problems seeks the critical interpretation by students of what is happening in the world and the development of creative or divergent thinking to solve these problems. Social thinking develops, in effect, by facing social problems, structural axes of the complexity that characterizes social reality and knowledge. In this sense, we should ask ourselves about the contribution of social disciplines to the development of citizens' social thinking and its capacity to resolve relevant

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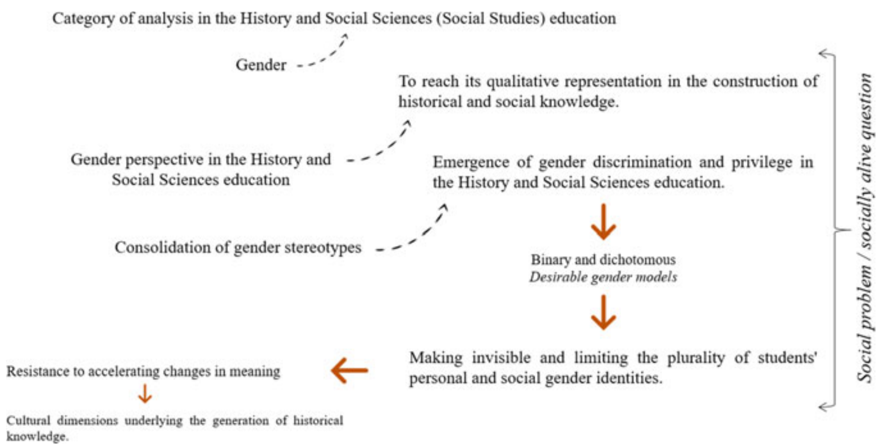
N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_16

social problems such as gender inequalities. From the point of view of critical reflection and social action, social science teacher training programs should assume gender as one of its basic analytical categories in social science teaching and should consider the application of resources of critical literacy aimed at social transformation and education in and for equality.

Graphical Abstract/Art Performance



Gender inequalities: a socially alive question in social studies education.

Keywords

Citizenship · Education · Gender · Social problems · Social science education · Social thinking skills · Socially alive questions

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword

and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

The purpose of working on social problems in social studies and historical education is a necessity to understand reality in increasingly heterogeneous societies critically [1], promote social values related to social justice, as well as to learn and teach how to participate actively, committed and responsibly in the construction of answers or alternatives [2–4]. Educating for social intervention or participation requires, therefore, the incorporation of the curriculum and the raising of relevant social problems, socially alive questions or controversial issues [5–9], and the acquisition of the professional skills needed to teach *in* and *for* democratic citizenship [10].

The didactic treatment of the problems that shape and singularize the social reality should necessarily be related to critical social thinking, the development of social skills, and democratic education for a participatory social culture [11]. Social problems, socially alive questions, or controversial issues are explanatory factors of social competencies and, consequently, social thought formation [4, 12]. The didactic transposition of social problems as content makes training opportunities possible [13, 14] to achieve truly competent learning [15].

Relevant social problems, socially alive questions, or controversial issues constitute one of the most outstanding research concerns of social science didactics, based on the study of interculturality [16], social and cultural minorities [17], historical memory [18], social justice [19], gender [20], or economic literacy [21].

2 Relevant Social Problems, Socially Alive Questions, and Controversial Issues in the Training Programs for Future Teachers

Reflection on social studies and historical education enables guidance and decision-making on teaching activities, promoting certain student models, and establishing links and coherence between the teacher's thinking and his/her teaching practice [22]. Indeed, "if the teacher [as an agent of change] is aware of and reflects on what the purposes of the Social Sciences should be, the development of the personal and democratic participation is promoted" [23, p. 154]. Defining these goals during the teacher training programs, and considering their teaching practice, is, therefore, a background knowledge for "distinguishing between different intentions, concretizing the didactic change and making decisions" [24, p. 514].

These aims should be oriented to a critical understanding of social reality and engaged and inclusive social participation. In this sense, achieving a comprehensive training of future teachers implies incorporating social problems in their programs [25], which would offer strategies, instruments, and didactic resources necessary to educate in social participation based on responsibility and commitment to the problematic complexity of social reality [26]. From this perspective, the formation of social thought and education for democratic citizenship should be the fundamental axes of social science teaching in schools. In this way, working on social problems with trainee teachers allows, precisely, for the formation of their social thought and decision-making from socio-critical approaches. Therefore, education for democratic participation is part of the formation of social thought [27]. This thinking develops from social problems, "those that occupy most of our lives, but which have little attention in school" [12, p. 26]. From a social and critical perspective, social problems should constitute one of the central axes of teaching so that academic knowledge is placed at the service of its didactic treatment [28, 29], and to think and be thought the reality through the development of students' social conscience.

The most recent scientific literature on the treatment and curricular inclusion of social problems or controversial social issues in the social science classroom insists on the need to "introduce students to the great social debates where there are different points of view, different interests at stake, and where they must construct their own opinion on the subject from a critical and well-founded perspective" [30, p. 26]. Pioneering research [31, 32] on the didactic treatment of musical resources (songs) for the curricular inclusion of social problems shows the advantages of working on contemporary issues, problematizing social content, and implementing socio-critical methodological changes in the teaching of social sciences.

The curricular permanence of technical-reproductive approaches in state regulatory norms and its development in the most commercially successful school publishing houses continues to hinder acquiring knowledge and social competencies adjusted to the understanding and intervention in social reality. Working with social problems, socially alive questions, or controversial issues "allows for a typology of analysis that includes the relative experience of the past and future expectations in a lived present, and to consider the temporal relationship from the analysis of changes and continuities that can be observed from a comparative perspective" [33, p. 49]. In short, the specific and didactically intentional inclusion of social problems in the curriculum [34] opens the possibility of having educational spaces for the development and acquisition of critical and creative thinking skills [35, 36] and, therefore, for a comprehensive understanding of reality.

In understanding and interpreting the historicity of the present and in the projection of the social future, this socio-critical perspective would constitute one of its elementary bases. In this sense, social sciences didactics should emphasize and deepen how social–historical thinking is promoted at school [12] and in teacher training to acquire critical skills that make possible solutions or interventions for the social problems surrounding students [37].

Research results demonstrate the advantages of working on contemporary problems with trainee teachers, its impact on social representations, and, finally, on their teaching practice. Investigating these representations is one of the first steps in mapping out, in an operational way, the goals of social science teaching designed for the understanding of reality and social intervention, even though, in principle, this does not presuppose effective changes in teaching practices [15]. Together with the understanding and didactic transposition of social problems in teacher training programs, "it is fundamental [to know] how we do it and how their representations are translated into teaching practice" [14, p. 390].

From the area of didactics of social sciences, teacher training plans aimed at the critical understanding of reality and social intervention would be unsuccessful without the structural incorporation of problems into the social sciences curriculum [25]. In this sense, education for democratic participation is necessarily related to forming critical and creative thought (social thought). Therefore, it is necessary to implement specific teaching actions to rethink the contents, objectives, and competencies set out in the area of teaching guides [38].

Determining the degree of identification, social and educational commitment, and the potential curricular response of future teachers to the conflicts of their contemporaneity necessarily involves thinking about a curriculum based on relevant social problems, socially alive questions, or controversial issues [5, 9]. From this perspective, critical teacher training should offer the necessary tools to articulate reflective practices [39] and adopt active and committed positions [40, 41] in the face of problems. To this end, there is a need for social sciences that "explain social problems and provide elements for active participation in decision-making" [42, p. 65].

Therefore, curricular decision-making by teachers should be directed towards the construction of social knowledge, focused on commitment, responsible social intervention, and the promotion of social justice–three nuclei of action capable of overcoming hegemonic and unidirectional positions. Nevertheless, the still representative attachment to technical-reproductive curricular conceptions confirms its scarce educational attention [37]. Consequently, it is necessary "a greater relationship of the contents with social and environmental problems, and with the community from which some of the problems under study should come" [43, p. 203], the first level of democratic participation and social intervention.

As a response to technological rationality, still dominant in social science teaching, teacher training should address their training as "critical intellectuals in the context of reflective practice" [44, p. 78]. This training model is, without a doubt, "one of the most effective ways for future teachers to give meaning to, understand and value their own practice" in complex social environments. Understanding, valuing, and proposing solutions or alternatives to these complex environments also connect with the formation of social thought. Indeed, "schools are not neutral places and therefore neither can teachers take a neutral position" [44, p. 78]. In this sense, a social science from the budgets of education for global citizenship must consider, analyze and assess the possibilities of approaches focused on everyday life, on controversial issues, or on the disciplinary knowledge generated to understand, interpret and try to solve problems of all kinds [45].

3 Relevant Social Problems, Socially Alive Questions, and Controversial Issues in the Social Science Classroom

Teachers must open a window to reality and to the present time and open schools to what is happening in time and space to their students [46]. The current problems, almost always, have their roots in the past, different attempts of solutions, and diverse results, which show their complexity. Its multiple interpretations involve analyzing its arguments and discerning between facts and opinions [47, 48]. Its treatment demands an interdisciplinary and holistic approach that overcomes the compartmentalization of knowledge in subjects and the linear rigidity of the most widely used textbooks [49].

When reference is made to the need for curriculum reform and education for critical and democratic citizenship in the teaching of social sciences, it is common to use socially alive questions and relevant social problems as equivalent terms. However, its focus in the classroom encounters distinctive particularities. Relevant social problems, not always linked to students' direct context and emotions, are key questions that define the complexity of social reality. In fact, social problems are the source of ideology, often associated with the information offered [50]. On the other hand, socially alive questions form transcendent problems, which are part of the students' and society's most immediate and daily reality. They are open social debates, which generate disparity in their analysis and proposals for solutions (Table 1).

Along these lines, there is an abundance of classroom research and didactic proposals designed based on printed, digital, or sound journalistic news to critically analyze its messages, warn of the underlying ideology, and define its persuasive mechanisms. The decoding or exercise of critical literacy must be related to the social context, reflect on the scope of the source, and determine which discourses and representations of reality it constructs and which it silences [55].

Critical literacy goes beyond developing critical thinking; it is not limited to providing decoding techniques or cognitive skills to unmask the intentions of social stories. Instead, this type of literacy seeks citizens' collective and transformative participation in socially conscious issues [56, 57]. The actions in the classroom, consequently, would have to materialize in small transformative changes in the locality, which demonstrate the viability and the real effectiveness of the proposals and social interventions [58, 59]. The proposal of creative alternatives to social problems, socially alive questions, or controversial issues implies, ultimately, the adoption of critical and democratic attitudes for social transformation [4, 60, 61].

Assuming the critical reading of the social narrative as a curricular objective [62, 63], the training of history and other social science teachers would have to consider current environments that are increasingly global and plural [64–66]. In this context, the use of critical literacy resources should focus on argumentation, debate, and participation [67], offering students the necessary tools to learn to think critically [68] and to identify in discourses social presences and absences [69], identities, and perspectives with the capacity to influence their social thoughts and actions [14, 70] (Table 2).

Table 1 Relevant social problems and socially alive questions in the history and social sciences education

Socially alive questions (French-speaking tradition)	
Definition and didactic purpose	Author
(a) It is an alive question for society, which questions social practices and refers to the actors' social representations. It raises debates, disputes or conflicts from the media treatment (b) It is a living issue for reference science and causes debate or controversy among specialists in the disciplines or among experts in the professional fields (c) It is a living question for school knowledge, which questions the contents and proposals of school programs and manuals, with which it enters into controversy	Legardez and Simonneaux [51]
The claims of groups or minorities who denounce the silence and forgetfulness of the suffering of those they have inherited are alive questions	Tutiaux-Guillon [52]
Socially alive questions contemplate ethical aspects and problems of social life, of relations with others, for example, the intercultural questions	Brusa and Musci [53]
The study of social issues at school implies thinking about the teaching of social sciences as a tool for social change	Santisteban [54]
Relevant social problems (Anglo-Saxon tradition)	
Definition and didactic purpose	*Author*
Relevant social problems allow students to relate school to life. This relationship has to be combined with different factors to be effective: (a) To directly relate the contents to the relevant social problems (b) Promote in class discussions, project work, debates, simulations or written essays, so that students get used to considering different points of view and interpretations of problems (c) That the students perceive that they can express their points of view freely and learn to listen to other opinions, in order to achieve knowledge, skills and social attitudes	Santisteban [54]

This critical understanding of social reality and the acquisition of the receptive critical competence of students also seems to correspond with the thinking and beliefs of teachers about critical literacy in their classroom activity [71]. We agree with Gamboa et al. [72, p. 65] on the "urgency of rethinking the legal practices in the school setting" and on the need to overcome the permanence of practices restricted to technical learning decontextualized of linguistic signs or functional literacy [73]. From this perspective, "there is no doubt that the purpose of history teaching must be to train a critical and responsible citizenship with sufficient historical competencies to propose and participate in social changes. In this sense, a renovating perspective is the role of history in an education for global citizenship, which makes visible the persons and groups or the invisible identities" [54, p. 67].

Teaching history and social sciences designed to educate critically and democratically requires the curricular consideration of the social uses of the word read, written, or audio-visually narrated to foster in its natural recipients increasingly

Table 2 End-purposes of history education

Key concept	Educational purpose	Learnings expected
Historical interpretation	To develop critical literacy in historical interpretation by analyzing primary and secondary sources to go beyond prejudices and stereotypes and take a position about the world's social problems	• To interpret primary and secondary historical sources, separate facts from opinions, and assess their veracity and reliability by comparing information from diverse origins • To identify intentionality, cultural and economic values, and the political ideology of information sources and their positioning concerning the controversial issues analyzed • To interpret the voids or silences in the media about specific minorities, cultures, and identities (invisible)
Historical problems, issues-centered social studies, and controversial issues	To analyze social problems and controversial issues by looking at their historicity in order to understand their development and alternatives and to contribute solutions	• To identify similarities and differences of past and present social problems and compare them to those in different countries or regions of the world • To relate past and present through conceptual thought on concepts like migrations, refugees, walls, freedom, democracy, and conflict • To analyze economic, cultural, political, territorial, and conflicts between countries by looking at their historical development
Historical awareness	To reflect on the fact of being human with temporal awareness, which lets us know where we come from, where we are and what type of future we want to build	• To evaluate our belonging to the human race and reflect on what has made us and makes us humans • To relate the past to the present and the future, understanding the historical process as a single inseparable fabric • To draft prospects for social problems starting from our historical past, including responsibility to participate, locally or nationally, and globally

inclusive, plural, and democratic attitudes, gestures, and critical positions [74]. It is necessary, therefore, to develop social thinking skills directed at the critical interpretation of reality, self-knowledge based on social interaction, and the assumption of *textual use* as a socio-cultural practice in education for global citizenship.

4 Gender Inequalities: A Socially Alive Question in Teacher Training

In the educational line of relevant social problems, socially alive questions or controversial issues as content, and of the formation of social thought in the teaching of history, the analysis of social invisibilities and absent identities is part of one of the most relevant lines of research in the area of didactics of social sciences in Spain [20, 64, 75–77]. Its scientific production is based on the treatment, as a procedure, of social inequalities, which are recognizable, among other things, in the deconstruction of gender relations and in the stereotyped attribution of social behaviors that limit the complexity and autonomous development of identity diversity.

Along these lines, the permanence of a school history marked by positivist historiographical trends of a markedly androcentric, ethnocentric, and socio-centric nature has been sufficiently demonstrated, which make invisible, restrict and limit the plural construction of the personal and social identities of the students [20, 64, 76, 78]. The results obtained in recent research [64] highlight the importance of analyzing the social representations of future teachers, which are markedly conditioned by these historiographical trends, to advance their gender training [20, 38].

In this sense, the development of teacher training programs, oriented to the acquisition of critical skills for education *in* and *for* equality, should consider as a priority the didactic innovation to have an impact on teaching practice and to critically reflect on teaching practice itself. It seems evident, therefore, the need to work with trainee teachers, as reflective critics-practitioners, in the purposes of social sciences education, in curricular content, in the models of their future teaching practice, and in the analysis of the principles that explain their own practice.

5 Conclusion

It is necessary to work on the social complexity in schools and teacher training so that social studies can be connected to contemporary problems and citizenship's everyday life. The construction of school knowledge demands from all social disciplines its contribution to the analysis, interpretation, and understanding of these problems to educate for democratic citizenship, committed and responsible with its present problems, and with the projection of its future.

Despite the progress achieved, it is still necessary to insist on the design, implementation, and evaluation of innovative teaching projects and didactic experiences aimed at dealing with social problems, socially alive questions, or controversial issues and, in particular, to include the gender perspective in social sciences and historical education from the perspective of active citizenship [79, 80]. More studies are needed on the training of future social science teachers to develop socio-critical competencies and articulation of reflective practices.

The permanence and technical reproduction of traditional curricular designs and approaches motivate the absence of the social problems that characterize a society. The purpose of social studies in education should assume socio-critical positions and perspectives in which social problems could explain the theoretical and methodological bases of teaching and learning social competencies [4, 81, 82].

In order to move towards social science teaching from the promotion and defense of human rights and social justice and to encourage social action on social problems such as gender inequalities, social science teacher training programs should include the concept of gender as one of the fundamental categories of analysis in the teaching of school history, and consider the use of critical literacy resources aimed at social transformation [83].

Core Messages

- Social thinking develops by facing social problems, structural axes of the complexity of social reality.
- Education for democratic participation necessarily relates to forming critical and creative thinking.
- Educating critically and democratically requires the curricular consideration of the social uses of the word.
- The permanence of positivist historiographic trends limits the plural construction of the students' identities.
- The need for teacher training programs aims at acquiring critical skills for education *in* and *for* equality.

References

1. Kello K (2016) Sensitive and controversial issues in the classroom: teaching history in a divided society. Teachers Teach 22(1):35–53. https://doi.org/10.1080/13540602.2015.1023027
2. Dam G, Volman M (2004) Critical thinking as a citizenship competence: teaching strategies. Learn Instr 14:359–379
3. Levstik LS, Tyson CA (eds) (2008) Handbook of research in social studies education. Routledge, New York-London
4. Pagès J, Santisteban A (eds) (2011) Les qüestions socialment vives i l'ensenyament de les Ciències Socials. Universitat Autònoma de Barcelona, Barcelona

5. Evans RW, Saxe DW (eds) (1996) Handbook on teaching social issues. NCSS, Washington
6. Hess DE (2004) Controversies about controversial issues in democratic education. PS: Polit Sci Politics 37(2):257–261
7. Hess D (2009) Controversy in the classroom. The democratic power of discussion. Routledge, New York-London
8. Legardez A (2003) L'enseignement des questions sociales et historiques, socialement vives. Le Cartable de Clio 3:245–253
9. Legardez A (2006) Enseigner des questions socialement vives. Quelques points de repéres. In: Legardez A, Simonneaux L (coords) L'école á l'épreuve de l'actualité. Enseigner les questions vives. ESF, París, pp 19–31
10. Jiménez MD, Moreno C (2012) Formar para enseñar en participación ciudadana. Una experiencia integradora. In: De Alba N, García FF, Santisteban A (eds) Educar para la participación ciudadana en la enseñanza de las Ciencias Sociales, vol 2. Díada Editora—AUPDCS, pp 511–519
11. Santisteban A (2012) La investigación sobre el desarrollo de la competencia social y ciudadana para una participación crítica. In: De Alba N, García FF, Santisteban A (eds) Educar para la participación ciudadana en la enseñanza de las Ciencias Sociales, vol 1. AUPDCS—Díada Editora, Sevilla, pp 277–286
12. Pagès J, Santisteban A (2014) Una mirada del pasado al futuro en la Didáctica de las Ciencias Sociales. In: Pagès J, Santisteban A (eds) Una mirada al pasado y un proyecto de futuro. Investigación e Innovación en Didáctica de las Ciencias Sociales, vol 1. Universitat Autònoma de Barcelona—AUPDCS, Barcelona, p 17–39
13. Huddleston T (2005) Teacher training in citizenship education: training for a new subject or for a new kind of subject? J Soc Sci Educ 4(3):50–63
14. Santisteban A (2015) La formación del profesorado para hacer visible lo invisible. In: Hernández AM, García CR, De la Montaña JL (eds) Una enseñanza de las ciencias sociales para el futuro: recursos para trabajar la invisibilidad de personas, lugares y temáticas. Universidad de Extremadura—AUPDCS, Cáceres, pp 383–393
15. Ortega-Sánchez D, Pagès J (2017) Las representaciones sociales de los problemas contemporáneos en estudiantes de Magisterio de Educación Primaria. Investigación en la Escuela. Revista internacional de investigación e innovación educativa 93:1–16
16. González-Monfort N, Henríquez R, Pagès J (2008) Enseñanza y aprendizaje de la historia en contextos interculturales. Una experiencia de investigación y aplicación didáctica con consecuencias curriculares. In: Ávila RM, Cruz MA, Díez MC (eds) Didáctica de las Ciencias Sociales, Currículo escolar y Formación del profesorado. La didáctica de las Ciencias Sociales en los nuevos planes de estudio. Universidad de Jaén, Jaén, pp 597–616
17. Cerezer OM, Pagès J (2014) Los actores invisibles de la historia: un estudio de caso de Brasil y Cataluña. In: Pagès J, Santisteban A (eds) Una mirada al pasado y un proyecto de futuro. Investigación e innovación en didáctica de las ciencias sociales, vol 2. Universitat Autònoma de Barcelona—AUPDCS, pp 37–44
18. Pagès J (2008a) El lugar de la memoria en la enseñanza de la historia. Iber. Didáctica de las Ciencias Sociales, Geografía e Historia 55:43–53
19. Oller M, Pagès J (2007) Las representaciones sociales del derecho, la justicia y la ley de un grupo de adolescentes catalanes de 4º de ESO. Enseñanza de las Ciencias Sociales 6:3–19
20. Ortega-Sánchez D, Pagès J (2018a) La construcción de identidades de género en la enseñanza de la Historia escolar: un estudio a partir de las narrativas históricas de los futuros y futuras docentes en Educación Primaria. In: López E, García CR, Sánchez M (eds) Buscando formas de enseñar: investigar para innovar en Didáctica de las Ciencias Sociales. Universidad de Valladolid—AUPDCS, Valladolid, pp 89–100
21. Olmos R, González-Monfort N, Pagès J (2017) Las representaciones sociales del alumnado sobre la crisis. ¿Qué soluciones ofrece el alumnado ante los problemas económicos? Didáctica de las Ciencias Experimentales y Sociales 32:51–70

22. Ortega-Sánchez D, Pagès J (2020) The end-purpose of teaching history and the curricular inclusion of social problems from the perspective of primary education trainee teachers. Soc Sci 9(2):9. https://doi.org/10.3390/socsci9020009
23. Hernández L (2013) La enseñanza de las Ciencias Sociales en la formación profesional de las estudiantes de maestra de Educación Infantil. Ph.D. Dissertation, Universitat Autònoma de Barcelona. Available at https://ddd.uab.cat/record/115328?ln=ca. Accessed 14 July 2020
24. Abellán J (2014) La reflexión sobre las finalidades de la enseñanza de la Historia. Un estudio de caso en la formación inicial del profesorado en el sistema educativo mexicano. Ph.D. Dissertation, Universitat Autònoma de Barcelona. Available at https://ddd.uab.cat/record/132348. Accessed 12 July 2020
25. Benejam P, Pagès J (1997) Enseñar y aprender Ciencias Sociales. Geografía e Historia en la Educación Secundaria. Institut de Ciències de l'Educació—Universitat de Barcelona—Horsori, Barcelona
26. Pagès J (2002) Aprender a enseñar Historia y Ciencias Sociales: el currículo y la Didáctica de las Ciencias Sociales. Pensamiento Educativo 30:255–269
27. Canal M, Costa D, Santisteban A (2012) El alumnado ante problemas sociales relevantes: ¿Cómo los interpreta? ¿Cómo piensa la participación?. In: De Alba N, García FF, Santisteban A (eds) Educar para la participación ciudadana en la enseñanza de las Ciencias Sociales, vol 1. AUPDCS—Díada Editora, Sevilla, pp 527–535
28. Ortega-Sánchez D, Alonso-Centeno A, Corbí M (2020) Socio-environmental problematic, end-purposes, and strategies relating to education for sustainable development (ESD) through the perspectives of Spanish secondary education trainee teachers. Sustainability 12(14):5551. https://doi.org/10.3390/su12145551
29. García FF (2014) Ciudadanía participativa y trabajo en torno a problemas sociales y ambientales. In: Pagès J, Santisteban A (eds) Una mirada al pasado y un proyecto de futuro. Investigación e Innovación en Didáctica de las Ciencias Sociales, vol 1. Universitat Autònoma de Barcelona—AUPDCS, pp 119–125
30. Díaz N, Felices de la Fuente MM (2017) Problemas sociales relevantes en el aula de primaria: la "cartografía de la controversia" como método. REIDICS. Revista de Investigación en Didáctica de las Ciencias Sociales 1:24–38
31. Martínez IA, Pagès J (2017) Aprender Historia y Ciencias Sociales utilizando las canciones. Resultados de una investigación. Clío Asociados. La historia enseñada 24:83–99
32. Martínez IA (2017) ¡Profe, enséñame con canciones! Una investigación sobre el uso de las canciones en la enseñanza y aprendizaje de las Ciencias Sociales. Ph.D. Dissertation, Universitat Autònoma de Barcelona. Available at https://ddd.uab.cat/record/187750?ln=ca. Accessed 8 Aug 2020
33. Grau V (2016) El valor de la alteridad: enseñanza-aprendizaje a partir de realidades problemáticas temporales. In: García CR, Arroyo A, Andreu B (eds) Deconstruir la alteridad desde la Didáctica de las Ciencias Sociales: educar para una ciudadanía global. Universidad de Las Palmas de Gran Canaria—AUPDCS, Las Palmas, pp 58–66
34. Segall A, Gaudelli W (2007) Reflecting socially on social issues in a social studies methods course. Teach Educ 18(1):77–92. https://doi.org/10.1080/10476210601151599
35. Pagès J (2015) La educación política y la enseñanza de la actualidad en una sociedad democrática. Educaçâo em Foco 19(3):17–37
36. Santisteban A (2009) Cómo trabajar en clase la competencia social y ciudadana. Aula de Innovación Educativa 187:12–15
37. Pagès J (2007) La enseñanza de las Ciencias Sociales y la Educación para la Ciudadanía en España. Didáctica Geográfica 9:205–214
38. Ortega-Sánchez D, Pagès J (2018) Género y formación del profesorado: análisis de las Guías Docentes del área de Didáctica de las Ciencias Sociales. Contextos Educativos. Revista de Educación 21:53–66

39. Mathison S, Ross EW, Vinson KD (2006) Defining the social studies curriculum: influence of and resistance to curriculum standards and testing in social studies. In: Ross EW (ed) The social studies curriculum. Purposes, problems and possibilities. State University of New York Press, Albany, NY, pp 99–114
40. Bronckbank A, McGill I (2007) Facilitating reflective learning in higher education. Open University Press–McGraw–Hill, Berkshire, New York
41. Perrenoud P (2011) Desarrollar la práctica reflexiva en el oficio de enseñar. Graó, Barcelona
42. Jara MA, Boixader A (2014) El currículo y la innovación en la enseñanza de las Ciencias Sociales, de la Geografía, de la Historia y de la educación para la ciudadanía. In: Pagès J, Santisteban A (eds) Una mirada al pasado y un proyecto de futuro. Investigación e Innovación en Didáctica de las Ciencias Sociales. Universitat Autònoma de Barcelona—AUPDCS, Barcelona, pp 53–78
43. Pagès J (2012) Enseñar a enseñar participar. In: De Alba, N, García, FF, Santisteban A (eds) Educar para la participación ciudadana en la enseñanza de las ciencias sociales. Universidad de Sevilla—AUPDCS, Sevilla, pp 199–209
44. Pagès J (2011) ¿Qué se necesita saber y saber hacer para enseñar Ciencias Sociales? La Didáctica de las Ciencias Sociales y la formación de maestros y maestras. EDETANIA 40:67–81
45. Pagès J (2016) La ciudadanía global y la enseñanza de las ciencias sociales: retos y posibilidades para el futuro. In: García CR, Arroyo A, Andreu B (eds) Deconstruir la alteridad desde la Didáctica de las Ciencias Sociales: educar para una ciudadanía global. Universidad de Las Palmas de Gran Canaria—AUPDCS, Las Palmas, pp 713–732
46. González-Monfort N, Santisteban A (2011) Cómo enseñar ciencias sociales para favorecer el desarrollo de las competencias básicas. Aula de Innovación Educativa 198:41–47
47. Pagès J (2008) Ensenyar l'actualitat, per què? Perspectiva Escolar 322:2–11
48. Wineburg S, McGrew S, Breakstone J, Ortega T (2016) Evaluating information: the cornerstone of civic online reasoning. In: Stanford digital repository. Available at http://purl.stanford.edu/fv751yt5934. Accessed 23 June 2020
49. Ortega-Sánchez D, Ibáñez J, Cal de la Sanz E (2019) Literacies and the development of social, critical, and creative thought in textbook activities for primary education in social sciences and the Spanish language. Front Psychol 10:2572. https://doi.org/10.3389/fpsyg.2019.02572
50. Santisteban A, Tosar B, Izquierdo A, Llusà J, Canals R, González N, Pagès J (2016) La literacidad crítica de la información sobre los refugiados y refugiadas: construyendo la ciudadanía global desde la enseñanza de las Ciencias Sociales. In: García CR, Arroyo A, Andreu B (eds) Deconstruir la alteridad desde la Didáctica de las Ciencias Sociales: educar para una ciudadanía global. Universidad de Las Palmas de Gran Canaria—AUPDCS, Las Palmas, pp 550–560
51. Legardez A, Simonneaux L (dirs) (2011) Education au développement durable et autres questions socialement vives. Educagri, Dijon
52. Tutiaux-Guillon N (2011) Les qüestions socialment vives, un repte per a la història i la geografia escolars? In: Pagès J, Santisteban A (eds) Les qüestions socialment vives i l'ensenyament de les ciències socials. Universitat Autònoma de Barcelona, Barcelona, pp 25–39
53. Brusa A, Musci E (2011) La didàctica difícil. Els problemes dels límits de l'ensenyament històric. In: Pagès J, Santisteban A (eds) Les qüestions socialment vives i l'ensenyament de les ciències socials. Universitat Autònoma de Barcelona, Barcelona, pp 41–52
54. Santisteban A (2019) La enseñanza de las Ciencias Sociales a partir de problemas sociales o temas controvertidos: estado de la cuestión y resultados de una investigación. El Futuro del Pasado 10:57–79. https://doi.org/10.14516/fdp.2019.010.001.002
55. Ortega-Sánchez D, Olmos R (2018) Los problemas sociales relevantes o las cuestiones socialmente vivas en la enseñanza de las ciencias sociales. In: Jara MA, Santisteban A (coords) Contribuciones de Joan Pagès al desarrollo de la didáctica de las ciencias sociales, la historia y la geografía en Iberoamérica. Universidad Nacional del Comahue—Universitat Autònoma de Barcelona, Cipolletti, pp 203–214

56. Sant E (2014) What does political participation mean to Spanish students? J Soc Sci Educ 13:11–25. https://doi.org/10.4119/UNIBI/jsse-v13-i4-1321
57. Sant E, Casas T, Pagès J (2011) Participar para aprender la democracia. Las representaciones sociales de jóvenes catalanes sobre la participación democrática. Uni-Pluri/versidad 11(2): 35–56
58. Mayor D (2018) Prácticas de aprendizaje-servicio como escenarios de confluencia entre la educación escolar y social. Revista Iberoamericana de educación 76:35–56
59. Puig JM, Gijón M, Martín X, Rubio L (2011) Aprendizaje-servicio y Educación para la Ciudadanía. Revista de Educación nº extra 45–67
60. Santisteban A (2011) La formación del pensamiento social y el desarrollo de las capacidades para pensar. In Santisteban A, Pagès J (eds) Didáctica del Conocimiento del Medio social y cultural en la Educación Primaria. Ciencias Sociales para aprender, pensar y actuar. Síntesis, Madrid, pp 85–103
61. Shor I (1999) Criticall literacy in action. Writing words, changing worlds. Boynton, Portsmouth
62. Atienza E (2007) Discurso e ideología en los libros de texto de ciencias sociales. Discurso Sociedad 1(4):543–574
63. Kellner D, Share J (2007) Critical media literacy is not an option. Learn Inquiry 1(1):59–69
64. Ortega-Sánchez D (2017) Las mujeres en la enseñanza de la Historia y de las Ciencias Sociales. Estudio de caso en formación inicial de maestros y maestras de Educación Primaria. Ph.D. Dissertation, Universitat Autònoma de Barcelona. Available at https://ddd.uab.cat/record/187752. Accessed 3 June 2020
65. Baildon M, Damico JS (eds) (2011) Social studies as new literacies in a global society. Relational cosmopolitanism in the classroom. Routdlege, London
66. Smith A, Hull G (2013) Critical literacy and social media. In: Avila J, Zacher J (eds) Critical digital literacies as social practices. Intersections and challenges. Peter Lang, New York, pp 63–84
67. Tosar B, Santisteban A (2016) Literacidad crítica para una ciudadanía global. Una investigación en Educación Primaria. In: García CR, Arroyo A, Andreu B (eds) Deconstruir la alteridad desde la Didáctica de las Ciencias Sociales: educar para una ciudadanía global. Universidad de Las Palmas de Gran Canaria—AUPDCS, Las Palmas, pp 674–683
68. Wolk S (2003) Teaching for critical literacy in social studies. Soc Stud 94:101–106
69. Ogle D, Klemp R, McBride B (2007) Building literacy in social studies. Strategies for improving comprehension and critical thinking. ASCD, Alexandria
70. Santisteban A, Pagès J, Bravo L (2018) History education and global citizenship education. In: Davies I, Ho L, Kiwan D, Peck C, Peterson A, Sant E, Waghid Y (eds) The Palgrave handbook of global citizenship and education. Palgrave Macmillan-Springer, London, pp 457–472
71. Avendaño de Barón GS (2016) La lectura crítica en Educación Básica Secundaria y Media: la voz de los docentes. Cuadernos de Lingüística Hispánica 28:207–232
72. Gamboa AA, Muñoz PA, Vargas L (2016) Literacidad: nuevas posibilidades socioculturales y pedagógicas para la escuela. Revista Latinoamericana de Estudios Educativos 12(1):53–70
73. Londoño DA (2015) De la lectura y la escritura a la literacidad: una revisión del estado del arte. Anagramas 14(26):197–220
74. Ortega-Sánchez D, Pagès J (2017b) Literacidad crítica, invisibilidad social y género en la formación del profesorado de Educación Primaria. REIDICS. Revista de Investigación en Didáctica de las Ciencias Sociales 1:102–117
75. Ortega-Sánchez D, Marolla J, Heras D (2020) Invisibilidades sociales, identidades de género y competencia narrativa en los discursos históricos del alumnado de Educación Primaria. In: Díez EJ, Rodríguez JR (dir) Educación para el Bien Común. Hacia una práctica crítica, inclusiva y comprometida socialmente. Octaedro, Barcelona, pp 89–103

76. Ortega-Sánchez D, Pagès J (2016) Deconstruyendo la alteridad femenina en la enseñanza de la Historia escolar: representaciones sociales del profesorado de educación primaria en formación. In: García CR, Arroyo A, Andreu B (eds) Deconstruir la alteridad desde la Didáctica de las Ciencias Sociales: educar para una ciudadanía global. Universidad de Las Palmas de Gran Canaria—AUPDCS, Las Palmas, pp 184–193
77. Ortega-Sánchez D, Pagès J (2019) Las emociones y los sentimientos en la enseñanza de la Historia y de las Ciencias Sociales. In: Hortas MJ, Dias A, De Alba N (eds) Enseñar y aprender Didáctica de las Ciencias Sociales: la formación del profesorado desde una perspectiva sociocrítica. Ediciones Escola Superior de Educação—Instituto Politécnico de Lisboa—AUPDCS, Lisboa, pp 118–127
78. Marolla J (2016) La inclusión de las mujeres en la enseñanza de la Historia y las Ciencias Sociales. Estudio colectivo de casos en las aulas chilenas sobre sus posibilidades y limitaciones. Ph.D. Dissertation, Universitat Autònoma de Barcelona. Available at https://ddd.uab.cat/record/173982. Accessed 28 July 2020
79. Jerome L (2006) Critical citizenship experiences? Working with trainee teachers to facilitate active citizenship in schools. Teach Dev 10(3):313–329. https://doi.org/10.1080/13664530600921858
80. Santisteban A, González-Monfort N (2019) Education for citizenship and Identities. In: De Alba N, Navarro E (eds) Handbook of research on education for participative citizenship and global prosperity. IGI Global, Hershey PA, pp 551–567
81. Éthier MA (2008) Investigación sobre el desarrollo de competencias en ciencias sociales a partir de prácticas políticas y comunitarias. Íber. Didáctica de las Ciencias Sociales, Geografía e Historia 58:89–107
82. Heimberg C (2010) ¿Cómo puede orientarse la educación para la ciudadanía hacia la libertad, la responsabilidad y la capacidad de discernimiento de las nuevas generaciones? Íber: Didáctica de las Ciencias Sociales. Geografía e Historia 17(64):48–57
83. Ortega-Sánchez D (2019) Teaching gender in the history classroom: an investigation into the initial training of primary education teachers. Educ Sci 9:114. https://doi.org/10.3390/educsci9020114

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17 Milestones of Bioeducational Approach in Mind, Brain, and Education Research

Flavia Santoianni and Alessandro Ciasullo

Every kind of education is brain-based.

Diamond, 2001

Summary

Educational neuroscience, and its sister disciplines, neuro-education, and brain-based education, are innovative fields of study in which scientists and practitioners from neuroscience, educational psychology, and educational research come together to explore the networked world of mind, brain, and education. This possible alliance enables research to design educational settings in order to improve effective learning. Italian research on mind, brain, and education is represented by bioeducational sciences, which introduce the emerging theories of cognitive educability. Milestones of the bioeducational approach consist of five keys: diversity, modifiability, discontinuity, inte(g) ration, and collaboration. These key concepts concern the flexibility of education (the potential to change continuously) to deal with variable situations and the integrated action of education (the possibility given by explicit and implicit double track to manage the conceptual organization). The concept of flexible education is based on the idea that every cognitive system is rooted within dynamic networks of individual and social aspects. Educational research needs

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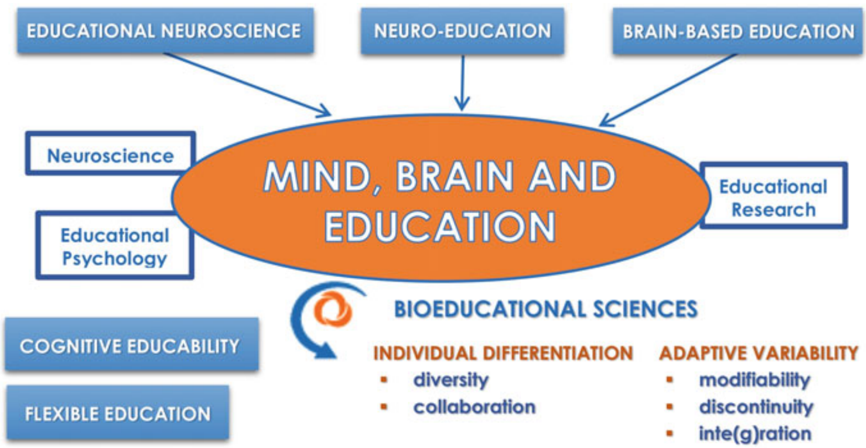
N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_17

flexible models of tailored educability based on individual differentiation and adaptive variability. Learners diverge indeed in their intertwined cognitive processing, emotional, and bodily approach to learning content. Cognitive systems activate processes of adaptive interaction with the environment regulated by experience. These processes concern the modularity of individual cognitive functions and their evolutive sharing. The individual developmental psychological, biological, and social processes are integrated into holistic and interactive theoretical perspectives of educability.

Graphical Abstract/Art Performance



Bioeducational sciences in mind, brain, and education research.

Sinorama
(Made by Sara Giusti).

Keywords

Adaptive variability · Bioeducational sciences · Brain-based education · Brain · Educability · Education · Educational neuroscience · Flexible education · Individual differentiation · Mind · Neuro-education

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

The idea of connecting neuroscience and education was born in the 1980s in various international scientific environments.[1] Since the beginning, this two-way collaboration [1] is not only a one-way route of influence [2], but it is a challenge to understand the role of mind and brain in teaching and learning processes. Even if neuroscience has already explained learning and is still doing it through studies on neural communication in synapse networks, how experiences arise and stabilize during individual development in relation to educability is a not yet fully explored research question [3, 4]. The potential of this idea is to uncover the added value of brain knowledge to improve education. Even if the constituent fields are different, neuroscience is observational, while education is interventional, and the challenge becomes to intertwine neuroscientific and educational settings [5].

Educational neuroscience, a new field of study in which scientists and practitioners from neuroscience, educational psychology, and education research come together to explore the networked world of mind, brain, and education [6], seeks to explain how knowledge about the brain changes during learning can be applied to the classroom, which interdisciplinary collaboration can arise, and how this field can play as a translator of languages [7]. Its sister disciplines are:

- neuro-education, a nascent discipline that joins neuroscience, psychology, cognitive science, and education to re-new teaching methods, curricula, and educational policy [8]; and
- brain-based education, all attributable to the broader movement of mind, brain, and education, which grounds education on research in biology, cognitive science, and development.

The intertwining of mind, brain, and education recognizes the active nature of knowledge construction and leverages the overcoming of the conduit model [9] towards brain-based teaching and learning [10]. The vision of mind, brain, and education research overcomes the traditional model according to which experimental data of neuroscience are made available to educators, leaving out teachers and students from their role of investigating learning where it takes place. The initial idea that is connecting brain knowledge directly to school-related learning is not possible [11] because the supposed bridge is "too far" [12] has been long discussed. The discussion focused on using biological concepts for interpreting

[1] In the late 1980s, the American Education Research Association (AERA) founded the interest group on the topic *Brain, Neurosciences, and Education*. In the 1990s, the *Decade of the Brain* started. In 1993, the Harvard Graduate School of Education (HGSE) launched the *Mind, Brain and Behavior* (MBB) initiative and, in 2004, Harvard International Mind, Brain and Education Society (IMBES) promoted the interdisciplinary program on *Mind, Brain, and Education* (MBE), linking their initiatives to the project *Learning Sciences and Brain Research* of the Council on Educational Research and Innovation of the Organization for Economic Cooperation and Development in Paris and to the activities of the Baby Science Society of Japan in Tokyo.

educational situations and personal learning differences, from disability to typical to exceptional ability, between people and social groups.

Individuals' management of change within their own learning environments can be explained through the study of developmental mechanisms of variations in relation to environmental factors and their feedbacks. Interactive specialization is an investigation of how changes in one system can impact another system and it contributes to co-create the change processes [13]. Brain-based education focuses on multimodal enriched environments designed to let students collaboratively participate in learning processes and enhance attentional, emotional, and motivational dimensions [14]. The educational goal is no more to let students achieve an always better performance, but the personalization of learning and the continuous development of skills, according to the reciprocal feedbacks between teacher and learner within their interactive, adaptive relation [15].

The possible alliance between mind, brain, and education enables research to design educational settings in order to improve effective learning and healthy development [16]. Engagement, strategies, and principles are three of the interpretative keys of the world of brain-based education, which overcome the nature-nurture false dichotomy between genes and environment [17] by analyzing:

- the relationship between neural growing and daily behaviors as physical exercise, stress levels, and adequate nutrition;
- how the brain rewires and remaps itself through neuroplasticity; and
- the influence of social conditions and environmental design on brain development [18]

To reduce the risk of misdirection, educational neuroscience and related disciplines need to consider misconceptions as neuromyths [19, 20]. These are misunderstandings:

- arising from misreading information about the brain and its functions from original scientific findings;
- wrongly interpreted, overgeneralized, or oversimplified [21];
- usable by pre-service and in-service teachers to support the use of neuromyth-based instructional practices [22]; and
- tending to survive even if adequate information is available.

Neuromyths can indeed be

- simplifications of scientific results, as the possible differentiation between the right and left hemisphere of the brain or between the male/female brain;
- offspring of scientific hypotheses, as the Mozart effect; or
- misinterpretations of experimental results, as the myth of the first three years, which concerns the role of brain plasticity in critical periods during epigenetic development and if it is worthwhile to organize enriched learning environments [23, 24].

Neuromyths are mainly concerned about two:

i. brain potential, as the chance to effectively manage the ability to multitask, to be sustained by the regular practice of brain games to improve cognitive functioning with desirable permanent effects, to prefer specific types of nutrients that could affect brain functions or by learning new information during sleep. These efforts are hypothetically devoted to resolving the main problems of brain misuse. The idea is that learners exploit only 10% of their brain in the classroom or find better solutions more quickly if they are forced to think under pressure [25]; and
ii. cognitive theories as multi-intelligence or learning styles are not based on observations. Issues as the shift from learning processes to knowledge structures, the changing of learning environments according to biological and cultural evolution, the development of diverse teaching and learning models in relation to cognitive differences and experiences can be, however, considered as complex issues, generating research questions which need to be answered through a multiplicity of theoretical points of view and methods, involving the intertwining of neuroscience, psychology, and education.

Italian research on mind, brain, and education is represented by bioeducational sciences [26]. The idea of linking education to biological sciences raises in this context as bio-pedagogy in the early 1980s when *bios* and *logos* were considered the two sides of the same coin [27]. The theme of bio-education is seen as situated in cultural environments since mental models and their biological roots influence meaning-making in human cultures [28]. Bioeducational sciences is nowadays a field of inquiry in which the challenge collaboration between neuroscience and education is embodied in a two-way dialogue focusing on learning, adaptation, experience, and development.

The field of study of bioeducational sciences focuses on some key concepts that introduce the emerging theories of cognitive educability. These key concepts concern the *flexibility* of education, its potential to continuously change to deal with variable situations, and the *integrated* action of education, the possibility given by explicit and implicit double track to manage the conceptual organization to cope with cognitive discomfort in more or less disadvantaged learning conditions [29]. The concept of flexible education is based on the idea that every cognitive system is rooted within dynamic networks of individual and social aspects, each of which can produce developmental changes in its organizational structures. Since development may be quantitative/qualitative, continuous/discontinuous, variant/invariant, and, as a consequence, experiences are shaped in a dynamic adaptive different way for each individual; educational research needs flexible models of tailored educability.

Every cognitive system can react to the educational action by transforming itself according to not predefined dynamic outcomes. Cognitive modifiability is an autonomous/interrelated synergic variable related to a plurality of intertwined aspects [30]. Individual complexity is then synchronic since multiple cognitive functions are combined together and diachronic since each function modifies itself during the lifetime, interacting with those previously structured. The bioeducational approach promotes research on adaptive learning environments designed to identify organizational criteria for educational actions [31]. Learners are individuals with their own dynamic peculiarities. Knowledge is individualized through the personal history of learning of everyone, in which the chances for effective development are played. The design of a learning environment cannot be separated from the specific characteristics of the knowledge structures which make each learner unique.

Bioeducational science research is narrow to any research connecting neuroscience and education and together can contribute to studying the individual cognitive differences and the variability of the multiple functions of the dynamic biological system. The intertwining of both these factors has a basic role in modifying educational processes [32].

2 Individual Differentiation

Learners are different. They may diverge in their intertwined processing, emotional, and bodily approaches to learning content. Cognitive variability has been deeply studied in its explicit aspects inside the cognitive prism. The cognitive prism is the result of a set of structural and functional elements and the synergistic relationships between them. The development of learners' cognitive identities depends on the dynamic and evolving interaction/integration of each facet of the cognitive prism, in which a plurality of aspects is fragmented into a multiplicity of levels that have been studied as knowledge constructs by psychological and educational research, even if they have not always been observed by neuroscientific research.

The perceptual level refers to how information accesses the cognitive prism and is linked to the individual perceptual preferences, e.g., auditory, visual, or tactile, which can be used by each learner in a combined or standing alone way, according to the personal choice. This level can be referred to as a style level, even if in literature is discussed if styles can be really defined as a theoretical construct and their systematization is not self-evident [33], which concepts are under systematization and which statements may be generalizable. Styles are akin to strategies but less aware and more adaptive [34], interfaced with intelligence and personality definition. This research field is highly knotty since, i.e., intellectual styles—how learners prefer to deal with cognitive tasks [35]—are a general field that includes cognitive (and perceptual), learning, and thinking styles within cultural matrices [36]. Cognitive styles refer to individual information processing and may include conceptual, relational, inferential, and categorical styles. Learning styles [37] mean the ways in which each student likes to learn and are related to teaching styles [38]. Thinking styles [39] represent the preferential way of using skills and have been categorized into creative, regulatory, and related types [40].

The perceptual level is then intertwined with the level which concerns how the cognitive prism can process inside/out information. The processing level is linked to the multiplicity of intelligence [41–45] and its triarchic architecture: analytical, practical, and creative [46]. The meta-reflective level, the field of monitoring and control of cognitive management, overlaps the previous ones and is interrelated to them in order to move their interactive complexity to awareness [47]. Implicit functionality of cognitive systems has been underestimated as a critic negative variable underlying the comprehension processes or denied as not knowledgeable [48]. Conversely, the adaptive potential of implicit has been positively highlighted by research on human evolution [49], which focuses on its pervasiveness at the roots of the origin of explicit thinking. The role of implicit in ontogenesis, however, is still mainly unexplored as concerns its supposed function of continuously supporting explicit at cognitive processing level [50], whereas it is already recognized the involvement of implicit at primary emotional and bodily, perceptual and sensorimotor, levels.

Cognition has long been considered a process of mediation of incoming information from the environment, detached from processes involving perception and action. Knowledge was intended to lie in a semantic memory separate from the brain systems involved in perception and action, activating stimulating processes [51]. The role played by cognition, semantically activating when involved in knowledge acquisition processes, was focused. In this view, thinking was seen as a consequence in the aftermath of external stimuli, to be interpreted, translated, and processed in response strategies according to individuals' patterns [52].

This view has been, however, overcome since many empirical studies have shown that perception and cognition, in particular the regulation of emotions and social interactions, are largely influenced by environmental contexts, which influence them and at the same time allow individuals to continuously interact with the environment itself [53, 54]. One of the dimensions of embodied cognition can be understood in the relationship between mind and corporeality, in interaction with the world. Cognition has its roots in internally centralized sensorimotor mechanisms.

Conceptual knowledge is located in brain-specific organizations involving simulation processes, pattern inferences of responses to stimulation, and prediction of future events in the subjective management of real events [55]. The sensorimotor simulation underlies and supports the representation of concepts [56] even if it seems to belong to a wider process since it can change in relation to the context within which a given concept is presented. Consequently, subjective experience influences the conceptual representation of the observed objects. In a study focused on the exclusive use of verbal stimuli [57], it has been demonstrated how a significant cognitive experience, if repeated in two distinct moments and linked to different situations, can modify the representation of concepts associated with the presented object.

Perception is the premise on which knowledge is developed, and it is the matrix where every implicit representation of oneself and the surrounding world is realized. In the bodily characteristics of the primates, in particular, in their facial features, a significant series of information can be traced, which become the basis on which the social relationships between individuals are built. The study of both human and non-human primates (monkeys) finds the areas of the body specialized in the visual perception in the focal regions of the visual cortex of higher level.

Perception of corporeality, movement, emotional dimension is a specific, unique characteristic, not always associated with other implicit individual acquisitions.

Working on the spatial perception of individuals means developing specific strategies that concern the perception of body patterns. This selective ability of the body perception is to be attributed to an area of the brain which can be distinguished from that which identifies facial expressions, although the study of intracranial electrical activity initially showed they could belong to the same area. The division between the perception of body patterns and facial expressions suggests that some areas of the brain are involved in the implicit perception of oneself and in personal body image, as well as in the perception of emotions and of movement [58]. The perception of body patterns co-exists with the individual perception of motor actions and emotions.

Body perception is a specific feature of primates. In humans, it can be modified by perceptual alteration in brain areas.[2] In information processing, the body gets somatosensitive and thermosensitive information and activates the control over the nerve structures that receive, transmit, and modulate painful stimuli, the perception of the body's internal state, and vestibular signals that play a role in the perception of the personal body. Perception has a selective and multisensory role that joins every sensory unit in a holistic whole internally represented as "my body." However, the internal multitude of stimuli makes it complex to define multisensory perception in a unique way, as stimuli, perceptions, and implicit internal organizations do not allow any experimental definition that can definitively clarify them [59]. The bodily dimension of humans may be implicit and not entirely detectable.

The somatic markers hypothesis is relevant for understanding the processes of human reasoning and decision-making involved in bodily responses to stimuli [60]. These markers[3] could explain how individuals may deliberately carry out a specific action following a stimulation. Bioregulatory processes, including those that concern emotions and feelings, would focus on activating implicit responses. In this hypothesis, implicit mechanisms could also regulate human reasoning and decision-making [61].

As concerns over the neuroscientific dimension of emotional perception, the vision according to which emotional perception would derive from the integration of internal and external signals has been overcome. Instead, the perceptual dimension is integrated, and it becomes a synergic part of the emotional process. Brain areas involved in emotions are indeed closely linked to the cerebral cortex areas involved in higher body representations [62]. Emotions and their conceptualization and expression may have implicit characteristics and are related to

[2] Damaged areas of the brain can cause somatophrenia, which consists in the inability to recognize one's limb as own. In the study of this pathology, research questions concern which processes of mind are played to recognize parts of the own body. The sense-perceptive brain capacity of individuals has neuro-physiological characteristic which allow them to identify the sensitive data of one's own body compared to others.

[3] Markers are defined as somatic because they refer to body regulation by a higher central unit which could inhibit or activate series of actions and then manage individuals' mental and bodily complexity.

corporeality. Emotional perception can be expressed through senses, and it involves the body dimension by considering both emotions and motor actions as integrated parts[4] [63].

In the visions of cognition as an implicit system of the individual considered as an entanglement of mind and body, six conditions can describe the meaning of embodied knowledge [64].

i. knowledge can be situated, enclosed in a temporal space;
ii. knowledge is downloaded and distributed into the environment;
iii. the environment is a substantial part of the cognitive system;
iv. knowledge is achieved through action; and
v. also mental processes which require longer thoughtful reflection are rooted in corporeality.

The last characteristic explains how the processes of cognitive analysis are linked to corporeality. This hypothesis would explain why exercises, activities, and learning mediated by corporeality are particularly effective in promoting a deep acquisition of cognitive concepts [65–67].

Implicit learning results from experience, during which learners acquire semantic or procedural knowledge without consciousness in a relatively effortless manner. While incidental learning allows learners to collect unintended information but have conscious access to it, implicit learning is defined as unconscious knowledge [68]. Whether implicit learning can be dissociated from explicit learning is still open. Research is now mostly in favor of the co-existence of two distinct processes, implicit and explicit, in a continuous synergic interaction [69]. In the late Sixties, the unaware processing [70] challenged the classical metaphor of the computational mind [71]. Since this symbolic and sequential metaphor was lasting, implicit learning could only be the "shadow" of it [72]. In the educational field, implicit has been consequently made explicit by research theories as meta-reflection [73] and developing theories of mind and world [74–77]. Around the Eighties, the connectionist view of a sub-symbolic and parallel mind [78], according to the related idea of a situated and embodied mind [79–81], has finally positioned the implicit learning inside the cognitive prism [82], overcoming the "polarity fallacy" [83] and then considering learning as a single process including the implicit as a concurrent part of cognition together with the explicit.

Dual-process theories analyze from

i. implicit, sub-symbolic, unaware, difficult-to-verbalize, hot (emotional), fast, heuristic, holistic, intuitive thinking; to

[4] The perception of others' emotions is connected to the perception of their meaning, which is given by our specular ability to interpret the emotional dimension of others. The dynamics of relation between emotions and actions are joined within a complex mechanism of double correspondence, which may involve the change of facial expressions in relation to the perception of emotions. The interchange of emotions between individuals takes place when the emotional channels can be shared.

ii. explicit, symbolic, aware, easy-to-verbalize, cool, slow, algorithmic, analytic, reflective thinking.

Even if it is rare to find a learning situation in which only implicit or explicit learning is involved, the multifaceted interactions between the two levels have not yet been fully investigated [84]. In the two-system views, different mechanisms are activated at separate levels, complementing each other interacting together [85]. Implicit and explicit attitudes seem to change according to different types of information: subliminally associative information below conscious awareness and consciously available verbal information of higher-order [86]. Nevertheless, ubiquitous implicit processes are involved in processing both elementary and high-level cognitive skills. To implicit learning has been recognized as an evolutionary default role, in which adaptive potential can produce basic knowledge representing the structure of the environment to solve problems and make decisions as abstract knowledge [87]. Implicit learning mechanisms can indeed operate associatively and generate even specific knowledge representations [88]. Nonconscious acquisition and generation of information involved in the initial stages of learning may also concern complex knowledge structures and multidimensional processing of interactive relations between variables [89–91].

Cognitive preferences, interpretive schemata, and encoding dispositions can have a gradual self-perpetuating development and influence individual differences and personality characteristics [92]. Implicit development is indeed characterized by constancy, invariability, and persistence, which interplay in knowledge evolution [82]. Nonconscious encoding may be represented by generalizable shared implicit patterns of information acquisition, which have the role of knowledge prototypes underlying cognitive structuring [93, 94]. According to Basic Logic Theory [95], if a cognitive collaboration between implicit and explicit is hypothesized, it should be possible to identify intermediary links represented by dynamic knowledge patterns of basic logic. The basic logic, indeed related both to implicit and explicit levels, can be spatially represented, and its prototypical functions:

- *add*, integration;
- *chain*, consequence;
- *each*, individuation;
- *compare*, comparison;
- *focus*, derivation; and
- *link*, correlation.

can process perceptual and as well higher-order cognition (Fig. 1).

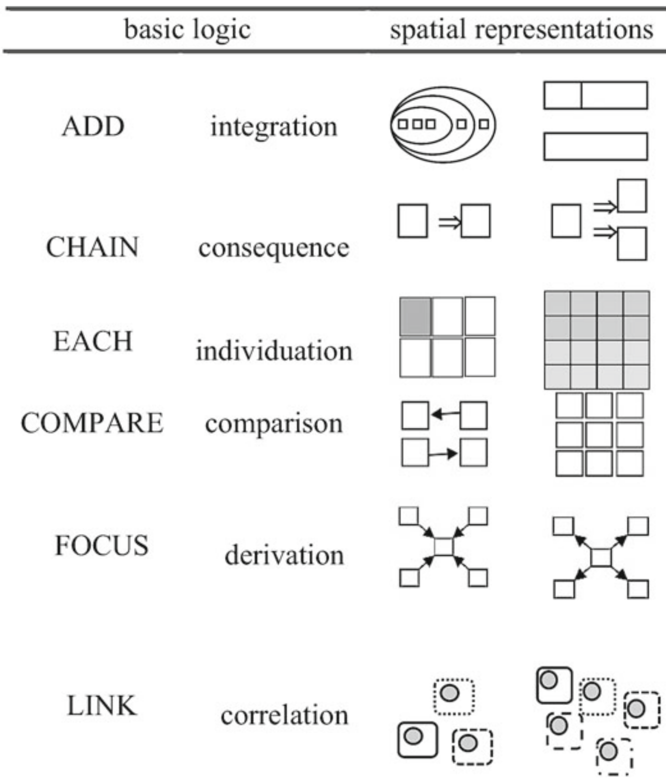


Fig. 1 Dynamic knowledge patterns of basic logic (in attachment)

3 Adaptive Variability

Learners have adaptive cognitive systems, which change over time. Cognitive systems activate processes of adaptive interaction with the environment regulated by experience. These processes concern the *modularity* of individual cognitive functions and their evolutive *sharing*. Individual variability is expressed through idiosyncratic ways and times relative to each adaptive, always educable, cognitive system. During their personal cognitive development, learners make indeed combinatorial choices of the use of their own functions to approach knowledge, selected according to adaptive criteria: if a cognitive behavior shows proven adaptive efficacy to its user, the learner will probably continue to maintain it; if instead, a cognitive behavior does not meet learners' expectations, it will easily be replaced in favor of another [50].

The cognitive identity of each learner develops (and continuously transforms itself) throughout the personal history of learning. Cognitive modifiability is strictly interrelated with each student's personal developmental tendencies in her/his own experiential path. These tendencies are gradually defined over time. The stronger an information, concept, or method has been through the individual recognition of its adaptive effectiveness, rooted in a cognitive system, the more difficult it will be to convince a learner to abandon it. The “resistance to change” phenomenon derives from the personal belief that an idea may be adaptively effective to understand situations, solve problems, and/or face events according to learners’ objectives.

At the same time, learners also show “openness to change,” which is the basis of the possibility itself of the learning process. The different, internal and external, indications that a cognitive system receives, both from its own functional processing tendencies and from educational stimulations of teachers, parents, and peers, have to be synergistically put together according to the personal regulatory mechanisms of cognitive functioning of each one [96]. Suppose there is a gap between internal tendencies and external stimulations. In that case, a cognitive system could be affected by cognitive discomfort [97], whose origin can be identified going backward in the personal history of learning to understand the rooted, often implicit, relationships between the internal and external boosts.

Cognitive discomfort is one of the possible manifestations of the presence of cognitive dysfunctions, which are not specific learning disorders, but simply the expression of the difficulties occurring when learners have uncertainty in choosing their own way of studying, in maintaining concentration and, from a meta-reflective point of view, in feeling confident when coping with a cognitive task. An effective cognitive system is a well-functioning mechanism in which the different components integrate together without any dissonance between the ways in which the system itself would independently operate and how the environment suggests (or asks) it to operate. The possible developmental integration between the different external and internal boosts within the cognitive system guarantees its functionality.

Adaptive variability is also regulated by processes of evolutionary sharing of individual cognitive functions. Cognitive systems tend to the compatibility of these processes in dynamic interactions by developing fit behaviors with the learning environment [98]. Fit behaviors are related to self-regulation, an individual difference variable through which each individual may control her/his actions relying on one’s own resources. Self-regulation is a multidimensional concept concerning alternatives to using skills and tools to implement goal-setting and strategies in line with the fixed goals [99]. The dichotomy between self-directed and autonomous learning and learning environments designed to develop it can be adjusted by the internal/external self-regulation of individuals across knowledge domains and by the dynamic measures of how learners manage it, integrated by the influence of learning environments, whose variability in the different contexts of reference continuously changes and requires regulatory processes. To focus on learning environments design is a key point of reflection because, through education, external self-regulation can be modified by virtue of the integration of behaviors and of the internalization of regulatory processes, thus arriving at internal self-regulation as a result of personal development [100].

To meet their goals, learners activate cognitions, behaviors, and emotions through self-regulatory processes [101]. In teaching and learning research, self-regulation also focuses on the regulatory processes that underlie social interactions. Co-regulation and shared regulation are the terms used to mean that an activity is carried on jointly by a group of learners working collaboratively. The main bodies of inquiry concerned with self-regulation are metacognition, the research in which monitoring mental strategies is studied, and executive functioning to better understand how to ensure efficient handling of information. These fields are interdependent and joined to mental processes' emotional and motivational regulation [102].

Parent–child relationships support self-regulation development through mutual interactions and scaffolding. According to self-determination theory [103, 104], self-regulation is a developmental process that takes place in intersubjective contexts as a function of different variables, such as the personal ability to perform a task or to pursue one's own well-being leading to different self-regulation results. Extrinsically motivated behaviors, which usually refer to the possibility to receive approval from the external context, can turn into internally motivated behavior if processes are put in place that integrate behaviors and internalize development dynamics. Learners accommodate themselves to the environment by internalizing and integrating external regulations, choosing which one may be preferred for truly effective use. If this process is hindered, internalization may not arrive to be really a form of full integration. Intrinsically motivated behavior may instead represent the prototype of self-determination [105].

Formal education and informal educational contexts aim to enhance self-regulatory skills, which can sustain and improve strategic knowledge based on internal resources. Instructional support given by teachers and parents, which is to be shaped as the adaptable and temporary system of scaffolding, more than external regulation, may vary and be differently effective because learners' needs are multiple and cannot be unified through one size fits all approaches. Instructional support should be continuously developed according to learners' changes [106].

Learners' engagement has been considered the outcome of the following key needs:

- the need for *belonging*, which requires a flexible relation between body and mind to let learners share their own interpretations of the environment with others;
- the need for *autonomy*, according to which body and mind ask the environment for time and space to express movements and to think;
- the need for *competence*, to sustain learners in developing a skilled adaptive orientation toward the environment; and
- the need for *meaning* and *creativity*–personal creative, meaningful interpretations arising from the individual embodied interaction with the environment are supported by learning contexts that meet the tension to explore the embodied self [107].

The person approach integrates the individual developmental psychological, biological, and social processes into a holistic and interactive theoretical perspective which can be effective for education because it relies on three main ideas, that are:

i. the person-environment system is complex, dynamic, and adaptive;
ii. individuals develop as integrated and undivided;
iii. organisms adapt themselves to changing external and internal conditions through both maturation and experiences in order to leverage change and resistance to change. Inappropriate causes of change may indeed generate malfunctions of the systems [108].

Functional interaction is an adaptive process that mediates between cognitive components and behavioral, biological elements within the environment through nonlinear transformation processes characterized by differentiation and self-organization. Developmental processes are holistic and regulated by interdependent functions such as functional interaction, nonlinearity, adaptation, transformation, and integration. Engagement in learning is an active personal process of embodied and social meaning-making in interdependent interaction within the socio-cultural learning environment. Knowledge acquisition is an embodied process that involves the learner as a whole.

The body can then be considered a social body, a basic ground of the emotional expression of individuals. It may represent a chance for learning in education and support implicit knowledge models. The concept of the body as a mediator of implicit learning dimensions is related to an idea of human intelligence linked to evolutionary phylogenetic processes and developmental epigenetic processes. In traditional cultures, educational transmission is informal and supported by on-the-job training, while, in modern societies, cultural knowledge is often acquired out of context. On the other hand, formal education in the classroom is relatively recent since it has roots in the last century.

According to an evolutionary view of the implicit nature of adaptive processes, educability regulates over time the intertwining of multiple, internal and external, levels of the organization, highlighting individual differences in environmental interactions and dynamic development of complex behaviors [109]. Development is specific to individuals, concerns interacting factors on different levels, is involved in self-organization processes [110].

Learners activate cognitive, emotional, and bodily shared participation within knowledge processes and can be considered holistic implicit learners [111]. The body's interaction with the environment is always different between individuals and rooted in perceptual and conceptual processing; simultaneously, it is socially related, and all these aspects contribute to developing and co-creating the processes of meaning-making. Educational research can highlight, through a bioeducational approach, how individuals are the dynamic result of a multiplicity of intertwined cognitive functions, integrated and self-regulated.

4 Conclusion

Milestones of the bioeducational approach consist of five keys which are: diversity, modifiability, discontinuity, inte(g)ration, and collaboration.

The concept of diversity focuses on the idea that each learner is unique, and her/his cognitive system can be continuously modified throughout individual pathways of experiences. Discontinuity means, in general, that a cognitive system changes itself in personal ways, which cannot be systematized and foreseen. Both keys of integration and interaction rely on the basic idea that cognitive systems are adaptive, and then they change and integrate themselves according to the self-regulation of internal and external stimulations, which is related to the evolutive sharing of their processing functions during cognitive interaction with the learning environment. Integration is a concept that includes collaboration, which refers to possible expected prototypical links between explicit and implicit levels during cognitive processing (Table 1).

Individual differentiation, in educational terms, answers the learner's questions "Who am I? How do I process information?" Since each individual is to be considered a specific biodynamic adaptive system, teachers and educators should focus on the qualitative variables of personal idiosyncrasy. They should ask themselves how the cognitive architecture of each learner is evolving, interacting in space and time, inside and outside, the cognitive prism.

Since the explicit clearly differentiates learners' strategy choices, while the implicit may instead join learners' knowledge approaches in generalizable models of concepts structuring, both have to be considered in their prototypical and higher-order levels. If implicit and explicit processing are related to learning, teachers and educators should encourage collaboration between these levels by using shared representational formats as the spatial one.

The milestone of individual differentiation develops three main educability criteria of bioeducational approach in mind brain and education research and highlights:

i. to enhance individuals' potentialities and competencies, based on the specific cognitive, emotional, and bodily processing trends of singularity development, individually tailored;
ii. to encourage and improve the expression of each cognitive identity in her/his own various multiple shapes and self-regulated tendencies as they are, and not as they hypothetically could be; and
iii. to empower the potential collaboration between implicit and explicit levels by discovering their on-demand dimensions of interaction.

Adaptive variability, in educational terms, answers to the learner's questions "Where, when, and how I change?". Each environment plays the role of an interactive partner in the adaptation processes, in which cognitive systems change according to their own developmental ways and times of evolution. "Fit" behaviors of adaptive systems regulate the interaction between learners and contexts.

Table 1 Milestones of bioeducational approach

Individual differentiation	Diversity
	Collaboration
Adaptive variability	Modifiability
	Discontinuity
	Integration

Teachers and educators should deepen the developmental characteristics of the cognitive potential of each learner in order to manage its levels of educability during epigenesis. Correlating previous adaptive experiences of learners to actual individual responses related to environmental stimulations and monitoring the feedbacks of each adaptive system to her/his context allows understanding the phenomenon of resistance to change and to cope with it.

The milestone of adaptive variability develops three main educability criteria of bioeducational approach in mind, brain, and education research as concluding remarks:

- to monitor how each adaptive system replies to environmental stimulation if the given feedbacks are open or closed to change, in order to tailor educational offer;
- to travel backward the personal history of learning to find eventual interferences between internal and external regulation which may cause cognitive discomfort;
- to encourage the personal awareness of self-efficacy in relation to the idiosyncrasy of each individual cognitive potential applied to learning.

The aim of bioeducational individual differentiation in mind, brain, and education is focused on cognitive entanglement and its development to re-shape the role of education as *educability* [116], that is, to customize teaching according to individuals' different preferences and their personal evolution.

Core Messages

- Two-way collaboration between neuroscience and education is challenging to understand the brain in teaching and learning.
- Role of education has to be re-shaped to customize teaching according to individual preferences and development.
- Aim of bioeducational sciences is to focus on individual differentiation and adaptive variability to tailor education.
- Individual differentiation enhances the development of cognitive identities and implicit/explicit collaboration.
- Adaptive variability encourages awareness of self-efficacy in relation to personal histories of learning.

References

1. Schwartz M (2015) Mind, brain and education: a decade of evolution. Mind Brain Educ 9 (2):64–71
2. Byrnes JP, Fox NA (1998) Minds, brains, and education: part II. Responding to the commentaries. Educ Psychol Rev 10(4):431–439
3. Santoianni F (2019) Brain education cognition. La ricerca pedagogica Italiana. RTH Res Trends Human 6:44–52
4. Santoianni F (2020) Brain based education. La ricerca bioeducativa sperimentale. RTH Res Trends Human 7:28–33
5. Rosenberg-Lee M (2018) Training studies: an experimental design to advance educational neuroscience. Mind Brain Educ 12(1):12–22
6. Aldrich R (2013) Neuroscience, education and the evolution of the human brain. Hist Educ 42(3):396–410
7. Feiler JB, Stabio ME (2018) Three pillars of educational neuroscience from three decades of literature. Trends Neurosci Educ 13:17–25
8. Carew TJ, Magsamen SH (2010) Neuroscience and education: an ideal partnership for producing evidence-based solutions to guide 21st century learning. Neuron 67(9):685–688
9. Fischer KW (2009) Building a scientific groundwork for learning and teaching. Mind Brain Educ 3(1):165–169
10. McBrien JL, Brandt RS (1997) The language of learning: a guide to education terms. Association for Supervision and Curriculum Development, Alexandria
11. Bowers JS (2016) The practical and principled problems with educational neuroscience. Psychol Rev 123:600–612
12. Bruer JT (1997) Education and the brain: A bridge too far. Educ Res 26(8):4–16
13. Fischer KW, Goswami U, Geake J (2010) The future of educational neuroscience. Mind Brain Educ 4(2):68–80
14. Solomon M, Hendren RL (2003) A critical look at brain-based education. Middle Matters 12 (1):1–3
15. Renck M (2008) Enriching the brain. The link between contemporary neuroscience and early childhood traditions. Early Childhood Educ 35:487–488
16. Fischer KW, Daniel DB, Immordino MH, Stern E, Battro A, Koizumi H (2007) Why mind, brain, and education? why now? Mind Brain Educ 1(1):1–2
17. Anreiter I, Sokolowski HM, Sokolowski MB (2017) Gene-environment interplay and individual differences in behavior. Mind Brain Educ 12(4):200–211
18. Jensen EP (2008) A fresh look at brain-based education. Phi Delta Kappan 89(6):408–417
19. Organization for Economic Cooperation, and Development (2002) Understanding the brain: towards a new learning science. Centre for Educational Research and Innovation, Paris
20. Organization for Economic Cooperation, and Development (2007) Understanding the brain: the birth of a learning science. Centre for Educational Research and Innovation, Paris
21. Dündar S, Gündüz N (2016) Misconceptions regarding the brain: the neuromyths of pre-service teachers. Mind Brain Educ 10(4):212–232
22. Ruhaak AE, Cook BG (2018) The prevalence of educational neuromyths among pre-service special education teachers. Mind Brain Educ 12(3):155–161
23. Goswami U (2004) Neuroscience and education. Br J Educ Psychol 74:1–14
24. Pasquinelli E (2012) Neuromyths: why do they exist and persist? Mind Brain Educ 6(2):89–96
25. De Bruyckere P, Kirschner PA, Hulshof CD (2015) Urban myths about learning and education. Academic Press, Cambridge
26. Frauenfelder E, Santoianni F (eds) (2003) Mind, learning and knowledge in educational contexts. Cambridge Scholars Press, Cambridge
27. Santoianni F, Ciasullo A (2017) Bios, logos, and soft skills for contemporary education. Philos Educ 1(10):179–188

28. Santoianni F (2017) Models in pedagogy and education. In: Magnani L, Bertolotti T (eds) Springer handbook of model-based science. Springer International Publishing, Switzerland, pp 1033–1049
29. Santoianni F (2018) Teorie emergenti in campo bioeducativo. RTH Res Trends Human 5:12–21
30. Santoianni F, Osorio M (2015) Inside the cognitive prism. possible correlations between explicit intelligences and implicit knowledge prototypes. exploring cognitive variability in university students of philosophy. Philos Educ 8:1811–1916
31. Frauenfelder E, Santoianni F, Ciasullo A (2018) Implicito bioeducativo. Emozioni e cognizione. RELAdEI Neurociencias y educación infantil 7(1):42–51
32. Vander BC, Pelphrey K (2011) Introduction to a special section of learning and individual differences: educational neuroscience. Learn Individ Differ 21(6):633–635
33. Sternberg RJ, Zhang LF (2001) Perspectives on thinking, learning, and cognitive styles. L.E. A., Mahwah
34. Wallach M, Kogan N (1965) Modes of thinking in young children. Holt, Rinehart & Winston, New York
35. Zhang LF, Sternberg RJ (2006) The nature of intellectual styles. L.E.A., Mahwah
36. Sternberg RJ (2011) Intelligence. In: Aukrust VG (ed) Learning and cognition in education. Elsevier, Amsterdam, pp 92–98
37. Dunn R, Dunn K (1978) Teaching students through their individual learning styles. Reston Publishing, Reston
38. Fischer BB, Fischer L (1979) Styles in teaching and learning. Educ Leadersh 36:245–254
39. Sternberg RJ (1997) Thinking styles. Cambridge University Press, Cambridge
40. Zhang LF, Sternberg RJ (2005) A threefold model of intellectual styles. Educ Psychol Rev 17(1):1–53
41. Gardner H (1983) Frames of mind: the theory of multiple intelligences. Basic Books, New York
42. Gardner H (1995) Reflections on multiple intelligences. Myths and messages. Phi Delta Kappan 77(3):200–203, 206–209
43. Gardner H (1996) Are there additional intelligences? The case for naturalist, spiritual, and existential intelligences. In: Kane J (ed) Education, information and trasformation. Prentice-Hall, Engelwood Cliffs, pp 111–131
44. Gardner H (1997) The first seven…and the eight: a conversation with Howard Gardner. Educ Leadersh 55(1):8–13
45. Gardner H, Boix V (1997) Of kinds of disciplines and kinds of understanding. Phi Delta Kappan 78(5):381–386
46. Sternberg RJ (1985) Beyond IQ: a triarchic theory of human intelligence. Cambridge University Press, Cambridge
47. Reder LM (ed) (1996) Implicit learning and metacognition. L.E.A., Mahwah
48. Perruchet P, Vinter A (2002) The self-organizing consciousness. Behav Brain Sci 25:297–388
49. Reber AS (1992) The cognitive unconscious: an evolutionary perspective. Conscious Cogn 1:93–113
50. Santoianni F (2014) Modelli di studio. Apprendere con la teoria delle logiche elementari. Erickson, Trento
51. Barsalou LW (1999) Perceptual symbol systems. Behav Brain Sci 22(4):577–660
52. Coello Y, Fischer MH (eds) (2015) Perceptual and emotional embodiment: foundations of embodied cognition, vol 1. Routledge
53. Black JB, Segal A, Vitale J, Fadjo CL (2012) Embodied cognition and learning environment design. Theoret Foundations Learn Environ 2:198–223
54. Smith L, Gasser M (2005) The development of embodied cognition: six lessons from babies. Artif Life 11(1–2):13–29
55. Barsalou LW (1999) Perceptions of perceptual symbols. Behav Brain Sci 22(4):637–660

56. Kontra C, Goldin-Meadow S, Beilock SL (2012) Embodied learning across the life span. Top Cogn Sci 4(4):731–739
57. Pecher D, Zeelenberg R, Barsalou LW (2004) Sensorimotor simulations underlie conceptual representations: modality-specific effects of prior activation. Psychon Bull Rev 11(1):164–167
58. Peelen MV, Downing PE (2007) The neural basis of visual body perception. Nat Rev Neurosci 8(8):636–648
59. Kilteni K, Maselli A, Kording KP, Slater M (2015) Over my fake body: body ownership illusions for studying the multisensory basis of own-body perception. Front Hum Neurosci 9:141
60. Damasio AR (1996) The somatic marker hypothesis and the possible functions of the prefrontal cortex. Philos Trans R Soc London. Ser B Biol Sci 351(1346):1413–1420
61. Brown L, Reid DA (2006) Embodied cognition: somatic markers, purposes and emotional orientations. Educ Stud Math 63(2):179–192
62. Caruana F, Gallese V (2011) Sentire, esprimere, comprendere le emozioni: una nuova prospettiva neuroscientifica. Sistemi Intelligenti 23(2):223–234
63. Niedenthal PM (2007) Embodying emotion. Science 316(5827):1002–1005
64. Wilson M (2002) Six views of embodied cognition. Psychon Bull Rev 9(4):625–636
65. Abrahamson D, Trninic D (2011) Toward an embodied-interaction design framework for mathematical concepts. In: Proceedings of the 10th international conference on interaction design and children, pp 1–10
66. Trninic D, Abrahamson D (2012) Embodied artifacts and conceptual performances. In: Proceedings of the international conference of the learning sciences: future of learning, pp 283–290
67. Malinverni L, Pares N (2014) Learning of abstract concepts through full-body interaction: a systematic. Educ Technol Soc 17(4):100–116
68. Kihlstrom JF (2009) Unconscious Cognition. In: Banks WP (ed) Encyclopedia of consciousness. Academic Press, Oxford, pp 411–421
69. Sun R, Mathews RC (2012) Implicit cognition, emotion, and meta-cognitive control. Mind Soc 11:107–119
70. Reber AS (1967) Implicit learning of artificial grammars. J Verbal Learn Verbal Behav 6:855–863
71. Sternberg RJ (1990) Methaphors of mind. Cambridge University Press, Cambridge, Conceptions of the Nature of Intelligence
72. Cleeremans A (1997) Principles for implicit learning. In: Berry D (ed) How implicit is implicit learning? Oxford University Press, Oxford, pp 196–234
73. Hacker DJ, Dunlosky J, Graesser A (eds) (1998) Metacognition in educational theory and practice. L.E.A., Mahwah
74. Wellman HM (1990) The child's theory of mind. MIT Press, Cambridge
75. Gopnik A, Wellman HM (1994) The theory. In: Hirschfeld LA, Gelman SA (eds) Mapping the mind. Domain specificity in cognition and culture. Cambridge University Press, Cambridge, pp 257–293
76. Wellman HM, Gelman SA (1997) Knowledge acquisition and foundational domains. In: Khun D, Siegler RS (eds) Handbook of child psychology. Cognition, perception and language. Wiley, New York, pp 523–573
77. Gopnik A (1999) Theory of mind. In: Wilson RA, Keil F (eds) The MIT Encyclopedia of the cognitive sciences. MIT Press, Cambridge, pp 830–841
78. Rumelhart DE, McClelland JL (1986) Parallel distributed processing. MIT Press, Cambridge
79. Dennett DC (1997) Kinds of minds: towards an understanding of consciousness. Basic Books, New York
80. Anderson ML (2003) Embodied cognition: a field guide. Artif Intell 149:91–130

81. Anderson ML (2007) How to study the mind: an introduction to embodied cognition. In: Santoianni F, Sabatano C (eds) Brain development in learning environments. Cambridge Scholars Publishing, Cambridge, Embodied and Perceptual Advancements, pp 65–82
82. Santoianni F (2011) Educational models of knowledge prototypes development. Mind Soc 10:103–129
83. Reber AS (1993) Implicit learning and tacit knowledge. Oxford University Press, Oxford, An essay on the cognitive unconscious
84. Sun R, Mathew RC, Lane SM (2007) Implicit and explicit processes in the development of cognitive skills: a theoretical interpretation with some practical implications for science education. In: Vargios EM (ed) Educational psychology research focus. Nova Publisher, New York, pp 1–26
85. Sun R (2015) Interpreting psychological notions: a dual-process computational theory. J Appl Res Mem Cogn 4:191–196
86. Rydell RJ, McConnell AR, Mackie DM, Strain LM (2006) Of two minds. Forming and changing valence-inconsistent implicit and explicit attitudes. Psychol Sci 17(11):954–958
87. Reber AS (1989) Implicit learning and tacit knowledge. J Exp Psychol Gen 118(3):219–235
88. Frensch PA, Rünger D (2003) Implicit Learning. Curr Dir Psychol Sci 12(1):13–18
89. Lewicki P (1986) Nonconscious social information processing. Academic Press, New York
90. Lewicki P (1986) Processing information about covariations that cannot be articulated. J Exp Psychol Learn Mem Cogn 12:135–146
91. Lewicki P, Czyzewska M, Hoffman H (1987) Unconscious acquisition of complex procedural knowledge. J Exp Psychol Learn Mem Cogn 13:523–530
92. Lewicki P, Hill T, Czyzewska M (1992) Nonconscious acquisition of information. Am Psychol 47:796–801
93. Lambiotte JG, Dansereau DF, Cross DR, Reynolds SB (1989) Multirelational semantic maps. Educ Psychol Rev 1:331–367
94. O'Donnell AM, Dansereau DF, Hall RH (2002) Knowledge maps as scaffolds for cognitive processing. Educ Psychol Rev 14(1):71–86
95. Santoianni F (2016) Spaces of Thinking. In: Santoianni F (ed) The Concept of time in early twentieth-century philosophy. Springer International Publishing, Switzerland, A philosophical thematic Atlas, pp 5–14
96. Santoianni F (2010) Modelli e strumenti di insegnamento. Carocci, Roma
97. Santoianni F, Sorrentino M, Lamberti E, Di Jorio D (2013) Bioeducational sciences on cognitive discomfort and specific learning disorders. In: Burgess EN, Thornton LA (eds) Cognitive dysfunctions. Nova Science Publisher, New York, pp 107–123
98. Santoianni F (2006) Educabilità cognitiva. Apprendere al singolare, insegnare al plurale. Carocci, Roma
99. Garcia T (1996) Self-regulation: an introduction. Learn Individ Differ 6(3):161–163
100. Weinstein CE (1996) Self-regulation: a commentary on directions for future research. Learn Individ Differ 8(3):269–274
101. Schunk DH, Zimmerman BJ (1994) Self-regulation of learning and performance: issues and educational applications. L.E.A., Hillsdale
102. Whitebread D (2020) Self-regulation processes in early childhood. In: Benson JB (ed) Encyclopedia of infant and early childhood development, pp 107–115
103. Deci EL, Ryan RM (1985) Intrinsic motivation and self-determination in human behavior. Plenum, New York
104. Ryan RM, Deci EL (2018) Self-determination theory. Basic psychological needs in motivation, development, and wellness. Guilford Press, New York
105. Deci EL, Ryan RM, Williams GC (1996) Need satisfaction and the self-regulation of learning. Learn Individ Differ 8(3):165–183
106. Boekaerts M (1997) Self-regulated learning: a new concept embraced by researchers, policy makers, educators, teachers, and students. Learn Instr 7(2):161–186

107. Anderson RC (2018) Creative engagement: embodied metaphor, the affective brain, and meaningful learning. Mind Brain Educ 12(2):72–81
108. Magnusson D (2003) The person approach: concepts, measurement models, and research strategy. New Dir Child Adolesc Dev 101:3–23
109. Bjorklund DF, Bering JM (2002) The evolved child. Applying evolutionary developmental psychology to modern schooling. Learn Individ Differ 12:347–373
110. Bergman LR, El- BM (2003) A person-oriented approach: methods for today and methods for tomorrow. New Dir Child Adolesc Dev 101:25–38
111. Lindgren R, Tscholl M, Wang S, Johnson E (2016) Enhancing learning and engagement through embodied interaction within a mixed reality simulation. Comput Educ 95:174–187

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Critical Thinking for Teachers

18

Diler Oner and Yeliz Gunal Aggul

Everything we teach should be different from machines. If we do not change the way we teach, 30 years from now, we will be in trouble.

Jack Ma

Summary

Developing critical thinking is an important educational goal for all grade levels today. To foster their students' critical thinking, future teachers themselves must become critical thinkers first. Thus, critical thinking should be an essential aspect of teacher training. However, despite its importance, critical thinking is not systematically incorporated into teacher education programs. There exist several conceptualizations of critical thinking in the literature, and these have different entailments regarding the guidelines and instructional strategies to teach critical thinking. In this paper, after examining the critical thinking literature, we suggested that critical thinking could be conceptualized in two distinct but complementary ways—as the acquisition of cognitive skills (instrumental perspective) and as identity development (situated perspective). We discussed the implications of these perspectives in teacher education. While the instrumental perspective allowed us to consider what to teach regarding critical

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N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_18

thinking, the situated perspective enabled us to emphasize the broader social context where critical thinking skills and dispositions could be means of active participation in the culture of teaching.

Graphical Abstract/Art Performance

Critical thinking.

Keywords

Critical thinking · Situated perspectives · Teacher education

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

Developing critical thinking is an important educational goal for all grade levels today. As the hallmark of the Western tradition of schooling originating from the Greeks to the Scholastics [1], critical thinking is related to the idea of rationality, which is regarded as a significant aim of modern education. While earlier definitions of critical thinking go back to as early as the beginning of the twentieth century, around the 1970s and 1980s, schools worldwide started to include instructional objectives related to critical thinking in their curricula and guidelines [2]. This was partly due to the changing nature of societies and economies, which were becoming increasingly global [3]. The world was on the brink of the 3rd industrial revolution, characterized by the rise of computers and automation in workplaces. This was a time when the types of skills needed in the workforce were noticeably changing. Machines have regularly replaced humans' physical and routine work tasks, as computer technology has been evolving.

We are now witnessing the unfolding of the 4th industrial revolution (4IR). Future thinking organizations, such as the Institute for the Future and the World Economic Forum, periodically publish reports to portray the types of skills demanded in the workforce in the age of the 4IR. Several initiatives have developed frameworks to teach the skills essential to succeed in a changing world. The most well-known among these is the Partnership for 21st Century Learning (P21), a coalition formed in 2001 by educators, education experts, policymakers, and business leaders. The P21 framework for 21st-century learning outlines the set of skills beyond the mastery of core subjects. Moreover, the most important 21st-century skills have been identified as the 4Cs, critical thinking being listed as one, along with communication, collaboration, and creativity [4].

Although preparing for work is not the only purpose of formal education, the changing needs of the workplace are a major driving factor for changes in educational systems [5]. Regardless of the source of motivation, there is a clear need for supporting teachers who could teach critical thinking skills to students. To develop their students' critical thinking, future teachers themselves should become critical thinkers in the first place [6, 7]. Thus, critical thinking should be an integral aspect of teacher education programs. But what is critical thinking? And, how can teacher educators develop future teachers' critical thinking to teach it? In what follows, we will address these issues. First, we review the literature's various definitions and conceptions of critical thinking. We will then suggest a conceptualization of critical thinking based on two distinct but complementary perspectives addressing the implications of these in teacher education.

2 Emphasis on Teaching (Critical) Thinking Skills in Schools

The view of thinking as the primary goal of education goes back to John Dewey, one of the most prominent philosophers of education in the twentieth century [8]. Dewey called a type of thinking reflective and referred to it as "active, persistent and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it, and the further conclusions to which it tends" [9, p. 6]. This explanation is accepted as one of the earliest definitions of critical thinking in the history of modern schooling. Dewey furthermore described the need for the training of such forms of thinking in his book *How we Think*. This idea progressed rather slowly. However, by the 1960s, curriculum design scholars Hilda Taba and Jerome Bruner were following suit. Their work explicitly focused on the importance of teaching "thinking" along with factual content. Bruner said: "We teach a subject not to produce little libraries on that subject, but rather to get a student to think … for himself, to consider matters as a historian does, to take part in the process of knowledge—getting. Knowing is a process, not a product" [10, p. 72]. Also, Taba argued that teaching is not only pertaining to the transfer of subject matter; instead, it should develop students' thinking skills [11].

Thus, one can trace back the origins of the conception of critical thinking, as understood today, to the early twentieth century. Although it took a while to incorporate educational objectives related to thinking skills in curricula, around the 1980s, there was a notable interest in developing thinking skills [2]. During this time, the terms "thinking" and "critical thinking" as an educational goal were often used interchangeably. One of the most potent forms of rationale scholars put forward for teaching thinking in schools was the importance of effective thinking for democratic societies [12]. Taba clearly explains the role of critical thinking for democracies: "one scarcely needs to emphasize the importance of critical thinking as a desirable ingredient in human beings in a democratic society. No matter what views people hold of the chief function of education, they at least agree that people need to learn to think. In a society in which changes come fast, individuals cannot depend on routinized behavior or tradition in making decisions, whether on practical everyday or professional matters, moral values, or political issues. In such a society, there is a natural concern that individuals be capable of intelligent and independent thought" [13, p. 49].

3 Definitions and Perspectives of Critical Thinking

3.1 Critical Thinking as Cognitive Processes and Skills

The emphasis on teaching thinking led to an initial conceptualization of critical thinking as cognitive processes and skills. In the book *Developing Minds*, by the Association for Supervision and Curriculum Development in the US, which is an early effort to provide a resource guide for educators to teach "thinking," Pressesien [14] presents a model of thinking skills that involves both what she calls basic processes and complex thinking. Basic or essential processes include the categories of

- *causation*, it involves establishing cause-and-effect and assessment;
- *transformations*, they relate known to unknown characteristics;
- *relationships*, they are about detecting regular operations;
- *classification*, it refers to determining common qualities; and
- *qualifications*, they are related to finding unique characteristics.

On the other hand, complex thinking skills are based on these essential skills for a particular purpose. Pressesien [14] cites Cohen [15], who considered the following as complex thinking skills:

- *problem-solving* includes suggesting, testing, simplifying, and explaining alternate solutions for a defined problem;
- *decision-making* corresponds to comparing alternative options, choosing the most effective one among them based on relevant information, and developing justification for this choice;
- *critical thinking* includes developing cohesive and logical reasoning to analyze, generate insight, and to determine underlying assumptions as to particular arguments, meanings, or interpretations; and
- *creative thinking* means using intuitive and rational thought to develop, invent, or create new, aesthetic, constructive ideas or products.

There is not any hierarchical relationship between and within these basic and complex thinking processes; complex thinking processes are built upon the essential ones, and some complex processes might be more relevant to specific subject areas than others might. For example, problem-solving skills might be favored in mathematics and science, while decision-making and critical thinking might seem more relevant for social sciences.

This understanding of critical thinking as such cognitive processes gave rise to comprehensive thinking models that helped shape K-12 curricula across the US. One of the most well-known of these models is the *Integrated Thinking Model* proposed by the Iowa Department of Education [16]. This model considers different higher-level thinking processes as interactive [17]. The interaction among content, critical, and creative thinking creates complex thinking, and this crucially engages the mind to make decisions, design, and solve problems—similar to Cohen's complex thinking processes [15]. In addition, the Integrated Thinking Model considers *content* as one of the inputs of complex thinking; therefore, suggesting a resolution to the tension between teaching content and teaching for higher-order thinking skills.

3.2 Critical Thinking as Cognitive Skills Plus Dispositions

While critical thinking was becoming increasingly more important in education, the critique was raised based on the idea that critical thinking attitudes or dispositions should complement critical thinking skill*s*. In other words, it was widely acknowledged that good critical thinkers possessed not only some cognitive skills but also the *tendency* to use their capacity for thinking [18]. Some authors assigned a more profound role to dispositions by relating them with having a "critical spirit" [19].

According to Paul, defining critical thinking as the composition of skills only reduces critical thinking to the status of "a battery of technical skills mastered more or less one by one" [20, p. 77]. He calls for educators to shift from this "weak-sense" approach of critical thinking to a "strong" one by emphasizing intellectual values, standards, matters of character, and motivation. He identifies nine traits of mind that are needed to activate one's critical thinking skills. For example, critical thinkers need "intellectual curiosity" so that they notice the contradictions and inconsistencies in their environments and seek an explanation for them; they need to be "fair-minded" to follow intellectual standards rather than their feelings or vested interests to evaluate other viewpoints; or they should display "intellectual perseverance" for pursuing "intellectual insights and truths despite difficulties, obstacles, and frustrations" [20, p. 79].

Based on this major shift in the conception of critical thinking, scholars expanded their definitions of critical thinking beyond "pure skills" or "pure logicality" by taking more account of decision-making, reasonableness, and reflection processes of the critical thinker [18]. For example, the definition of critical thinking provided by Ennis has evolved from "correct assessing of statements" [21, p. 599] to "reasonable reflective thinking focused on deciding what to believe or do" [22, p. 68]. Along with more comprehensive definitions of critical thinking, much scholarly work was devoted to identifying critical thinking dispositions along with cognitive abilities. Ennis determined fourteen dispositions and twelve skills for a critical thinking curriculum in 1985, and he has preserved this outline with minimal changes in his recent articles [23].

Towards the end of the 1980s, the growing concern for specifying critical thinking skills and dispositions and infusing them into K-12 and post-secondary curricula entailed professionals developing consensus on critical thinking's core aspects. Forty-six prominent experts in teaching, learning and assessing critical thinking skills came together under the leadership of the American Philosophical Association in 1988. The product was the Delphi Report, in which an "ideal critical thinker" was characterized as: "[h]abitually inquisitive, well-informed, trustful of reason, open-minded, flexible, fair-minded in evaluation, honest in facing personal biases, prudent in making judgments, willing to reconsider, clear about issues, orderly in complex matters, diligent in seeking relevant information, reasonable in the selection of criteria, focused in inquiry, and persistent in seeking results which are as precise as the subject and the circumstances of inquiry permit" [19, p. 3].

This specific combination of skills and dispositions was proposed as the framework for educating good critical thinkers of "a rational and democratic society" [19, p. 3]. In addition to this definition, the experts developed a taxonomy including six main cognitive skills, namely interpretation, analysis, evaluation, inference, explanation, and self-regulation together with 16 sub-skills; and 19 dispositions under two categories "approaches to life and living in general" and "approaches to specific issues, questions, or problems" [19, pp. 14–15].

A more recent taxonomy of critical thinking skills and dispositions has been suggested by Davies [24]. In this framework, *critical thinking skills* are classified under four main categories:

- lower-level thinking skills, e.g., assumption identification and interpretation;
- higher-level thinking skills, e.g., claim analysis and synthesis;
- complex thinking skills, e.g., argumentation and verbal reasoning; and
- thinking about thinking, e.g., metacognition, self-regulation.

Critical thinking dispositions, in turn, fall into four major groups:

- dispositions arising in relation to self;
- dispositions arising in relation to others;
- dispositions arising in relation to the world; and
- other dispositions [24, p. 57].

4 Alternative Critical Thinking Conceptualizations

Thus, the notion of critical thinking in time has evolved from a skills-only view to a skills-plus-dispositions view. However, this critical thinking conceptualization has been subject to critique from other schools of thought. More specifically, critical thinking as skills and dispositions perspective has been criticized for reducing the function of critical thinking to the detection of illogical arguments and beliefs, which are accused of preventing individuals from taking control of their own lives and making rational choices. Furthermore, from this perspective, dispositions have been regarded simply as a catalyst for the appropriate use of critical thinking skills [25]. That is, this perspective conceptualizes critical thinking at the individual level;

and disregards not only the function of social context in the development of critical thinker but also the transformative power of the critical thinker as an actor of the social context in which she/he participates [24, 26, 27]. These criticisms towards the critical thinking movement are mainly based on the perspective represented by another prominent approach in the critical thinking literature called critical pedagogy.

The word "critical" in critical pedagogy is borrowed from "critical theory," which is a sociological perspective founded by a group of German scholars under the influence of Marxism, phenomenology, and psychoanalysis [28]. The central premise of this school of thought is that forms of domination in society -economic, political, or cultural- continue their existence by permeating every sphere of life. And the educational system is one of the mechanisms that reproduce "the discourses, values, and privileges of existing elites" [29]. Critical pedagogy attempts to reverse the role of education in society by advocating curriculum and instruction methods, which can allow students to reflect on their place in power relations that are present in society and produce counter-hegemonic practices.

The Brazilian educator Paulo Freire has put forward the foundational ideas of critical pedagogy and influenced educators worldwide [30]. Freire suggested that liberating education should primarily promote learners' critical reflection on their position in society to reach a level of critical consciousness. Reflection needs to go beyond individual intellectual effort and be complemented with action. This authentic unity of reflection and action is called *praxis* [31].

From the critical pedagogy perspective, pedagogy is a political and moral practice dedicated to providing conditions for students to be critical citizens and participants of an emancipatory struggle [32]. Accordingly, higher education should be organized to cultivate students not only as critical intellectuals but also as critical citizens to "transform inequitable, undemocratic, or oppressive institutions and social relations" [1, p. 3]. In other words, education is a means to empower students to recognize injustice and change it. Critical thinking is a sociopolitical practice through which citizens as autonomous political actors create alternatives rather than passively choose among provided ones [28, 29]. While the critical thinking movement puts emphasis on individual skills and dispositions, critical pedagogy prioritizes the sociocultural dimension of critical thinking.

Meanwhile, both critical thinking and critical pedagogy traditions received criticisms from feminist and post-structuralist perspectives. According to these views, what is claimed to be the universal criterion of "rationality" by the critical thinking tradition is biased concerning gender, class, and cultural issues [33]. For feminist scholars, the dominant understanding of "rationality" in the critical thinking tradition, whose prominent advocates are mostly male, reflects the masculinist way of viewing the world, thinking, and knowing [34, 35]. The biased position of the critical thinking tradition is not restricted with the exclusion of women's perspective; it also ignores other racial or ethnic groups by determining the Western forms of thinking as the norm [25, 36, 37]. Along the same lines, critical pedagogy was criticized for acknowledging a single type of oppression resulting from capitalist and class-based relations and for being blind to the other forms of oppression in society [1].

5 Implications of Different Critical Thinking Perspectives in Teacher Education

While critical thinking might be one of the most frequently used terminologies in education, one can now realize that its meaning widely differs with respect to the specific schools of thought. The above discussion only provides a glimpse of the complexity of the issues around critical thinking. It could be impossible to classify the variety of critical thinking perspectives along one dimension. Further complicating the matters is that all critical thinking perspectives exist in relation to each other. Different critical thinking perspectives have different implications when designing instructional strategies and learning environments to cultivate teachers' critical thinking. In organizing this section, we will refer to the literature concerning the guidelines for teaching critical thinking, not just the teacher education literature. Our primary assumption inherent in the instructional suggestions that follow is that not only will teachers teach what they know but will also teach *the way* they are taught.

Based on the above discussion around the construct of critical thinking, we will classify the critical thinking perspectives in the literature into two major categories: critical thinking as cognitive skills (the instrumental perspective) and critical thinking as identity development (the situated perspective) (Table 1). This categorization will allow us to highlight both the role of the individual and social context in developing teachers' critical thinking.

The "instrumental" perspective of critical thinking promotes critical thinking as a form of logical thinking (put forward by philosophers) and "higher-order skills" (formulated by psychologists) [38]. This perspective is essentially captured by the critical thinking as cognitive skills perspective, explained above, and focuses on individual cognitive development. This critical thinking development can be considered instrumental, that is, as a means to the individual's involvement in the social

Table 1 Critical thinking perspectives

Critical thinking perspective	Explanation	Purpose	Knowing
Instrumental perspective	Critical thinking as cognitive skills	Individual development	Possessing knowledge
Situated perspective	Critical thinking as identity development	Becoming a critical participant in a democratic school context	Belonging, participating, communicating

context. Once this cognitive development is achieved, it is assumed that the individual can meaningfully contribute to society.

The situated critical thinking perspective, on the other hand, conceptualizes critical thinking as a form of identity development. The critical thinking dispositions also discussed above partly capture the identity development perspective; however, the idea of dispositions underpins a level of growth at the individual level, failing to represent the situated understanding adequately. Sfard's [39] metaphor-based analysis of learning theories suggests that a situated critical thinking perspective can be explained with the "participation" metaphor. The participation metaphor highlights the part-whole relationships by defining them in relation to each other. Rather than taking possession of specific skills or dispositions as determinants of identity, the situated critical thinking perspective defines identity as a function of becoming a part of a larger whole. This implies that the context is not just a background or a facilitator for any learning process; it is an indispensable part of it.

Based on ten Dam and Volman's work [33, 38], we consider this identity a competence that teachers need for critical participation in a plural and democratic school context. Ten Dam and Volman [38] argue that democratic citizenship requires thinking critically and politically, but that is insufficient. It also entails commitment, empathy, and a caring attitude. They propose that we need to think about alternative instructional designs "that do not capitalize on applying tricks of arguing, nor on the cognitive activity of analyzing power structures, but contribute to the ability as well as the readiness of students to participate independently in a meaningful and critical way in concrete real social practices and activities" [38, p. 371].

5.1 Implications of the Instrumental Perspective of Critical Thinking in Teacher Education

Most instructional strategies to teach critical thinking have been proposed and empirically researched based on an instrumental understanding of critical thinking, that is, the development of cognitive critical thinking skills [38]. Instruction that has been useful for enhancing critical thinking focused on active and problem-based learning and fostered interaction among students [33].

Tsui's [40] review on courses and instructional designs related to critical thinking revealed that students' participation in a diverse range of courses from writing and mathematics to ethnic and women's studies is positively correlated with the development of (self-reported) critical thinking. Specifically, courses with an interdisciplinary approach are found to support critical thinking growth. Still, it is worth noting that content is presented in an integrative, synthesized manner in these courses rather than the remote transition of pieces of discrete information [40].

Writing assignments accompanied by the critical feedback of instructor, independent group or individual research projects, class presentations [40], activities providing the opportunity for dialogue and discussion, and authentic problem-solving [41] are determined as helpful instructional strategies supporting students' critical thinking competencies. According to Mpofu and Maphala [42], in teacher education courses, these strategies can be used implicitly, such as instructor modeling during different activities, or explicitly, such as exercising Socratic dialogue as a classroom activity. Ennis [43] classifies instructional strategies for teaching critical thinking skills and dispositions under four approaches: general, infusion, immersion, and mixed. The general approach aims to develop "general" critical thinking abilities through direct instruction of abstract rules of logic or informal logic to analyze an ordinary topic from daily life. The infusion and immersion approach both integrate critical thinking instruction into subject-matter instruction. However, while general critical thinking skills and dispositions are explicitly referred to during the subject matter instruction in the former, in the latter approach, they are embedded into the subject matter, and students implicitly learn them. The mixed approach corresponds to the combination of general and subject-specific methods.

From this perspective, teacher educators need to delve into the question of subject-specificity of critical thinking; that is, if critical thinking should be taught in specific subject matter courses (e.g., math or science) or in more general critical thinking courses. This issue is also related to the question of transfer, which is an essential topic of discussion within cognitively oriented learning theories [39].

Some researchers argue that specifically designed critical thinking courses should be dedicated to teaching critical thinking as a generic set of skills [43–46]. This view assumes that claims and arguments can be abstracted and decontextualized to a level where they are analyzed according to the rules of logic not specific to any subject matter [25]. Others, on the other hand, claim that there are not any generalizable critical thinking skills [47–50]. Thus, critical thinking cannot be learned independently from a subject matter, and some reviews supported this viewpoint documenting a lack of evidence regarding the effectiveness of general critical thinking courses [40]. This discussion took the form of synthesis when Brown [51] suggested that the transfer of general critical thinking skills is possible when the subject matter is utilized as a context to teach these skills, which is more likely if significant real-life problems are used.

One implication of these findings is that teacher education programs should not limit critical thinking to a specific course assuming the existence of abstract critical thinking skills across disciplines. Even if that should be the case, critical thinking should be taught so that the transfer to the other domains of study in teacher education is possible. This can be achieved by designing teacher education programs that will allow teacher candidates to integrate essential disciplinary knowledge within reflective cycles [52]. According to Shulman [53], the knowledge base for the teaching profession involves seven categories: "content knowledge; general pedagogical knowledge; curriculum knowledge; pedagogical content knowledge; knowledge of learners and their characteristics; knowledge of educational contexts; and knowledge of educational ends, purposes, and values along with their philosophical and historical grounds." Teacher candidates could meet this content separately in different courses. However, they also need to be provided explicit opportunities to integrate these different types of knowledge in reflection-based learning activities. This could be done in separate courses or as part of their teaching practicum. The reflective tasks could be constructed so that teacher candidates can develop their critical skills by continually interacting with their peers and instructors—e.g., challenging their or others' assumptions, evaluating different viewpoints, and identifying areas of improvement based on feedback. Oner and Adadan [54, 55] showed that these could be done effectively by constructing web-based portfolios using customized portfolio software, which is carefully designed by combining both technological and pedagogical elements.

5.2 Implications of the Situated Critical Thinking Perspective in Teacher Education

The situated perspective conceptualizes learning as becoming a member of a community of practice [56]. From this perspective, critical thinking is embedded within the social context it emerges [36]. As Walters determines, "[A]ll thinking is performed in concrete situations by concrete individuals, and to abstract from either of these two settings is to risk missing the overall meaning, purpose, and nuances of a claim or argument. Styles of thinking, as well as ideas themselves, are inextricably connected with broader, more complex environments of discourse, place, time, value, and worldview, and to neglect these environments is to limit the function and range of thinking in an unwarranted way" [25, p. 16].

Thus, learning critical thinking is a social learning process [57]; and it can be enhanced through social practices in which critical thinking is adopted as a socially valued norm [37]. Developing critical thinking from this perspective means that teacher educators need to pay attention to teacher candidates' active participation processes in community activities, take responsibility, and gradually become critical members of the teaching community [38, 58]. As learning is located in a social context, and knowledge or skills are an aspect of the practice, critical thinking should be an integral part of the teaching practice. That is, teacher candidates' participation within the teaching community should require critical thinking skills within meaningful activities.

The educational objective from this perspective is not just able to think critically but also showing "the competence to participate critically in the communities and social practices to which a person belongs" [38, p. 372]. *Participation* [38] and *action* [1, 26] can be viewed as the critical aspects of teacher education built on a situated understanding of critical thinking. Part of the challenge for teacher educators espousing this critical thinking perspective is to create such learning situations involving *authentic activities* [59], that is, the *ordinary practices of the culture* [60], while in reality, such critical teaching culture may not even exist.

One interpretation of the situated critical thinking perspective can be the teacher candidates' direct exposure to teaching culture as a pedagogical strategy. For example, one may become an excellent Argentine tango dancer in Buenos Aires by just living there and participating in ordinary daily activities. As dancing is naturally integrated into the Argentinian culture, one works toward becoming an active member of this culture, which results in becoming a good dancer (rather than the other way around). The same may not be accurate in Beijing, China, for example. Similarly, teacher candidates can become active members of a critical teaching community more easily when such a culture exists.

However, there are other conceptualizations of an authentic context from the situated perspective. Putnam and Borko [59] argue that what makes an activity authentic is the kinds of thinking fostered that will transfer to out-of-school settings. Similarly, the cognitive apprenticeship model put forward by Brown, Collins, and Duguid [60] suggests that educators can use the situated perspective by creating community practices in the classroom. The knowledge-building pedagogy by Scardamalia and Bereiter [61] is also built on the understanding that the school can be the context for real knowledge work.

These ideas imply that teacher educators could provide opportunities for teacher candidates to enter the culture of teaching in their college classrooms. For that, teaching programs could take advantage of technology that affords to create virtual worlds. One novel approach in teacher education is using *virtual internships* [62, 63]. Virtual internships, also known as epistemic games, provide simulations of professional workplaces. As such, they offer authentic contexts in which learners could participate in the practices of a specific profession. In these learning environments, learners act as professionals while working on authentic tasks by interacting and collaborating with their peers and mentors. Although virtual internships are new research areas in teacher education, they could be useful tools to actualize the implications of the situated critical thinking perspective and support future teachers' critical thinking development. In using these virtual environments, teacher educators could design learning activities so that teacher candidates take on several roles requiring critical thinking skills to complete, which could then be made gradually more complicated. These would involve, for example, working as an assistant for the organization of a school science fair, a coordinator for a school trip to disadvantaged communities, or a district representative for a research project focusing on equity. The tasks should be created so that the acquisition of critical thinking skills will be a "by-product" of participation in these activities [33]. Thus, a meaningful setting can be created not simply as a problem-solving context but as a setting that requires "critical participation" in the practices of the community, which has value for both the community and the participant. Critical thinking should be what enables teacher candidates to participate in the traditions of the teaching community.

When critical thinking is conceptualized from a situated perspective, traditionally used assessment strategies may not be sufficient. The data are usually collected with tests and self-report instruments to measure critical competencies. However, these instruments are typically constructed based on an understanding of critical thinking from the instrumental perspective [38]. That is, they usually focus on individual critical thinking skills, such as *being able to identify assumptions* or *being able to consider alternatives*. Portfolio development and essays would be more suitable means of assessing critical competencies based on the situated critical thinking perspective [38].

6 Conclusion

In this paper, our purpose was to examine the critical thinking literature and discuss instructional strategies to develop critical thinking in teacher education. We observed an evolving understanding of critical thinking and identified perspectives focusing on individual cognitive skills, dispositions, and approaches that consider the individual as part of a broader social context. Based on Sfard's [39] metaphor-based analysis of learning theories, we suggested that critical thinking could be conceptualized in two fundamentally distinct ways: critical thinking as the acquisition of cognitive skills (instrumental perspective) and critical thinking as identity development (situated perspective). While the instrumental perspective of critical thinking focuses on what to teach regarding critical thinking, the situated critical thinking perspective enables us to emphasize the broader social context where those skills and dispositions are embedded in participation structures and can be used for meaningful purposes in the culture of teaching. Critical thinking skills and dispositions are a by-product of participation and action in the activities of the culture.

These different critical thinking perspectives have different implications when designing instructional strategies and learning environments to cultivate future teachers' critical thinking. From an instrumental understanding of critical thinking and based on the findings from the literature, we suggested that teacher candidates should be given opportunities to integrate essential disciplinary knowledge within reflective cycles, even if they are introduced to those ideas in different courses. The reflective tasks could be constructed so that teacher candidates can develop their critical skills by continuously interacting with their peers and instructors. The situated critical thinking perspective, on the other hand, requires a different take on the critical thinking pedagogies. Teacher educators should offer opportunities for teacher candidates to enter the culture of teaching and use their critical thinking skills to participate in that culture. We suggested that virtual internships could be effective tools to enculturate teacher candidates into a critical teaching community.

Although we examined the implications of both critical thinking perspectives separately, this does not suggest that teacher educators should take sides and religiously follow the implications of a single perspective. We believe that teacher educators should take advantage of multiple critical thinking perspectives when designing learning environments for the critical thinking outcome. Following Sfard [39], we further advocate that the individual and social critical thinking perspectives should complement each other. Learning could be the most complex phenomenon we have ever encountered; thus, adopting multiple perspectives would only help us serve many needs.

Core Messages

- Developing critical thinking is an important educational goal for all grade levels today.
- Critical thinking should be an essential outcome of teacher education.
- Instrumental and situated perspectives should be combined when designing learning environments to improve teachers' critical thinking skills.

References

1. Burbules N-C, Berk R (1999) Critical thinking and critical pedagogy: relations, differences, and limits. In: Popkewitz T-S, Fendler L (eds) Critical theories in education. Routledge, New York, pp 45–65
2. Hitchcock D (2018) Critical thinking. In: Zalta E-N (ed) The Stanford Encyclopedia of philosophy. https://plato.stanford.edu/archives/fall2018/entries/critical-thinking. Accessed 8 Aug 2020
3. Costa A-L (1985) Developing minds: preface to the revised edition. In: Costa A-L (ed) Developing minds: a resource book for teaching thinking. Association for Supervision and Curriculum Development, Virginia, pp ix–x
4. National Education Association (2012) Preparing 21st-century students for a global society: an educator's guide to "the four Cs." http://www.nea.org/assets/docs/A-Guide-to-Four-Cs.pdf . Accessed 08 Aug 2020
5. Oner D (2019) Education 4.0: the skills needed for the future. In: Paper presented at the 5th Turkish-German frontiers of social science symposium (TUGFOSS) by Alexander von Humboldt Foundation, Stiftung Mercator, and Koç University, Leipzig, Germany, 24–27 Oct 2019
6. Elder L, Paul R (1994) Critical thinking: why we must transform our teaching. J Dev Educ 18 (1):34–35
7. Williams R-L (2005) Targeting critical thinking within teacher education: the potential impact on society. Teach Educ Q 40(3):163–187
8. Holder J-J (1994) An epistemological foundation for thinking: a Deweyan approach. Stud Philos Educ 13:175–192
9. Dewey J (1910) How we think. D.C. Heath and Company, Lexington
10. Bruner J (1966) Toward a theory of instruction. Harvard University Press, Cambridge
11. Laanemets U, Kalamees-Ruubel K (2013) The Taba-Tyler rationales. J Am Assoc Advance Curriculum Stud 9:1–12
12. McTighe J, Schollenberger J (1985) Why teach thinking? A statement of rationale. In: Costa A-L (ed) Developing minds: a resource book for teaching thinking. Association for Supervision and Curriculum Development, Alexandria, pp 2–5
13. Taba H (1962) The teaching of thinking. Element English 42(5):534–542
14. Pressesien B-Z (1985) Thinking skills: meanings and models revisited. In: Costa A-L (ed) Developing minds: a resource book for teaching thinking Association for Supervision and Curriculum Development, Alexandria, pp 56–62
15. Cohen J (1971) Thinking. Rand McNally, Chicago
16. Iowa Department of Education (1989) A guide to developing higher-order thinking across the curriculum. Department of Education, Des Moines (ERIC Document Reproduction Service No. ED-306-550)

17. Jonassen D (1996) Computers as mindtools for schools: engaging critical thinking. Prentice Hall, New Jersey
18. Ennis R-H (1996) Critical thinking dispositions: their nature and accessibility. Informal Logic 18:165–182
19. Facione P (1990) Critical thinking: a statement of expert consensus for purposes of educational assessment and instruction. California Academic Press, Millbrae
20. Paul R-W (1985) Goals for a critical thinking curriculum. In: Costa A-L (ed) Developing minds: a resource book for teaching thinking. Association for Supervision and Curriculum Development, Alexandria, pp 77–84
21. Ennis R-H (1964) A definition of critical thinking. Read Teach 17(8):599–612
22. Ennis R-H (1985) Goals for a critical thinking curriculum. In: Costa A-L (ed) Developing minds: a resource book for teaching thinking. Association for Supervision and Curriculum Development, Alexandria, pp 68–71
23. Ennis R-H (2015) Critical thinking: a streamlined conception. In: Davies M, Barnett R (eds) The Palgrave handbook of critical thinking in higher education. Palgrave Macmillan, New York, pp 31–47
24. Davies M (2015) A model of critical thinking in higher education. In: Paulsen M (ed) Higher education: handbook of theory and research, vol 30. Springer, Cham, pp 41–92
25. Walters K-S (1994) Introduction: beyond logicism in critical thinking. In: Walters K-S (ed) Re-thinking reason: new perspectives in critical thinking. SUNY Press, Albany, pp 1–22
26. Barnett R (1997) Higher education: a critical business. Open University Press, Buckingham
27. Phelan A-M, Garrison J-W (1994) Toward a gender-sensitive ideal of critical thinking: a feminist poetic. Curric Inq 24(3):255–268
28. Kaplan L-D (1991) Teaching intellectual autonomy: the failure of the critical thinking movement. Educ Theory 41(4):361–370
29. McLaren P (1994) Critical pedagogy and predatory culture. Routledge, London
30. Giroux H-A (2010) Lessons from Paulo Freire. https://www.chronicle.com/article/lessons-from-paulo-freire/. Accessed 8 Aug 2020
31. Freire P (2000) Pedagogy of the oppressed. Continuum, New York
32. Giroux H-A (2011) On critical pedagogy. The Continuum International Publishing Group, Auckland
33. Volman M, ten Dam G (2015) Critical thinking for educated citizenship. In: Davies M, Barnett R (eds) The Palgrave handbook of critical thinking in higher education. Palgrave Macmillan, New York, pp 593–603
34. Belenky M-F, Clinchy B-M, Goldberger N-R, Tarule J-M (1997) Women's ways of knowing: the development of self, voice, and mind. Basic Books, New York
35. Warren K-J (1994) Critical thinking and feminism. In: Walters K-S (ed) Re-thinking reason: new perspectives in critical thinking. SUNY Press, Albany, pp 199–204
36. Thayer-Bacon B (2000) Transforming critical thinking. Teachers College Press, New York
37. Atkinson D (1997) A critical approach to critical thinking in TESOL. TESOL Q 31(1):71–94
38. ten Dam G, Volman M (2004) Critical thinking as a citizenship competence: teaching strategies. Learn Instr 14:359–379
39. Sfard A (1998) On two metaphors for learning and the dangers of choosing just one. Educ Res 27:4–13
40. Tsui L (1999) Courses and instruction affecting critical thinking. Res High Educ 40(2):185–200
41. Abrami P-C, Bernard R-M, Borokhovski E, Waddington D-I, Anne Wade C, Persson T (2015) Strategies for teaching students to think critically: a meta-analysis. Rev Educ Res 85 (2):275–314
42. Mpofu N, Maphalala M-C (2017) Fostering critical thinking in initial teacher education curriculums: a comprehensive literature review. Gender Behav 15(2):9226–9236
43. Ennis R-H (1989) Critical thinking and subject specificity: clarification and needed research. Educ Res 18(3):4–10

44. Norris S-P (1985) The choice of standard conditions in defining critical thinking competence. Educ Theory 35(1):97–107
45. Paul R-W (1985) McPeck's mistakes. Informal Logic 7(1):35–43
46. Siegel H (1991) The generalizability of critical thinking. Educ Philos Theory 23(1):18–30
47. McPeck J-E (1981) Critical thinking and education. St Martin's Press, New York
48. McPeck J-E (1984) Stalking beasts, but swatting flies: the teaching of critical thinking. Can J Educ 9(1):28–44
49. McPeck J-E (1990) Critical thinking and subject-specificity: a reply to Ennis. Educ Res 19 (4):10–12
50. Adler M (1986) Why critical thinking programs won't work. Educ Week 6(2):28
51. Brown A (1997) Transforming schools into communities of thinking and learning about serious matters. Am Psychol 52(4):399–413
52. Oner D (2010) Öğretmenin bilgisi özel bir bilgi midir? Öğretmek için gereken bilgiye kuramsal bir bakış. Boğaziçi Üniversitesi Eğitim Dergisi 27(2):23–32
53. Shulman L-S (1987) Knowledge and teaching: foundations of the new reform. Harvard Educ Rev 57(1):61–77. https://doi.org/10.17763/haer.57.1.j463w79r56455411
54. Oner D, Adadan E (2011) Use of web-based portfolios as tools for reflection in preservice teacher education. J Teach Educ 62(5):477–492
55. Oner D, Adadan E (2016) Are integrated portfolio systems the answer? An evaluation of a web-based portfolio system to improve preservice teachers' reflective thinking skills. J Comput High Educ 28(2):236–260
56. Lave J, Wenger E (1991) Situated learning: legitimate peripheral participation. Cambridge University Press, Cambridge
57. Brookfield S (2012) Teaching for critical thinking: tools and techniques to help students question their assumptions. Jossey-Bass, San Francisco
58. Korthagen F-A-J (2010) Situated learning theory and the pedagogy of teacher education: towards an integrative view of teacher behavior and teacher learning. Teach Teach Educ 26 (1):98–106
59. Putnam R-T, Borko H (2000) What do new views of knowledge and thinking have to say about research on teacher learning? Educ Res 29(1):4–15
60. Brown J-S, Collins A, Duguid P (1989) Situated cognition and the culture of learning. Educ Res 18(1):32–42
61. Scardamalia M, Bereiter C (1991) Higher levels of agency for children in knowledge building: a challenge for the design of new knowledge media. J Learn Sci 1(1):37–68
62. Shaffer D-W (2005) Epistemic games. Innovate J Online Educ 1(6):Article 2
63. Oner D (2020) A virtual internship for developing technological pedagogical content knowledge. Australas J Educ Technol 36(2):27–42

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19 Education of Integrated Science: Discussions on Importance and Teaching Approaches

Kaan Bati

Science is the only true guide in life.

Mustafa Kemal Atatürk

Summary

The economic and technological development of societies depends on the training of students who can make connections between daily life and science issues and have problem-solving skills. Integrated science education supports the holistic development of the student's personality by establishing a relationship between school and real life. Although there are different approaches, it is understood that all approaches to integrated science are more effective than the traditional single discipline-based approach for the student to learn. This chapter discusses the importance of integrated science education, teaching approaches at the K-12 level, and the skills that need to be emphasized to answer this question. An integrated science teaching program based on the transdisciplinary approach is exemplified as well.

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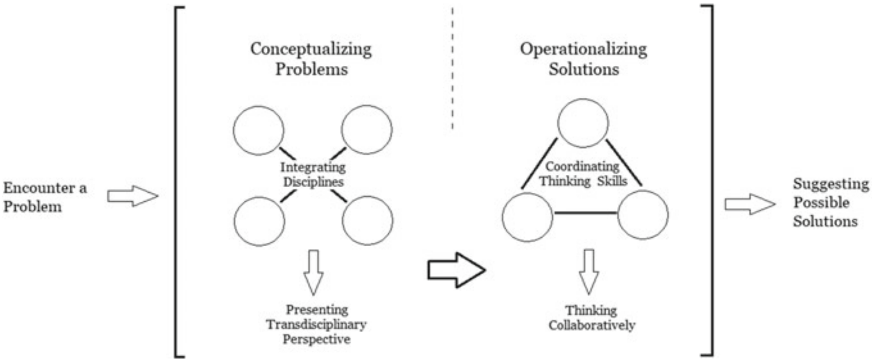
N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_19

Graphical Abstract/Art Performance



Transdisciplinary teaching process.

Keywords

Computational thinking · Creative thinking · Critical thinking · Integrated science education · Interdisciplinarity · Multidisciplinarity · Transdisciplinarity

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*

1 Introduction

Today, education aims to raise individuals who can understand, produce scientific knowledge and technology, and solve daily or professional life problems. In particular, given the positive contribution of the export of high value-added technological products to countries' economic growth, it becomes clearer that societies should update their education systems in line with this vision. One of the most effective ways to achieve this vision is to provide students with creativity, critical thinking, information and media literacy, collaboration, and entrepreneurship, defined as twenty-first-century skills [1, 2]. The results of international student monitoring and evaluation studies concretely demonstrate the contribution of individuals with twenty-first-century skills to the economic development of their communities [3]. However, in today's world, where information is growing rapidly, discussions are ongoing about which skills and content should be gained to students with which methods. Besides, with the rapid advancement of knowledge and technology, problems become more complex, and individuals are expected to grow up with a multidisciplinary perspective to solve these problems. For this, it is undeniable that scientific, social, and technological content should be integrated into schools. Education policymakers and researchers have been conducting research and discussions on the integrated science education program and its outcomes for a long time. According to the literature, the integrated education program supports knowledge, skills, and conceptual development and offers students meaningful learning experiences [4–6]. Integrated education programs aim to show how different disciplines are related in nature by having an interdisciplinary perspective of the student instead of a single disciplinary perspective [6, 7]. However, given the dynamic structure of knowledge and technology, how to implement an effective integrated science education and which skills should be important becomes noteworthy. This chapter discusses the importance of integrated science education, teaching approaches at the K-12 level, and the skills that need to be emphasized to answer this question. An integrated science teaching program based on the transdisciplinary approach is exemplified as well.

2 Importance of Integrated Science—A Close Look from Educational Science Perspective

The economic and technological development of societies depends on the training of students who can make connections between daily life and science issues and have problem-solving skills. According to literature, societies are needed for more innovative, creative, versatile, and flexible individuals of our age [8–10]. For this purpose, one approach links the areas in the education program with each other and daily life. The effort to investigate the science-technology link and its effects on social life is not new. Science-technology-society (STS) and socio-scientific issues-based approach, for example, have been studied in science fields for many years and support the multidimensional development of students [11–14]. This effort emerged in the 90s, including interactions between science, technology, and society in education programs, and education programs revised themselves in line with this vision [15]. This vision of integration, which emerged with STS, evolved into the science, technology, engineering, and mathematics (STEM) approach after the 2000s, with the addition of mathematics and engineering. In the twenty-first century, since information and communication technologies have started to play an important role in many areas of life, STEM education which supports the multi-faceted development of individuals has gained importance [16]. STEM program has emerged as an approach to integrate these fields [17, 18]. According to the literature, STEM education has two main objectives; to increase the literacy of all students related to the core STEM fields and to guide them towards careers in science, technology, engineering, and mathematics. To raise successful students to participate in science and engineering careers, students should study integrated STEM fields [19]. It is generally recognized that more student-centered learning environments can attract more students to STEM and allow them to develop basic 21st-century skills such as solving complex problems and teamwork. Students should develop and use their strategies to examine complex problems, use various tools, and solve these problems in a collaborative way [20]. To achieve this goal, it is stated that learning approaches in which students actively participate in the process should be employed, and the "integrated STEM" (iSTEM) approach should be emphasized [21]. iSTEM can often be defined as "a seamless amalgamation of content and concepts from multiple STEM disciplines" [21]. Unlike traditional STEM, iSTEM requires the knowledge and skills of STEM disciplines to solve complex interdisciplinary problems.

STEM education is becoming more and more common in the world. However, studies in the literature show that students' interest in STEM applications has increased, but students prefer to pursue a career in other fields by changing these fields [22]. This is a fact that needs to be considered. Moreover, the need for effective integrated science education should not be overlooked. When the literature is examined, STEM education practices are focused on technology development and use rather than being life-based. In a more concrete statement, STEM education is focused on coding and robotics applications [23]. It can be said that this area has become dominant in STEM education because most of the programs used (Arduino, Strach, etc.) are free and accessible, and algorithms are so simple that they can be taught to pre-school students [24]. Besides, it is unavoidable that robotic applications address science, technology, engineering, and mathematics in terms of hardware and software. However, a question arises: is an education covering the four areas sufficient to raise the desired creative and innovative individuals? The science, technology, engineering, the arts, and mathematics (STEAM) approach is recommended to overcome this shortcoming of the STEM approach. The STEAM approach is an approach that aims to combine arts with STEM topics to develop students' cognitive skills, including creativity, innovation, problem-solving, and employability skills to support career and economic advances such as teamwork and communication [25]. For a STEM program to be balanced, it needs to incorporate art rather than just reading, writing, and speaking skills [26].

3 How to Teach and Learn Integrated Science

Teaching and learning integrated science refers to a process that is structured by integrating many disciplines. Integrated learning is seen as one of the most importantly effective and meaningful learning methods. It combines various educational paradigms to provide learning opportunities in accordance with each student's style and cognitive structure [27]. By providing a multidisciplinary perspective, integrated education can also prevent misconceptions students can make while learning a single subject [28]. It creates motivation by offering a learning environment where each student can participate according to their abilities. To design an effective integrated teaching/learning process, it is necessary to consider the students' cognitive, emotional, and social development rather than only acquiring the learning contents with a holistic approach. There are three approaches to integration: multidisciplinary, interdisciplinary, and transdisciplinary [28, 29], and the boundaries between them are often blurred, and their definition is unclear [30]. In this section, I will try to define these three approaches and clarify the boundaries between each other.

3.1 Multidisciplinary Approach

The term multidisciplinary refers to an approach in which different disciplines examine the parts of a particular problem situation related to them together or separately [31]. Each discipline tries to solve the problem by remaining within its borders [30]. More specifically, in the multidisciplinary approach, participants from different disciplines exchange views for a problem situation in their common interests, maybe they work together for a certain part of the problem, but each researcher solves the problem from his perspective [32]. From the educational perspective, the clearest practice of the multidisciplinary approach can be seen in science education. For many years, science education has been a discipline where physics, chemistry, and biology disciplines are integrated. The education program consists of units that include specific topics of physics, chemistry, and biology. However, science education aims not to teach physics or chemistry; teaching physics is the problem of physics discipline. The aim of science education should be to gain knowledge, skills, and understanding about scientific knowledge and the scientific method. The way to achieve this is to consider and teach science as a whole instead of separating the branches of science with sharp lines. With the Next Generation Science Education Standards (NGSS) definition, this understanding could promote science education development based on four domains: physical science, life science, earth and space science, and engineering design [33]. However, although this new vision claims to integrate different science disciplines, the need to integrate more different disciplines continues to provide meaningful learning.

3.2 Interdisciplinary Approach

The term interdisciplinary refers to an approach in which researchers from different disciplines work to integrate each discipline's conceptual, theoretical, and empirical perspectives to solve a problem or explain a phenomenon [32]. The interdisciplinary approach is a holistic and mutually interactive approach based on synthesizing perspectives from various disciplines that provide a new level of thinking and work on an existing discipline or introduce a new hybrid discipline [34]. Unlike the multidisciplinary, disciplines are intertwined in this approach. Interdisciplinary teaching and learning is a process in which students integrate knowledge, method, perspective, concept, or theory from different fields to explain a phenomenon or solve a problem [35]. Interdisciplinary teaching and learning require students to manage their learning process and develop their design pathways in accessing learning content [36]. From an educational perspective, it can be said that the STEM approach is the practical application of this approach. STEM is a systematic education covering science, technology, engineering, and mathematics at the primary and secondary levels [37]. It is possible to say that the STEM approach has an interdisciplinary perspective because, in this approach, it is necessary to integrate the knowledge, skills, and understanding of these disciplines to solve a particular problem or to deal with a phenomenon.

3.3 Transdisciplinary Approach

The term transdisciplinary, a relatively new concept, applies to integrating natural, social, and even health sciences to reach beyond their traditional boundaries [34]. In a more precise definition, a transdisciplinary approach is a holistic approach that exceeds disciplinary boundaries to build a shared conceptual–theoretical–empirical structure for solving a problem [34]. For example, in a public health problem, the process by which sociologists, food engineers, and community health professionals work together to develop a common theory, understanding, or method can be defined as transdisciplinary. In transdisciplinary teaching/learning, it is important to ensure that students ask real questions, connect them between their daily lives and their course content, and encourage them to think from different perspectives [28, 30, 32]. From the education perspective, STEAM education is shown as the practical application of the transdisciplinary approach [38, 39]. STEAM is an approach that aims to develop students' creativity as well as innovation and problem-solving skills and combines arts with STEM subjects for this purpose [25].

4 Thinking Skills for Teaching Integrated Science

As discussions about the importance of thinking skills and how they should be acquired continue, so as talks about those beyond discipline boundaries do. What is meant here are the skills not related to a specific discipline, such as creativity and critical thinking skills. It is emphasized that well-educated and creative individuals have these skills [10]. Students need to develop and use their strategies to understand, analyze, and collaborate with complex problems [20]. I think that achieving this aim is to focus on creative thinking, critical thinking, and computational thinking.

4.1 Creative Thinking

The concepts of creativity and creative thinking have been one of educators' and psychologists' most important discussion topics for many years. Because creativity is linked to innovation and progress by their nature, whether in science or art, fostering creativity is considered an important purpose. Creative thinking is associated with creating different ideas, and different ideas are not derived from each other but are produced independently [40]. Although creativity is a complex skill that its definition remains under discussion [41], it can be expressed mainly in perceiving, understanding, and producing new ideas in a problem or situation [42, 43]. It is commonly referred to as "the ability to develop original and functional ideas, behaviours, or products and is seen as the ability to adapt to individual, situational and cultural variations" [44, 45]. Creativity is not a single character, skill, trend, or preference; it is a personality feature shaped by motivation and especially divergent thinking and intelligence [45]. Creative individuals have four basic characteristics:

i. they produce ideas using divergent and metaphoric thinking;
ii. they examine ideas through convergent and critical thinking;
iii. they are open to discovering ideas, and they dare to do so; and
iv. they are always ready to listen to their inner voices [46].

Creative thinking ability in any field is also deeply related to thinking in other fields that seem irrelevant. This relationship also can create new perspectives in different fields of science. Although there are clear differences between disciplines, there are critical similarities between successful thinkers in those areas [8]. Weisberg claims that the way to bring different disciplines together is a creative problem-solving process [47]. Because creative thinking requires observing and analyzing a problem from different angles, formulating new solutions, and reaching new cognitive entities that did not exist before, creative thinking becomes an important skill for integrated science. The relationships between interdisciplinary approaches and creative thinking have already been studied. Spooner emphasized that creativity includes the synthesis of different items, and this feature is one of the main goals of interdisciplinary approaches [48]. The STEAM education model crucially aims to cultivate creativity in students' personalities [49]. The creative personality reflects creativity in the dimension of personality development. When the literature is examined, the sub-factors defined for the product of creative personality can be listed as self-confidence, risk-taking, determination, humor, curiosity, broad interest, independence, risk-taking, duty responsibility, and imagination [49].

Holistic and integrated education can be achieved by appropriately blending ability and personality development. For this reason, separate fields of education need to be combined, and this point of view is also one of the reasons for the inclusion of art in STEM education. The integration of arts into STEM provides opportunities to develop students' creativity, problem-solving, critical thinking, communication, risk-taking, and collaboration skills, which are described as twenty-first-century skills [50].

4.2 Critical Thinking

Critical thinking is a crucial trait an individual should acquire; however, debates about identifying it or making it available for all individuals are ongoing. According to the literature review, critical thinking has different definitions in philosophy [51], cognitive psychology [52], and education [53]. From a philosophical point of view, critical thinking is the process through which one decides what to do or believe in a rational manner [54]. Bailin [51] improved the philosophical definition and described critical thinking as a certain quality of thinking that meets the correctness and adequacy of knowledge. In brief, it can be stated that the philosophical approach focuses on the operation of logic rules to define critical thinking [52] and considers being open-minded and welcoming different perspectives as significant to becoming a critical thinker [55].

The cognitive psychological approach criticized the philosophical approach to determine the standards or criteria of "good thinking" and addressed critical thinking as a phenomenon that cannot be directly observed behaviorally, focusing on the products of thinking, such as analyzing and interpreting [51]. According to the cognitive psychological approach, critical thinking refers to cognitive processes, strategies, and representations used for problem-solving, decision-making, and learning [52]. The use of cognitive skills provides observable outcomes as to be open to new evidence, seeking support by evidence, and deriving conclusions based on existing facts [56]. From the educational perspective, as for the cognitive psychological approach, instead of providing a direct definition of critical thinking, researchers define skills related to critical thinking; e.g., analysis of arguments, claims, or evidence [53, 55, 57]; inference using inductive or deductive reasoning [53, 55–57]; judging and evaluation [53, 55, 58]; and decision-making and problem-solving [53, 56]. In summary, critical thinking is the combination of the most important skills that should be acquired by individuals. However, as in the definition of this phenomenon, discussions on developing critical thinking continue.

Many researchers [53, 55–57] chose to refer to critical thinking as critical thinking dispositions. Disposition is used literally to mean tendency, creation (habits), and talent. If it is mentioned concerning talents or habits, it can be considered that developing critical thinking is very difficult in educational processes. However, the concept of disposition is expressed in three main components: inclination, sensitivity, and ability [59], different from the lexical meaning given above. According to this definition and point of view, critical thinking skills are learnable. Similarly, Lai [60] stated that critical thinking has two dimensions: cognitive ability and disposition. He emphasized that the latter could be seen to refer to attitudes. Moving from these discussions, it can be stated that critical thinking has two dimensions: inborn features and acquired skills. Inborn features (habits) are open-mindedness [53, 61], fairness [55, 61], curiosity [61, 62], desire to be well-informed [53, 55], and flexibility [55]. The second dimension includes acquired cognitive skills mostly learned in education, such as analyzing data, interpreting outcomes, deducing, explaining phenomena, evaluating, and reasoning [62]. Although critical thinking comprises both innate and acquired skills, there is insufficient research on how innate traits form individuals' critical thinking skills. But Lai [60] suggested that people develop their critical thinking competencies early in life, and this development continues for a lifetime. Even though many adults fail to think critically, theoretically, all people can achieve this.

The purpose of integrating critical thinking into education programs is to develop an objective, open-minded, and decisive individuals. To develop critical thinking in schools, there are two basic approaches: content-based and skill-based. Ruggiero [63] argued that skill-based educational programs should be developed to raise students as critical thinkers. Similarly, Ennis [59] emphasized that the skill-based approach is more effective because the second approach may overlook critical thinking skills by focusing on content. Pithers and Soden [64], approaching critical thinking from a different view, stated that the tendency of students to engage in critical thinking may be increased through maturing their ontological and epistemological views.

4.3 Computational Thinking

One of the twenty-first-century skills that students should gain is computational thinking. Although computational thinking is theoretically defined, discussions are ongoing on how to measure computational thinking skills and what kind of teaching approach can be more effective to develop computational thinking skills [65]. Although computational thinking was defined as one of the twenty-first-century skills, it was considered algorithmic thinking in the historical process, especially in the 1960s and 1970s [66]. Today, it has focused on producing algorithmic solutions for different problems and determining the best solution proposals [67]. Computational thinking involves problem-solving steps such as problem formulation, so the problem is well-defined for solving with computers, data organization, analysis, and abstract data presentations, for example, using models and simulations [68, 69]. Computational thinking is often seen as systematic thinking of computer science; however, it is not unique to computer science but rather a multidisciplinary thinking skill as it is a problem-solving process [67] because computational thinkers think like a mathematician in solving a problem, an engineer in embodying a complex system, and a social scientist in understanding the mind and human behavior [69].

Wing first conceptualized computational thinking in 2006 as a fundamental skill for everyone [70]. Then, in 2008, Wing embodied "… is taking an approach to solving problems, designing systems, and understanding human behavior that draws on concepts fundamental to computing" [69, p. 3377]. Up to this point, the importance and necessity of computational thinking were emphasized, but it was not yet clear which sub-dimensions it covered. These sub-dimensions have been clarified by Barr, Harrison, and Conery [68, p. 21], who consider computational thinking a problem-solving process that includes the following skills;

- *formulating problems in a way that enables us to use a computer and other tools to help solve them;*
- *logically organizing and analyzing data;*
- *representing data through abstractions, such as models and simulations;*
- *automating solutions through algorithmic thinking (a series of ordered steps);*
- *identifying, analyzing, and implementing possible solutions to achieve the most efficient and effective combination of steps and resources; and*
- *generalizing and transferring the problem-solving process to a wide variety of problems*

Many researchers have considered computational thinking as a problem-solving process [65, 71, 72], and computational thinking skills are claimed to help students choose and use appropriate tools and strategies for problem-solving [72]. Barr, Harrison, and Connery [68] state that the integration of computational thinking into education programs can help students develop their computer software skills, solve their insecurity against the complex problems of nature, and improve their emotional skills, such as working and communicating with their peers.

5 An Example of Transdisciplinary Education Course

In this transdisciplinary science education program designed to be used at the middle school level to develop students' computational thinking and problem-solving skills, the "communication" term has been determined as the focal point. In this context, it is aimed to

- understand the role of sound, light, and electromagnetic waves in communication technologies; and
- develop and use these technologies for problem-solving

The purpose of this program is to

- provide students the ability to understand the importance of communication, communication methods, technologies, and social role of communication;
- have the scientific and mathematical knowledge and skills under communication;

- use and develop communication methods and technologies; and
- identify and solve the problems arising from communication deficiencies.

This context aims to create and present teaching environments that support learning needs and motivations for creative, critical, and computational thinking skills. This theme involves, within the scope of:

- science course, light, sound, electrical circuits, frequency;
- mathematics course, patterns, coordinate plane, measurement;
- technology, sound and light technologies, EMD technologies, media tools;
- engineering understanding, working principles of communication technologies; and
- art, general music theory

All classroom activities have been described in Table 1.

Table 1 Example of transdisciplinary science education program

Activities	Purpose and context of an activity	Conceptualizing problems	Operationalizing solutions
Construct your own koto	This activity aimed to gain knowledge about the nature of sound waves to middle school students	In this activity, students are asked to construct Koto which is a traditional Japanese string instrument. In this process, they will try to solve a lack of communication problems in their social lives by composing simple melodies	Students should integrate their mathematics, science, and music knowledge and skills
Power of music	In this research, students will try to solve a communication problem in their social lives by preparing their xylophones	In this activity, the copper bars must calculate the lengths correctly to capture the correct note frequencies	Students are expected to design melody patterns to solve a communication problem in their social life
Emergency signal tool	This activity aimed to develop students' coding and computational thinking skill by designing communication tools which use electronic circuits and Arduino microcontroller		Students should try to solve emergency communication problems with sound signals in Morse Code or another coding pattern designed by them

(continued)

Table 1 (continued)

Activities	Purpose and context of an activity	Conceptualizing problems	Operationalizing solutions
Mysterious signal	This activity is targeted to develop the algorithmic thinking and computational thinking skills of students	The activity's context is light waves, and students need to develop a long-distance light-based communication tool to solve a lack of communication problems	After they design tools, they should construct a simple signal language to channel simple directives
Designing light board	Students need to design a 4 × 4 LED matrix via following the instructions provided in the activity sheet and code this LED matrix to solve a lack of communication problems in social settings		Like the emergency signal tool activity, students will use the Arduino microcontroller to construct communication languages such as emoji or letters
Significance of colors in communication	In this activity, students should notice the importance of colors in communication and they will design a communication tool consist of different color LEDs		In this process, students should use the Arduino microcontroller and construct an algorithm to solve a lack of communication problems in their lives

ICILS (2018) addresses computational thinking in two steps:

i. *conceptualizing problems* that involve knowing and understanding digital systems, problem formulation and analysis, and data curation and interpretation; and
ii. *operationalizing solutions* consisted of two skills

- planning solutions; and
- evaluating and developing algorithms, programs, and interfaces [73].

I prefer this classification to organize computational thinking and problem-solving in this program.

Students first face a real-life problem situation in this transdisciplinary curriculum. Students should be ensured to collaborate to provide possible solutions to this problem. In this process, they should first integrate their knowledge of different disciplines to conceptualize the problem and then coordinate their thinking skills to demonstrate and test their solutions. The process has been tried to be explained concretely in Graphical Abstract.

In this way, students can solve their problem situations with a transdisciplinary perspective and achieve a holistic perspective in which they will experience it in their professional lives.

6 Conclusion

Integrated science education is a preferred approach in the first years of education for many years. Generally, the education programs of science education and social studies education courses in primary education are developed according to the integrated science approach. On the other hand, this preference causes the importance of some lessons not to be sufficiently emphasized. For example, the science education concept has been considered the sum of physics, chemistry, and biology both by teachers and students. Because natural sciences such as physics, chemistry, and biology are associated with the common term of "science," it has long been understood as a combination of physics, chemistry, and biology units. While developing science education programs, I think that it draws sharp lines between the units, beyond associating with disciplines such as mathematics or technology, it cannot provide integrity even within itself, and this situation is an obstacle to meaningful learning. Numerous studies show that students fail to transfer their knowledge to other fields. The main reason for this deficiency is that education programs do not provide transferable knowledge and skills. Because it is very difficult to expect the knowledge and skills acquired separately and independently to be made sense of by the students—this calls for a well-developed education program to ensure that students consider the full context when configuring their knowledge.

In the literature, integrated science education programs are shown as a powerful tool in developing students' knowledge and skills [7]. However, the effective implementation of integrated science education programs is, for example, based on adequately prepared teachers on the education program-related content knowledge [4, 74]. At this point, policymakers and education researchers should consider the priority of the transition of the integrated science education program from multidisciplinary to transdisciplinary. Because although each approach has strengths and weaknesses relative to each other, transdisciplinary offers a more integrated and integrated framework than others. When the education programs are examined, the interdisciplinary approach, which is generally preferred at the primary level, is replaced by the disciplinary approach in the following years. This view is partially acceptable because specialization in a discipline is expected to increase time spent in education. However, in this case, it is seen that individuals have difficulties in establishing interdisciplinary relations and cannot transfer information and agreement belonging to one discipline to another discipline. For this reason, the approach to be preferred should be to provide a holistic education framework by focusing on discipline rather than directing students to a specific discipline. The second important point for policymakers and education researchers to consider is integrating content and skills. Since it is inevitable to consider the needs of the age in determining the content, the curricula to be developed will inevitably be much more flexible than the disciplinary curricula. This may make content and skill integration more possible.

In this chapter, I especially tried to define and explain cross-cutting skills, which I see as core skills for integrated science education. Creative and critical thinking are basic skills for problem-solving; educators need to be willing to bring these skills into their classrooms. Besides, these skills are associated with students' success in their personal and social lives and academic performances. Also, according to Barr, Harrison, Connery [68], computational thinking is not only related to cognitive skills, but also it supports self-confidence, tolerance to uncertainty, the ability to deal with open-ended problems, and collaboration for a purpose. From this point of view, I think these three skills are the basis of integrated science education.

Core Messages

- Integrated science education can help people develop and to be employed according to their age.
- Integrated science education should foster a school-real life relationship that supports the personality development of students.
- Effective integrated science education is possible with instructional designs that prioritize cross-cutting skills rather than content.

References

1. Ananiadou K, Claro M (2009) 21st century skills and competences for new millennium learners in OECD countries. OECD Education Working Papers, 41, OECD Publishing, Paris. https://doi.org/10.1787/218525261154
2. Rotherham AJ, Willingham DT (2010) 21st-century skills, not new, but worthy challenge. American Educator, Spring, 17–20
3. OECD (2019) PISA 2018 results (volume I): what students know and can do. OECD Publishing, Paris, PISA
4. Leung WLA (2006) Teaching integrated curriculum: teachers' challenges. Pacific Asian Educ 18(1):88–102
5. Lipson M, Valencia S, Wixson K, Peters C (1993) Integration and thematic teaching: integration to improve teaching and learning. Language Arts 70(4):252–264

6. Yager RE, Lutz MV (1994) Integrated science: the importance of "how" versus "what." Sch Sci Math 94:338–346
7. Harrell PE (2010) Teaching an integrated science curriculum: linking teacher knowledge and teaching assignments. Issues Teacher Educ 19(1):145–165
8. Henriksen D (2011) We teach who we are: creativity and trans-disciplinary thinking in the practices of accomplished teachers. Michigan State University, Educational psychology and educational technology
9. Henriksen D (2014) Full STEAM ahead: creativity in excellent STEM teaching practices. STEAM J 1(2):1–7
10. Henriksen D (2016) The seven transdisciplinary habits of mind of creative teachers: an exploratory study of award winning teachers. Think Skills Creativity 22:212–232
11. Zeidler DL, Keefer M (2003) The role of moral reasoning and the status of socio-scientific issues in science education: philosophical, psychological and pedagogical considerations. In Zeidler DL (ed) The role of moral reasoning on socio-scientific issues and discourse in science education. Kluwer Academic Press, The Netherlands
12. Sadler TD (2004) Informal reasoning regarding socio-scientific issues: a critical review of research. J Res Sci Teach 41(5):513–536
13. Zeidler DL, Sadler TL, Simmons ML, Howes EV (2005) Beyond STS: a research based framework for socio-scientific issues education. Sci Educ 89(3):357–377
14. Walker AK, Zeidler LD (2007) Promoting discourse about socio-scientific issues through scaffolded inquiry. Int J Sci Educ 29(11):1387–1410
15. Yetisir MI, Kaptan F (2008) STS from a historical perspective and its reflection on the curricula in Turkey. Int J Environ Sci Educ 3(1):3–8
16. Olson S, Labov J (2014) STEM learning is everywhere: summary of a convocation on building learning systems. National Academies Press
17. Bybee RW (2013) The case for STEM education: challenges and opportunities. NSTA Press, Arlington, Virginia
18. Dugger WE (2010) Evolution of STEM in the United States (Paper). In: Australia: 6th bi-ennial international conference on technology education research
19. Öner AT, Capraro RM (2016) Is STEM academy designation synonymous with higher student achievement? Educ Sci 41(185):1–17
20. Brush T, Saye J (2000) Implementation and evaluation of a student-centered learning unit: a case study. Educ Tech Res Dev 48(3):79–100
21. Nadelson LS, Seifert AL (2017) Integrated STEM defined: contexts, challenges, and the future. J Educ Res 110(3):221–223
22. Jon JE, Chung HI (2013) Consultant report securing Australia's future STEM: country comparisons-STEM Report Republic of Korea
23. Papanikolaou K (2010) Introducing robotics to teachers and schools: experiences from the terecop project. Constructivism, Paris. Available via http://hermes.di.uoa.gr/frangou/papers/eurologo%202010.pdf
24. Resnick M, Silverman B (2005) Some reflections on designing construction kits for kids. In: Proceedings of the 2005 conference on interaction design and children (IDC '05), pp 117–122
25. Perignat E, Katz-Buonincontro J (2019) STEAM in practice and research: an integrative literature review. Thinking Skills Creativity 31:31–43
26. Armknecht MP (2015) Case study on the efficacy of an elementary STEAM laboratory school. A Dissertation submitted to the Education Faculty of Lindenwood University in partial fulfillment of the requirements for the degree of Doctor of Education School of Education
27. Csorba C (2013) Design and delivery of a training program for teachers in primary education: interdisciplinary organization for key competences training for young schoolchildren, from pre-school class to class IV. Procedia Social Behav Sci 76:285–290
28. Helmane I, Briška I (2017) What is developing integrated or interdisciplinary or multidisciplinary or transdisciplinary education in school? Signum Temporis 9(1):7–15

29. Drake SM, Burns RC (2004) Meeting standards through integrated curriculum. ASCD
30. Collin A (2009) Multidisciplinary, interdisciplinary, and transdisciplinary collaboration: Implications for vocational psychology. Int J Educ Vocat Guidance 9(2):101–110
31. Slatin C, Galizzi M, Melillo KD, Mawn B, Phase In Healthcare Team (2004) Conducting interdisciplinary research to promote healthy and safe employment in health care: promises and pitfalls. Publ Health Rep 119:60–72
32. Fawcett J (2013) Thoughts about multidisciplinary, interdisciplinary, and transdisciplinary research. Nurs Sci Q 26(4):376–379
33. Pruitt SL (2014) The next generation science standards: the features and challenges. J Sci Teacher Educ 25(2):145–156
34. Choi BCK, Pak AWP (2006) Multidisciplinarity, interdisciplinarity, and transdisciplinarity in health research, services, education and policy. 1. Definitions, objectives, and evidence of effectiveness. Clin Invest Med 29:351–364
35. Boix-Mansilla V (2010) Learning to synthesize: the development of interdisciplinary understanding. In: Frodeman R, Thomson-Klein J, Mitcham C, Holbrook JB (eds) The Oxford handbook of interdisciplinary. Oxford University Press, Oxford, pp 288–306
36. Kidron A, Kali Y (2015) Boundary breaking for interdisciplinary learning. Res Learn Technol 23
37. Çorlu MS, Capraro RM, Capraro MM (2014) Introducing STEM education: implications for educating our teachers in the age of innovation. Educ Sci 39(171):74–85
38. Liao C (2016) From interdisciplinary to transdisciplinary: an arts-integrated approach to STEAM education. Art Educ 69(6):44–49
39. Costantino T (2018) STEAM by another name: transdisciplinary practice in art and design education. Arts Educ Policy Rev 119(2):100–106
40. Awang H, Ramly I (2008) Creative thinking skill approach through problem-based learning: pedagogy and practice in the engineering classroom. Int J Human Social Sci 3(1):18–23
41. Isaksen SG, Lauer KJ, Ekvall G, Britz A (2001) Perceptions of the best and worst climates for creativity: preliminary validation evidence for the situational outlook questionnaire. Creat Res J 13(2):171–184
42. Alves J, Marques MJ, Saur I, Marques P (2007) Creativity and innovation through multidisciplinary and multisectoral cooperation. Creativity Innov Manage 16(1):27–34
43. Ward TB, Smith SM, Vaid JE (1997) Creative thought: an investigation of conceptual structures and processes. American Psychological Association, pp xv-567
44. Cevik M (2018) From STEM to STEAM in ancient age architecture. World J Educ Technol Current Issues 10(4):52–71
45. Martinsen QL (2011) The creative personality: a synthesis and development of the creative person profile. Creat Res J 23(3):185–202
46. Selby EC, Shaw EJ, Houtz JC (2005) The creative personality. Gifted Child Quart 49(4):300–314
47. Weisberg RW (2006) Creativity: understanding innovation in problem solving, science, invention, and the arts. Wiley
48. Spooner M (2004) Generating integration and complex understanding: exploring the use of creative thinking tools within interdisciplinary studies. Issues Integr Stud 22:85–111
49. SoonBeom K, Dongsoo N, TaeWuk L (2011) The Effects of Convergence Education based STEAM on Elementary School Students' Creative Personality. T. Hirashima et al. (Eds.). Proceedings of the 19th International Conference on Computers in Education. Chiang Mai, Thailand: Asia-Pacific Society for Computers in Education
50. Sousa DA, Pilecki T (2013) From STEM to STEAM: Using brain-compatible strategies to integrate the arts. Corwin Press.
51. Bailin S (2002) Critical thinking and science education. Sci Educ 11(4):361–375
52. Sternberg RJ (1986) Critical thinking: Its nature, measurement, and improvement. National Institute of Education. Available via http://eric.ed.gov/PDFS/ED272882.pdf

53. Ennis RH (1985) A logical basis for measuring critical thinking skills. Educ Leaders 43 (2):44–48
54. Norris SP (1989) Can we test validly for critical thinking? Educ Res 18(9):21–26
55. Facione PA (1990) Critical thinking: a statement of expert consensus for purposes of educational assessment and instruction. The California Academic Press, Millbrae, CA
56. Willingham DT (2007) Critical thinking: why is it so hard to teach? Am Educ 31(3):8–19
57. Paul RW (1992) Critical thinking: what, why, and how? New Directions Commun Colleges 1992(77):3–24
58. Case R (2005) Moving critical thinking to the main stage. Educ Can 45(2):45–49
59. Ennis RH (1991) Critical thinking: a streamlined conception. Teach Philos 14(1):5–24
60. Lai ER (2011) Critical thinking: a literature review. Pearson's Res Rep 6:40–41
61. Bailin S, Case R, Coombs JR, Daniels LB (1999) Conceptualizing critical thinking. J Curric Stud 31(3):285–302
62. Facione PA (2000) The disposition toward critical thinking: Its character, measurement, and relation to critical thinking skill. Informal Logic 20(1):61–84
63. Ruggiero VR (1988) Teaching thinking across the curriculum. Harper & Row
64. Pithers RT, Soden R (2000) Critical thinking in education: a review. Educ Res 42(3):237–249
65. Grover S, Pea R (2013) Computational thinking in K–12: a review of the state of the field. Educ Res 42(1):38–43
66. Knuth DE (1985) Algorithmic thinking and mathematical thinking. Am Math Mon 92 (3):170–181
67. Denning PJ (2009) Beyond computational thinking. Commun ACM 52(6):28–30
68. Barr D, Harrison J, Conery L (2011) Computational thinking: a digital age skill for everyone. Learn Lead Technol 38(6):20–23
69. Wing JM (2008) Computational thinking and thinking about computing. Phil Trans R Soc 366:3717–3725
70. Wing JM (2006) Computational thinking. Commun ACM 49(3):33–35
71. Weintrop D, Beheshti E, Horn MS, Orton K, Jona K, Trouille L, Wilensky U (2014) Defining computational thinking for science, technology, engineering, and math. In: Poster presented at the annual meeting of the American educational research association (AERA 2014), Philadelphia. Available via http://ccl.northwestern.edu/2014/CT-STEM_AERA_2014.pdf
72. Yadav A, Zhou N, Mayfield C, Hambrusch SE, Korb JT (2011) Introducing computational thinking in education. In: Proceeding SIGCSE '11 proceedings of the 42nd ACM technical symposium on computer science education, pp 465–470
73. Fraillon J, Ainley J, Schulz W, Friedman T, Duckworth D (2019) Preparing for life in a digital world: the IEA international computer and information literacy study 2018 international report. IEA, Amsterdam
74. Huntley MA (1998) Design and implementation of a framework for defining integrated mathematics and science education. Sch Sci Math 98(6):320–327

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20 Cultivating Thinking Skills in Education

Nurulwahida Azid and Tee Tze Kiong

Any man who reads too much and uses his own brain too little falls into lazy habits of thinking.

Albert Einstein

Summary

Cultivating a mind is crucial in preparing a successful personal and professional life. Educators and students need to develop their thinking and values essential to practice. However, developing thinking is not an easy job. This chapter discusses the importance of thinking in education, contextualizing thinking skills through the theory of successful intelligence and multiple intelligences. This chapter also discusses the three engaging ways to teach thinking skills: i, thinking using multiple intelligences activity; ii, thinking using case-based

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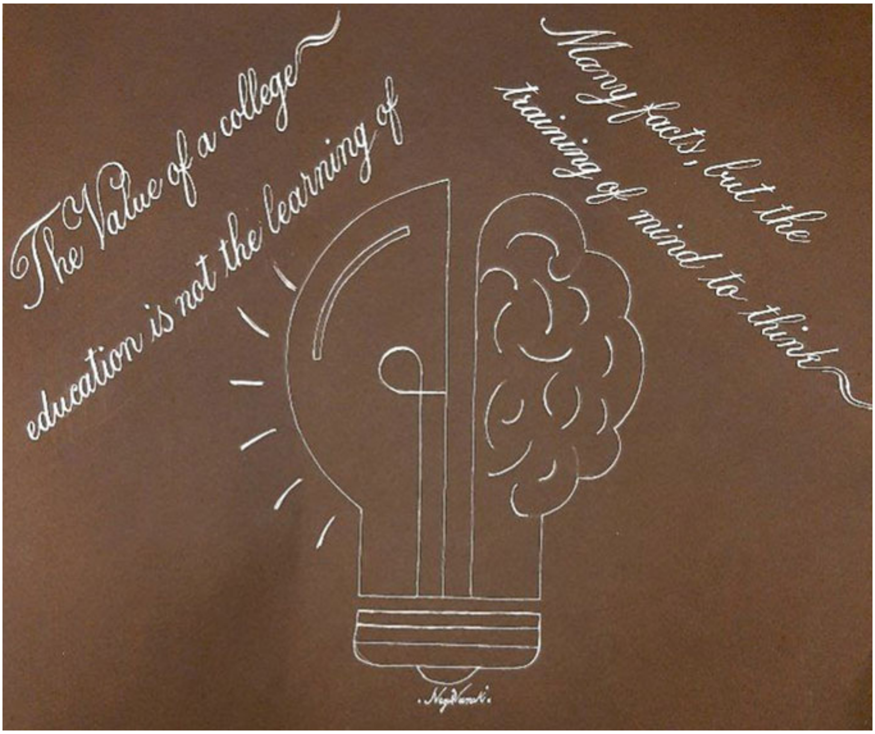
N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_20

learning activity; and iii, thinking using a thinking map. Lastly, two case studies on cultivating thinking in elementary and secondary school students are included. The first case study discussed developing interactive application courseware to empower remedial class students using the edutainment approach. On the other hand, the second case study focused on constructing an interactive pedagogical tool in improving higher-order thinking skills. Each case study explains the research design, instrumentation, research procedures, samples, findings, and discussion in detail.

Graphical Abstract/Art Performance



Cultivating thinking skills in education.

The work is inspired by the quote from Albert Einstein "*The value of a college education is not the learning of many facts but the training of the mind to think.*"

(Adapted with permission from the Association of Science and Art (ASA), Universal Scientific Education and Research Network (USERN); Made by Negar Vanaki).

Keywords

Case-based learning activity · Multiple intelligences · Successful intelligence theory · Thinking maps · Thinking skills

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

Education is important as early as preschool age from 4 to 5 years when children are introduced to the learning process. Since 2018, UNICEF has made educational contributions to 12 million children worldwide [1]. Programs with critical skills on learning and personal empowerment to produce active citizens who have jobs have been provided to 2 million children and adolescents worldwide [1]. Through strategic planning, the study [1] has outlined Goal area 2, which enshrined UNICEF's focus on education starting from early childhood education through skills development among children. These skills mainly include communication skills, decision-making, problem-solving, and thinking skills.

Business leaders, politicians, and educators mostly believe that students need 21st-century skills to succeed in life. Life in the age of technology is constantly changing in line with the development of the industrial revolution causing the field of education to concoct new and different skills and abilities among its students. However, the skills needed by students in the twenty-first century are not new. Thinking and problem-solving skills, for example, have become components that reflect the progress and process of human development. Historically, thinking skills have evolved from early human development to agricultural advances and vaccine discovery to land and sea exploration. The need for thinking skills stimulates students to communicate and react to various types of knowledge, from facts to complex analysis.

2 The Contextualizing of Thinking Skills Through Successful Intelligence Theory

The educational transformation that is taking place in the education system around the world, including developed countries like the United States, emphasizes that students in schools learn thinking skills [2]. Thinking skills, problem-solving, creativity, analytical thinking, collaboration, and communication skills have been critical in the twenty-first century. Students need to be creative in thinking and working in any environment and ensure that their creations and resolutions are unique and meaningful [3]. Creativity is the main platform that inspires students to know who they are, what they can do, and realize their ability to achieve something. Further, students should be analytical in their thinking when making comparisons and assessments and synthesize and apply ideas autonomously during supervision [4]. In other words, analytical thinking skills allow them to use higher-order thinking skills (HOTS).

There are several approaches to gauge thinking skills. In this part, thinking skill refers to the concept introduced by [5], which is known as successful intelligence. It denotes the students' ability to manipulate and use whatever strength they have to handle weaknesses and to solve problems in their daily lives which in the long run will achieve success in society. At present, this country needs academically intelligent students and those who are apt at solving problems and making sound decisions through analytical, creative, and practical thinking. Boosting the students to embrace cognitive intelligence through problem-solving skills should be given serious attention in the education system. Some believe excellent students can make analytical, creative, and practical thinking [6]. According to [7], to produce a society that is innovative, scientific, progressive, and providers, the country needs many citizens who have critical and creative thinking skills, especially highly educated ones. HOTS is one of the employability elements focused on by every employer before they hire their workers. To be employed, undergraduates need to have HOTS to survive in the working environment. The commonly mentioned and accepted aspects of employability are categorized in three sections, as displayed in Table 1.

Skills such as solving problems, making decisions, and critical and creative thinking are in the employers' list of characteristics they look for in the graduates applying for jobs. Graduates with these skills will contribute ideas, make sound decisions and use their thinking skills to solve problems they face at work. Thus, employers need graduates with these abilities and skills to increase the organizations' performance. Bloom's Taxonomy divides thinking skills into low and high levels of knowledge [8]. It begins with having knowledge, understanding, and

Table 1 Employability skills [9]

Basic skill	HOTS	Personal skill and attitude
Communicating	Critical thinking	Social skill
Reading and Understanding Instructions	Studying	Good work attitude
Basic arithmetic	Solving problems	Cooperation
Writing	Making decisions	Confident
		Responsible
		Discipline
		Able to acclimatize oneself

application at the low level, while at the higher level, there are analysis, evaluation, and creative skills. HOTS is seen as an important aspect of solving problems and making decisions. In preparing channels for undergraduates to enhance their HOTS, learning sessions must be active [10]. Active learning can be implemented in various ways such as case-based, problem-based, and project-based, discovery-based, and inquiry-based, simulations-based, and game-based types of learning, writing, debate, and so on. If students have HOTS, they will become a professional source of human capital for their country. This type of quality is crucial to ensure the development and prosperity that wants its citizens to be resourceful and productive.

3 Thinking Through Successful Intelligence Theory [5]

Successful intelligence theory [5] proposed a different intelligence perspective than the traditional intelligence theory. It is different because it emphasizes intelligence that can be applied in daily lives. This theory is based on an information processing approach that connects the world within and outside of individuals. Through successful intelligence theory, an individual has three thinking skills: analytic, creative, and practical [11]. These three types of thinking skills exist in three different levels whereby a person will either excel in one of the three or excel in all three aspects. However, certain individuals are weak in all three. One intelligent individual can:

i. associate intelligence with the individual's inner world and explain what happens when an individual is thinking intellectually, which involves the component's element of analytical thinking skills;
ii. relate to the individual’s experience, which involves the experience element of creative thinking skills; and
iii. give attention to the outside connection as having the association with an individual's intelligence and displays how intelligence functions in the real-life. This involves the element of context that is equivalent to practical thinking skills [6].

The study [6] designed a successful intelligence theory with three elements to explain an individual's intelligence. He named the elements a sub-theory component or analytical thinking intelligence, sub-theory experience or creative thinking intelligence, and sub-theory context or practical thinking intelligence. These three affect each other and enhance information processing more pragmatically [3].

3.1 Analytical Thinking Intelligence

Analytical thinking intelligence or sub-theory component is related to cognitive process. It explains the general information processing done by humans to obtain and manipulate knowledge. Analytical thinking intelligence is required to analyze and evaluate options in life, among which are identifying problems, defining problems, selecting a suitable strategy, and monitoring resolutions made. In summary, analytical thinking intelligence is used to process information.

3.2 Creative Thinking Intelligence

Creative thinking or sub-theory experience explains the influence of experience in implementing cognitive tasks [5]. Solving daily life problems requires creative thinking skills to determine the options to solve problems [12]. Creative thinking skills are involved when an individual is engaged in activities such as organizing, inventing, exploring, discovering, predicting, and imagining. Creative thinking intelligence is an interaction between the individual's ability and prior experience [3]. The stages in creative thinking intelligence show how the individual's ability to solve problems improves when the individual continues to face similar or near to similar problems. Individuals with creative thinking skills can usually relate to past experiences and automatically process the information.

3.3 Practical Thinking Intelligence

Practical thinking intelligence associates intelligence with the real environment relevant to the individual [6]. Practical thinking intelligence shows how the individual adapts, develops, and selects the surroundings. This is one of the aspects of practical thinking, known as street smart, where the individual is familiar with his/her surroundings. The individual will adapt to the surroundings optimally, set a clear vision, share skills with the public, and display strength to balance the weaknesses [6]. Individuals with practical thinking can hide self-weakness [6]. They will display strength by adapting to their surroundings, especially their society. Problem-solving activities can increase and enhance the thinking ability of individuals towards becoming more analytic, creative, and practical [12]. Students' thinking abilities will always be challenged using various ways and methods of solving problems.

4 Thinking Through Multiple Intelligences Theory [15]

Multiple intelligences are one of the tools used to stimulate individuals to think. Some believe that intelligence involves a person's capability to solve problems or create a masterpiece (composing a song, poem, or dance choreography) in the cultural context [13]. Multiple intelligences theory can encourage students to solve a problem using various intelligences [14]. Multiple intelligences and thinking intelligence have similarities for that the best way to study intelligence is to observe how individuals solve problems in their living environment by using thinking intelligence in meeting their needs [6, 15]. Eight intelligences are verbal-linguistic, logic math, visual-spatial, kinesthetic, music, interpersonal, intrapersonal, and naturalist [13]. According to this theory, every human being has all these intelligences at different levels of development and can improve them through learning activities provided in and outside the classroom. It is supported by [16] that children can show what is referred to by [13] as proclivities or inclinations in a particular intelligence at a very young age.

Verbal linguistic intelligence is a language-related aptitude that includes listening, reading, and writing. People with verbal-linguistic intelligence use language to acquire information or knowledge. They are usually writers, poets, reporters, comedians, narrators, and others related to language. They can

i. understand the meaning, sequence, spelling, and meaning of words, master the reading, organize the ideas to be conveyed by the task, and spell the words found in it;
ii. have confidence when speaking. They can engage during class discussions and are confident in participating in speech competitions or discussion forums;
iii. learn and teach by explaining. They can learn and teach a topic using a storytelling approach and give a detailed explanation;
iv. make jokes. They can joke in front of friends using funny language and apply elements of humor in reading that can improve memory;
v. can analyze language. They can distinguish and master the types of languages known in terms of speech style and usage; and
vi. have a good memory of names, places, and dates. They can remember books, names of new friends, recently visited places, and special dates such as dates of birth, death, and marriage.

Verbal-linguistic intelligence can be summarized as students' ability to use words and language in more complex meanings.

Logic-math intelligence is the intelligence associated with scientific and mathematical thinking. Students with a tendency in this intelligence demonstrate thinking abilities such as calculating, reasoning, solving problems involving numbers and number systems, structuring, and others related to science and mathematics. Those who have this intelligence are often mathematicians, accountants, scientists, and so on, related to science and mathematics. Students who have this type of intelligence will usually analyze the components of the problem before solving it systematically. Students with logic-math intelligence can:

i. recognize abstract patterns. They can understand an abstract (non-concrete) theory such as the theory of electric current flow, which involves the movement of electrons that cannot be detected through the naked eye;
ii. make inductive reasoning and conclude from general observations. If certain students are more actively studying in the morning every time an observation is made, the inference is that all students may prefer to study in the morning;
iii. make deductive reasoning. They can draw conclusions from specific to general based on observations. For example, a little boy sees a winged pigeon fly (perception of all winged birds can fly), then this little boy is confident and believes the ostrich can also fly because it is also a kind of winged bird;
iv. make connections and relationships. They can recognize and understand the relationships between one mathematical formula and another, such as the use of Pythagoras theorem in trigonometry;
v. solve complex problems. They can solve some complicated problems that were never encountered simultaneously, such as solving some new tasks in a short time; and
vi. make scientific reasoning. They can reason (think logically) something with systematic evidence, such as doing experiments in the laboratory.

In conclusion, logic-math intelligence involves thinking skills related to calculation operations involving numbers, reasoning, thinking logically, making hypotheses, and solving complex mathematical problems. Scientists, accountants, engineers, computer programmers, computer engineers, and chemists are the representative professionals.

Visual-spatial intelligence is a skill related to visuals, image formation, and the ability to transfer a world view space into a mental image. This capability is indispensable for construction, material surveying, and engineering work. Their abilities include creating, recognizing patterns, shapes, designs, colors, exploring and capturing vast oceans, and always depicting things in the form of images. Everyone has this ability, including the blind. They may be painters, architects, sailors, soldiers, pilots, architects, photographers, video makers, designers, sculptors, and navigators who can:

i. have an active imagination. They can always imagine something they like, such as three-dimensional (3D) car models or a perspective view of a building;
ii. think in the form of images. They can translate something read into the form of a picture or imagine it in 3D forms;
iii. can use space. They can optimize a small space, such as completing additional notes on a reference book;
iv. can produce images or sculptures. They can paint and build models;
v. design a graphic form. They can produce and explain the results of mechanical drawings to others;
vi. find the relationship between objects in an empty space. They can arrange simple and functional electronic components on an empty circuit board; and
vii. can make perceptions of an object from different angles or views. They can imagine an object from different angles, such as a one-point, two-point, or three-point perspective.

Visual-spatial intelligence can be inferred as the ability to think in three dimensions, can describe images that are designed, modified, or altered. Students with this intelligence can produce or identify information presented in graphic form.

Bodily-Kinesthetic intelligence involves the physical use of the hands and other parts of the body. Students with kinesthetic intelligence have good body coordination, such as dancers, sportspeople, surgeons, drama actors, and handicraft makers. They often use gestures, have a flexible body, and love to touch when they see something. Body coordination is related to the balance of the body controlled by the brain in the cortex. Students with kinesthetic tendencies often can:

i. voluntary control movement. They can do yoga and control the body's movement easily and elastically, or read while recording important content spontaneously;
ii. control the arrangement of movements. They can run an experiment regularly and carefully;
iii. connect mind and movement. They can move around the room while reciting memorized readings;
iv. increase greater awareness of body movements. They are not static while studying; instead, they do body movements at certain periods to ensure they have a correct and healthy posture while studying; and
v. imitate the movements of others. They can experiment with seeing a teacher do it.

In conclusion, kinesthetic intelligence involves the movement of muscles and the whole body. Students who have this intelligence can manipulate objects with physical skills.

Musical intelligence is related to auditory intelligence. It is also related to the ability to hear using rhythms, tones, and melodies. They can turn sounds into beats and remember melodies. They are sensitive to human voices, nature sounds, and musical instruments. They may be singers, music performance conductors, musicians, musical instrument designers, dancers, songwriters, composers, and music listeners. They can:

i. evaluate the structure of music. They can distinguish interesting music compositions from those which are not and, in addition, able to choose the right music to play while studying;
ii. be sensitive towards sounds. They can recognize the sounds in the environment while adapting to the most comfortable atmosphere while learning; and
iii. assess the quality of music. They can differentiate between high-quality music and non-music and listen to preferred music while studying.

So, we can easily find students with musical intelligence when playing musical instruments, remembering the song's melody, identifying off-key music notes, learning while listening to music, and often singing songs to themselves [13]. In addition, students who have musical intelligence can show a high sensitivity to sound and connect with emotions.

Interpersonal intelligence is the ability to understand and interact with others effectively. They work well in groups and usually play a role in the leadership aspect. Educators, coaches, scholars, actors, social workers, and politicians have this kind of intelligence. They can

i. have active communication abilities. They can give a speech before an audience and communicate effectively with lecturers and course partners;
ii. be sensitive to the feelings, motivations, and habits of others. They can take into account the needs of others by not being too selfish in completing an assignment;
iii. work in groups. They can perform a group task well without causing any difficulties in cooperating;
iv. recognize and categorize the behavior of others. They can distinguish between friendly, quiet, passive, aggressive, and archive friends. This will make it easier for one to work together in group assignments where there is no tension in the group; and
v. spend time with friends, groups, and family. They can review and complete assignments together with classmates.

Among the traits highlighted by students who have this intelligence are: having many friends, showing empathy and understanding others, often engaging in group activities, and socializing wisely either at school or in the community.

Intrapersonal intelligence is the intelligence to understand inner feelings, self-reflection, the supernatural, and self-life in this world. Individuals know themselves that involves feelings, intentions, goals, and motivations in life. Philosophers, psychologists, and screenwriters use this type of intelligence. They can:

i. focus on the mind. They can focus on self-thinking without being disturbed by external factors in making decisions and able to concentrate while studying or listening to lectures;
ii. reason. They can think logically about an event, such as planning time to complete an assignment by reviewing an exam;
iii. concentrate on something easily. They can concentrate in the classroom or do practical work in a workshop; and
iv. understand themselves. They can understand their needs and wants clearly, such as the exam results to be achieved.

Among the characteristics of students who have this intelligence are being independent, being able to voice a thoughtful opinion on a controversial topic, having high self-confidence, living life with privacy, and being alone in the pursuit of goals, hobbies, or performing tasks at school.

Naturalist intelligence is thinking by identifying and classifying the environment's components. This intelligence has developed since human evolution, where humans worked as hunters, harvesters, and farmers. Students with naturalist intelligence show interest in gardening, caring for plants at home, and building beautiful landscapes. It is easy for them to recognize and remember the names of plants and animals. Students with this intelligence enjoy activities such as camping, hiking, diving, bird watching, mountain climbing, or observing small changes in the environment and are enthusiastic about acquiring the knowledge of biology, zoology, botany, geology, meteorology, and astronomy. Among the characteristics of students who have this intelligence are learning activities such as collecting dried butterfly species or snail shell collection, identifying the names of plants and animals, and keeping pets such as cats, birds, rabbits, and others. They love gardening activities and ornamental trees. In conclusion, learning activities preferred by students who tend to have this intelligence show skills appreciating the environment well.

5 Three Engaging Ways to Teach Thinking Skills

5.1 Thinking Using Multiple Intelligences Activity

The learning process becomes more effective and interesting if teachers are sensitive to match teaching and learning. The construction and preparation of learning activities that match students' intelligence will further enhance the effectiveness of teaching and learning in a subject. Multiple Intelligences is also a learning tool for thinking, problem-solving created for use by all ages [13]. Multiple Intelligences can be conceptualized into three categories:

i. object-related intelligences: visual-spatial intelligence, logic-math intelligence, kinesthetic intelligence, and naturalist intelligence are;
ii. object-free intelligences: verbal-linguistic intelligence and musical intelligence;
iii. person-oriented intelligences: interpersonal intelligence and intrapersonal intelligence.

As for the learning-oriented verbal-linguistic intelligence, teachers

- focus on the use of students' language;
- encourage the improvement of language skills naturally;
- build language skills and language development cognitively;
- always connect language and writing; and
- integrate language components by incorporating language appropriateness components in reading, writing, and conversation.

Examples of learning activities are slogan creation, student experience writing, songwriting, school bulletin writing, and writing dialogues, letters, posters, advertisements, bookmarks, essays, and booklets. Activities in the form of speech include storytelling, class discussions, Think-Pair-Share (sharing of opinions), Buzz group, and interview sessions. For logic-math intelligence-oriented learning, teachers need to:

- place functional objects around students;
- familiarize students with the concepts of quality, time, cause, and effect;
- use abstract symbols and present in the form of objects or concrete concepts;
- demonstrate problem-solving skills;
- present and test hypotheses;
- stimulate mathematical skills such as statistics, physics, and computer programming or expose them to research methods.

As active learning activities, teachers:

- ask questions in the form of strategies;
- present problems and ask students to solve them;
- build models based on specific concepts;
- encourage students to demonstrate a concrete object;
- encourage students to present logical results such as testing hypotheses;
- encourage students to defend the facts and opinions presented; and
- create opportunities for students to conduct surveys and investigations.

Further, learning using kinesthetic intelligence is by conducting tours. Through this activity, the teacher stimulates students to think through kinesthetic intelligence by giving the role to students to:

- identify the purpose of the visit and the results of the visit;
- identify information related to, for example, place, time, clothing, items to be brought, signature permission of parents, and so on;
- form a student committee and assign duties of each member;
- create small groups in the classroom to hold discussions, make summaries or artwork from the visit;
- arrange meetings to share their experiences in other classes, management, parents, or the local community.

Thinking activities using visual-spatial intelligence learning require teachers to stimulate students to think through learning by observing and conducting surveys. For example, identifying surfaces, objects, shapes, colors, etc. in detail, seeing an object effectively through space such as seeing a road in the woods, seeing a car through traffic or seeing a kayak in a river, imagining something, thinking through pictures, describing something in-detail, using visual images to convey information, produce graphs, charts, and maps, learn with graphics, and present something visually. Teachers also encourage students to draw, color, look at something in the 3D form, look at something in a different direction or dimension than usual, produce a concrete creation in visual form to convey information, or produce a space-based media. Thinking through music is also one of the learning methods that can stimulate students to learn and remember [13]. Teachers are advised to stimulate students to think through musical intelligence by holding activities such as

- listening and responding to sounds including the human voice, sounds from the environment, music, and categorizing music according to the meaning of a particular pattern,
- learning sessions outside the classroom which allows students to hear surrounding sounds, live sound, and music; and
- learning activities involving dance, matching emotions with the tempo of the music, discussing music, analyzing and evaluating music, and discussing the differences, styles, types, and cultures of music.

Interpersonal intelligence is thinking about others. For learning activities in the classroom, teachers can

- involve students in an effective study group;
- practice values and rules;
- involve students with meetings to get the consensus of peers;
- create collaborative learning such as jigsaw activities;
- expose students to the skills of communicating with others and managing conflicts;
- familiarize students to manage conflicts between them by way of problem-solving wisely; and
- give merit to students who contribute their services to the school.

Thinking using intrapersonal intelligence requires students to know themselves. Among the learning activities suitable for this purpose to be fulfilled are activities that involve students identifying their feelings, for example, self-reflection and thinking about their future, the direction of their life, and the future they dream of. Emotional thinking skills can also be carried out by reflecting students' feelings through art activities such as visual arts, music, role-play, creative writing, etc. In addition, students can also be further exposed to thinking learning activities through naturalist intelligence. To promote students think through this type of intelligence, teachers can

- organize poetry writing activities based on students' ideas about the environment and ask students to explain the meaning of the poems to the audience;
- ask students to write or draw a climate that can change their lives through the experience;
- organize discussions by addressing current problems or issues in newspapers related to the environment; and
- hold discussion sessions related to environmental values that can be implemented with peers.

5.2 Thinking Using Case-Based Learning Activity

Case-based learning can stimulate thinking skills among students. Case-based learning activities have been introduced in medical, nursing, and business for a long time and are increasingly popular in the education field. The practice of case-based activities engages students in discussing specific scenarios that are similar or sometimes a real-life experience. This method is student-centered, with close interaction between peers as they build their knowledge and work together to analyze and evaluate the case. The role of the teacher is as a facilitator while students collaboratively analyze, investigate, evaluate, and solve problems and questions that have more than one correct answer.

Case-based learning as a learning activity not only generates students' thinking skills but also provides relevant opportunities for students to apply theory in real-life situations [17]. These real-life situations expose students to various sources of different perspectives, providing them with the opportunity to witness how decisions can have a positive or negative effect on problem-solving made based on analyzed cases. Using case-based learning, students become more involved in the learning process and more interested in participating in the classroom [18]. This is because thinking uses cases to provide learning opportunities for students to find answers and achieve results through discussion. Students also need to establish real data, think analytically, articulate problems, reflect on the experiences, and make inferences. This process enables students to acquire knowledge, develop analytical thinking, form collaborations, and enhance communication skills. Many educators use cases in their classroom instructions to teach content, associate students with raw and authentic data or provide opportunities for students to position themselves in the decision-making process [18].

5.3 Thinking Using a Thinking Map [19]

Mind maps are also considered advance organizers or graphic organizers [19]. Advance organizers are similar to thinking maps, concept maps, and mind maps**.** A learning process that focuses on high-level thinking skills with a mind map can help students become competitive globally. In addition, the use of eight mind maps can generate high-level thinking skills and attract students to continue learning independently. According to [20], teaching models fall into four:

i. *information processing family*;
ii. *social family*;
iii. *personal family*; and
iv. *behavioral systems family*.

This chapter emphasizes two models: information processing family and behavioral systems family. The information processing family emphasizes how to process data and solve problems. This model also helps students how to build knowledge. The focus of this model is on intellectual ability, where this model can help students handle information whether the information is obtained through the students' own experience or the help of learning tools. Among the teaching models in this information processing family are "inductive thinking, concept attainment, scientific inquiry" and the backbone of this is the Advance organizer model developed by [21]. An advance organizer is specially designed to enhance the ability to absorb information and organize learning information obtained through reading or lectures. Thinking maps are one of the graphic organizers introduced by [19] to encourage thinking activities, namely i-Think maps. This i-think map comes from a mind map founded by [19]. There are numerous types of i-think maps developed by Hyerle:

i. *circle map*, it will encourage students to define according to context;
ii. *bubble map*, it allows students to explain quality;
iii. *double bubble map*, it helps students to compare and contrast information;
iv. *tree map*, it allows students to classify;
v. *brace map*, it trains students to see part to the whole relationship;
vi. *flow map*, it trains students to see sequence;
vii. *multiple flow map*, it allows students to see cause and effect; and
viii. *bridge map*, this map allows students to make an analogy.

Using these eight thinking maps helps students absorb the information and translate it into a map. This study's findings [22] have proven that implementing eight thinking maps in secondary school in electronic lessons has helped increase students' ability to answer high-level questions for the subject.

6 Case Study 1: Educate Fun Learning Approach: The Development of Interactive Application Cerdik BM Series 1 Towards Empowering Remedial Class Students in Malay Language Subject

This study applied 4D development methods involving (Define, Design, Develop and Disseminate) and interactive pedagogical tools built using adobe flash CS6 software. Data collection techniques involved questionnaires, application evaluation rubrics, and semi-structured interviews. The evaluation samples of Cerdik BM Series 1 were distributed to eight UUM academicians, a senior FasiLINUS (Malay Language) & Remedial Class, two LINUS teachers, and two groups of LINUS primary students, each from urban and rural areas. Cerdik BM was built for children who have not passed the reading skills screening. The uniqueness of this pedagogical tool construction is that it was built based on multiple intelligences theory. Eight types of intelligence were placed in this interactive application to offer a learning environment based on students' multiple intelligences.

The purposive sampling design was selected results would directly address the aims and objectives of the study. A total of eight academic staff was appointed as evaluators consisting of lecturers from public universities. They were academicians with expertise in the field of the Malay Language, evaluation and measurement in education, curriculum and teaching, education management, moral and values education, and mathematics. The evaluators have more than ten years of teaching and research experience. The evaluation process took place simultaneously for about five hours. The evaluators tried the Cerdik BM Series 1 interactive application during the evaluation process. Meanwhile, the sample of 30 students consisted of primary level 1 students, aged 7–9 years. In the meantime, six special education teachers with more than seven years of teaching experience were also involved in this study.

The results of the expert evaluation found that the agreement value of all experts for information design, interaction design, presentation design, and Cerdik BM Series 1 curriculum was high. The reliability of Cerdik BM was also excellent, which was between 0.87 and 0.97. Meanwhile, based on the rubric assessment scored by students, showed more than 60% (n = 18) of the total students (n = 30) gave an excellent score, 37% (n = 11) gave a good score. The remaining 3% (n = 1) gave an average score to interactive application Cerdik BM Series1. Quantitative and qualitative data showed that Cerdik BM Series 1 met the evaluation criteria. Interview data found that teachers and students liked this application because it was an interactive learning material that combines five multimedia elements and eight multiple intelligences. The evaluators agreed that Cerdik BM Series 1 is one of the many pedagogical tools that can help LINUS students effectively use their writing and reading skills.

Overall, the study findings showed almost perfect agreement between academicians on information design, interaction design, presentation design, and Cerdik BM Series 1 curriculum. For information design, there was high agreement among experts on the application's content, language use, thinking skills aspects, students' experience and knowledge, and the interactive entertainment concept. All these elements were important to nurture perfect learning motivation in students. This was also agreed by [23], who argued that teaching tools used in classroom instructions would enhance students' learning and increase self-learning awareness and function to provide knowledge to them.

While the second criterion, which is the interaction design, there was an agreement between all evaluators on the following items: not straying from objectives, contained instructions, clear navigation representation, easy to reach the desired part, independent control of the presentation sequence, could give the correct response, easy to handle, representations like icon buttons were easily identifiable in function, and the navigation system was consistent. This is in line with [24], who stated good interaction design makes interactive learning content able to achieve learning outcomes well. The application was said to have a positive impact on learning. This illustrated that Cerdik BM Series 1 has elements that make it easy for users to use it as a pedagogical tool in the classroom.

Furthermore, for the design of the presentation, there was a high level of consensus between the evaluators in the aspects such as graphics and texts. This finding concurs with the statement [23], which says that multimedia tools can easily attract students' attention compared to conservative methods. Students are motivated to get more information when attracted to multimedia tools especially interactive learning applications [23, 25, 26]. Students' involvement in learning will increase [23].

Therefore, multimedia technology can create several initiatives, including providing retention for students to continue learning based on the learning environment of students' eight multiple intelligences. Furthermore, according to [27], multimedia such as animation (e.g., object movement will stimulate students' kinesthetic intelligence) can improve student performance, increase the fun in learning and maintain focus in the long run. This statement is also agreed by [28], who stated that multimedia helps intensify students' sensory stimulation through sounds, images, and texts; animations make instruction effective; the use of 3D graphics can clearly increase interest and attention and student learning competence.

Meanwhile, for the last criterion, the Cerdik BM Series 1 curriculum also has a high value of agreement between expert evaluators. Among the items evaluated for these criteria were: learning outcomes (can be made, seen, measured, and assessed), learning input according to the syllabus, activities in line with learning outcomes, and assessments that measure lesson content and learning outcomes. The constructive alignment model integrated into the Cerdik BM Series 1 curriculum encouraged student-centered learning. Student-centered teaching can encourage students to use self-assessment, which can avoid grade-focused learning and assessments done by teachers only [23].

All evaluator experts confirmed, "Cerdik BM contained various theoretical elements of intelligence." It is consistent with the results of the assessment rubric application by teachers. Students expressed "Cerdik BM Series 1 motivated them" and engaged them in learning [29]. They also agreed that multimedia with the integration of various intelligences could stimulate, encourage and help students gain knowledge self-reliantly. This finding is similar to what [30] found in a multidisciplinary intelligence project in Irish that students feel valued when teachers apply multiple intelligences in the classroom. This is because [30], again, celebrating all multiple intelligences makes students feel significant, and they are allowed to show their talents and abilities.

Technology integration should have user-friendly elements to make it easier for students to use an application. In fact, these criteria were also considered when researchers built the "interactive applications for learning purposes." Based on the assessment rubric by teachers and students, they confirmed "Cerdik BM Series 1 was very easy to use," each instruction was given in a clear, concise, and easy-to-follow voice. It was found that an "interactive application technology" can create a stimulating learning environment because it is easy to use and attract students. It is in line with [31] the belief that good lessons are not only related to the level of knowledge of teachers but also related to the design, steps, and links used during the teaching process in the classroom. Therefore, multimedia can enrich the teaching content in the classroom and create a user-friendly element when all multimedia elements are presented to suit various students' backgrounds.

In a study conducted by [32], multimedia technology could help students learn thinking skills of higher-order. This statement aligns with the findings of interviews with experts who stated that Cerdik BM Series 1 could promote learning and thinking in LINUS students. Interactive assessment entertained students when student achievement scores could be viewed automatically on the Cerdik BM Series 1 application interface. The process of learning activities that allowed students to "try and try" was used by researchers to stimulate students' motivation and thinking skills. Cerdik BM Series 1 was intended to boost LINUS students' learning, helping them achieve a high sense of self-confidence. Digital learning is very fun and popular among primary school students. Students are more focused on learning and even more active and confident when teachers use computers as teaching aids. This aligns with [23] findings that interactive multimedia can promote critical thinking skills and problem-solving skills during learning among students. In fact, through attractive digital images, students will be more attracted and make them more focused in the classroom. In addition, the use of computer-assisted materials will make it easier for teachers to design more enjoyable teaching sessions. Cerdik BM Series 1 has succeeded in creating an atmosphere of entertaining learners through games-based activities and assessments according to multiple intelligences theory.

7 Case Study 2: Science Smart i-Think: Construction of Interactive Pedagogical Tools to Improve HOTS in Primary Level Learning and Teaching Science

This study [33] implemented a quasi-experimental study design using pre-test and post-test to treatment group and control group. In addition, the ADDIE model was used in the application development process where mind maps served as pedagogical tools in the learning of science subjects in primary schools. The Science Smart i-Think interactive application was built with eight i-THINK-based learning activity structures: "circle map, bubble map, double bubble map, tree map, brace map, flow map, multiple flow map, and bridge map." The learning activities required primary school students to understand the scientific facts for the earth, the moon, and the sun and translate their understanding into a thinking map. Study data collection techniques involved pre- and post-tests, expert evaluation questionnaires, activity implementation checklists, student application evaluation questionnaires, and interview protocols.

The study sample was identified according to the class set by the school and was divided into the control group and the treatment group. This method of selection is suggested by [34]. Both the control and treatment groups were given pre-test and post-test in the first week, pre-tests were given to the control and treatment groups. The pre-test consisted of 30 multiple choice questions of 30 marks and two questions in the form of a restricted essay of 10 marks for the topic of the moon, earth, and sun. After the lesson, a post-test was given to both groups. The period between pre-test and post-test was four weeks.

According to [35], the effect can be interpreted as significant when there is a reasonable time interval between pre-test and post-test assessment, e.g., a month, six months, or a year. The treatment group underwent teaching and learning activities using the Science Smart i-Think interactive application in the fifth week. Learning activities were carried out individually with the help of computers using multimedia elements through learning activities based on thinking maps. The program was conducted during science teaching and learning hours. Learning using the Science Smart i-Think interactive application provided students with self-directed learning skills using multimedia applications to improve HOTS through eight mind maps. The control group followed the conventional learning where students were taught the same topic using the i-Think map Science Module without the computer application.

The rationales for having six hours of learning include:

- in line with the period provided in the Science Curriculum and Assessment Standard Document year five (2014) [36]; and
- to avoid bias between the control and treatment groups, a post-test was given after one week of treatment to both the control and the treatment groups.

The study found that the post-test mean scores of the treatment group differed compared to the control group. Meanwhile score from the pre-test was higher than the post-test. Academics and primary school science teachers gave a good assessment for the features found in this application (for example, it has interesting animations and graphics, user-friendly) which made the learning and teaching process interesting and effective. Student interviews showed that learning using Science Smart i-Think interactive application had helped students better understand the earth, moon, and sun, which indirectly attracted students to science and technology. The teacher's comments and observations also showed that the implementation of learning through applications has a positive effect because it has motivated students towards mastery learning.

From the aspect of science teacher evaluation of the Science Smart i-Think interactive application, this application has stimulated students' HOTS by integrating eight mind maps. Apart from that, this application has also attracted students to learn science and cultivate students' self-learning. This application has also motivated students through mastery learning. Meanwhile, from the aspect of evaluation, academic experts found that this application was also able to stimulate students' HOTS through fun activities combined with eight mind maps. According to academics, this application also contained graphics and animations that attracted students' attention and made students comfortably understand the concept of science. In addition, this application was user-friendly and interactive; therefore, it could attract students to science and technology.

The analysis of the science achievement profile found that most students were at a high level in the post-test. This showed that students who learned using the Science Smart i-Think interactive application were better because they scored higher marks than learning using the i-Think science module. The teaching observation checklist analysis results found that the learning and facilitation were student-centered. Communication took place between students and students and teachers and students. It was a feature of 21st-century learning that aimed to be applied in students.

The interviews with science teachers found that the implementation strategy of science learning activities that took into account the eight mind maps used in this application effectively helped students comprehend and remember the lesson content. This strategy also effectively stimulated students' HOTS because all the activities in this application started from the easy level to the higher level. The interviews with students found that this application has helped students understand the earth, moon, and sun quickly and easily. Apart from that, this application has also helped students apply eight i-Think maps in other subjects. In conclusion, this interactive application has a significant effect on classroom instructions. It enhances HOTS, fosters self-learning, and improves 21st-century skills and competencies.

8 Conclusion

There are several ways to stimulate thinking skills among students. Among those discussed in this chapter are multiple intelligences learning activities, case-based learning, and thinking maps. Learning through Multiple Intelligences offers learning that considers student diversity and stimulates students to think through eight different ways. For example, it is concluded that for verbal-linguistic intelligence, students convey their thoughts easily through words; students with logical-mathematical intelligence prefer to use reasoning; the bodily-kinesthetic intelligence students are more sensitive to the sensations registered through parts of their body; students with musical intelligence are apt in rhythms and melodies; the interpersonal intelligence students prefer to connect with other people while the intrapersonal intelligence students based their thinking on their own needs, feelings, and goals Naturalist intelligence students are more connected with nature and natural things. Learning using cases has urged students to make case-based investigations, examine the facts contained in the case and apply the body of knowledge learned to think and solve problems presented through case-based learning. Furthermore, thinking maps are learning tools to cultivate and attune thinking skills among students. As mentioned in [19], mind maps are,

i. reflective, so they promote thinking through visual patterns;
ii. consistent with cognitive skills;
iii. integrative, so they involve the process of thinking and development of content knowledge;
iv. flexible, so they are easy to use; and
v. developable

The writing of this book proves that thinking skills are not static but can be stimulated, nurtured, and enhanced through proper learning activities and thinking tools. Therefore, it is the role of teachers to provide meaningful learning activities to students to ensure the formation of human capital that can use thinking skills and problem-solving strategies in the context of real life.

Core Messages

- Thinking skills in education can be cultivated through multiple intelligences, case-based learning, and thinking maps.
- Teachers need to provide meaningful learning activities and experiences to enhance students' thinking.
- Problem-solving activity is one of the ways to make students think critically.
- Thinking skills involve imagination and the ability to deliver new and unique ideas.

References

1. UNICEF (2018) Annual report 2018: for every child, every right. Syrian Arab Republic, United Nations Children's Fund (UNICEF)
2. Rotherham JA, Willingham D (2010) 21st century skills: the challenges ahead. Educ Leadersh 67(10):16–21
3. Sternberg RJ (2018) Speculations on the role of successful intelligences in solving contemporary world problem. J Intell 6(4):1–10
4. Sternberg RJ, Kaufman JC, Grigorenko EL (2008) Applied intelligence. Cambridge University Press, Cambridge
5. Sternberg RJ (1996) Successful intelligence: how practical and creative intelligence determine success in life. Simon & Schuster, New York
6. Sternberg RJ (2004) Psychology. Thomsom Learning Inc., United States
7. Marlina A, Shaharom N (2006) Tahap Penguasaan Kemahiran Berfikir Kritis Di Kalangan Pelajar pendidikan FIzik Merentas Jantina. Buletin Persatuan Pendidikan Sains dan Matematik Johor Jilid 15 Bil. 1 Tahun
8. Anderson LW, Krathwohl DR (2001) A taxonomy for learning, teaching and assessing: a revision of bloom's taxonomy of educational objectives, Complete. Longman, New York
9. Robinson JP (2000) The workplace. Alabana Cooperative Extension System. Unpublished
10. Rajendran NS (2013) Teaching & acquiring higher-order thinking skills: theory & practice. Universiti Pendidikan Sultan Idris Press, Perak
11. Nevid JS (2003) Psychology-concepts and application. M.A. Houghton, Mifflin Co., Boston
12. Sternberg RJ, Lautrey J, Lubart TI (2003) Models of intelligence: international perspectives. American Psyhological Association, United States
13. Gardner H (1999) Intelligence reframed: multiple intelligences for 21st century. Basic Books, United States of America
14. Azid N, Hashim R, Tee T-K, Yee M-H (2019) The effect of interactive multiple intelligences activities flip module: its effects on students' multiple intelligences. Int J Innov Technol Explor Eng 8(11):342–348
15. Gardner H (1983) Frames of mind: the theory of multiple intelligences. Heinemann, London
16. Armstrong T (2009) Multiple intelligences in the classroom, 3rd edn. ASCD Publications, United States of America
17. Mishra R, Kartikeya M (2019) Accelerating innovation and problem solving in engineering by design thinking. Int J Adv Sci Technol 28(18):691–698

18. Azid N, Hashim R, Tee T-K, Yee M-H (2020) Malaysia and China students' feedback on the implementation of critical thinking pedagogy: a case study. Int J Adv Sci Technol 29(3): 227–237
19. Hyerle D (2009) Visual tools for transforming information into knowledge. Corwin Press, Thousand Oaks
20. Joyce BR, Weil M, Calhoun E (2015) Models of teaching. Pearson Education Inc., United States of America
21. Ausubel DP (1968) Educational psychology: a cognitive view. Holt, Rinehart and Winston, New York
22. Hashim R, Azid N, Amzah F (2020) Infusing engineering interest: the effect of "electronic topic-THINK module" toward secondary school students' achievement. Int J Adv Sci Technol 29(6):5063–5077
23. Li W-Y (2016) Transforming conventional teaching classroom to learner-centred teaching classroom using multimedia-mediated learning module. Int J Inf Educ Technol 6(2):105–112
24. Khaleel FL, Ashaari NS, Siti T, Tengku M, Ismail A (2016) Gamification elements for learning applications. Int J Adv Sci Eng Inf Technol 6(6):868–874
25. Kennedy MJ, Deshler DD, Lloyd JW (2015) Effects of multimedia vocabulary instruction on adolescents with learning disabilities. J Learn Disabil 48(1):22–38
26. Gabrielli S, Dianti M, Maimone R, Betta M, Filippi L, Ghezzi M, Forti S (2017) Design of a mobile app for nutrition education (TreC-LifeStyle) and formative evaluation with families of overweight children. JMIR Mhealth Uhealth 5(4):e48
27. Chiou C-C, Tien L-C, Lee L-T (2015) Effects on learning of multimedia animation combined with multidimensional concept maps. Comput Educ 80:211–223
28. Chun-hui Z, Fu L (2015) The use of multimedia in higher special education. US-China Educ Rev 5(8):568–571
29. Andresen BB, van den Brink K (2013) Multimedia in education: curriculum. UNESCO Institute for Information Technologies in Education, Moscow
30. Hanafin J (2014) Multiple intelligences theory, action research, and teacher professional development: the Irish MI project. Austr J Teacher Educ 39(4):126–141. https://doi.org/10.14221/ajte.2014v39n4.8
31. Wang L (2018) A study of students' English cooperative learning strategy in the multimedia environment. Theor Pract Lang Stud 8(6):601–605
32. Sabu N (2018) The effect of using interactive multimedia courseware with pedagogical agent in learning nutrition towards higher order thinking skills. Int J Acad Res Bus Soc Sci 8 (2):623–635
33. Azid N, Shaik-Abdullah S, Mohamed ZH (2018) The making of science smart i-THINK: science expert teachers' evaluation. Int J Eng Technol 7(3.7):287
34. Lay Y-F, Khoo C-H (2013) Pengenalan kepada pendekatan kuantitatif dalam penyelidikan pendidikan. Sabah, Universiti Malaysia Sabah, Kota Kinabalu
35. Campbell DT, Stanley JC (1966) Experimental and quasi-experimental design for research. Houghton Mifflin Company, Boston
36. Ministry of Education Malaysia (2014) Science curriculum and assessment standard document: science—year five. Curriculum Development Division, Putrajaya

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21 Concept Mapping: A Tool for Adolescent Science Teachers to Improve Learning Activity Design

Gerald P. Ardito

The empirical basis of objective science has thus nothing 'absolute' about it. Science does not rest upon solid bedrock. The bold structure of its theories rises, as it were, above a swamp. It is like a building erected on piles. The piles are driven down from above into the swamp, but not down to any natural or 'given' base; and if we stop driving the piles deeper, it is not because we have reached firm ground. We simply stop when we are satisfied that the piles are firm enough to carry the structure, at least for the time being.

Karl R. Popper

Summary

Recent reforms to curriculum standards for the teaching and learning of science have increased the expectations of science teachers to address more depth and complexity required at all grade levels. This case study investigated concept mapping to support the development of this increased complexity and depth. Twelve adolescent life science in-service teacher candidates in an urban alternative certification program were asked to participate in two rounds of concept mapping along with learning activity development. Analysis of the two rounds of concept maps and learning activities demonstrated increased complexity in these teacher candidates' understanding of science concepts along with an increase in their ability to design learning activities addressing higher-order thinking skills in Bloom's taxonomy. Future research and implications for practice are discussed.

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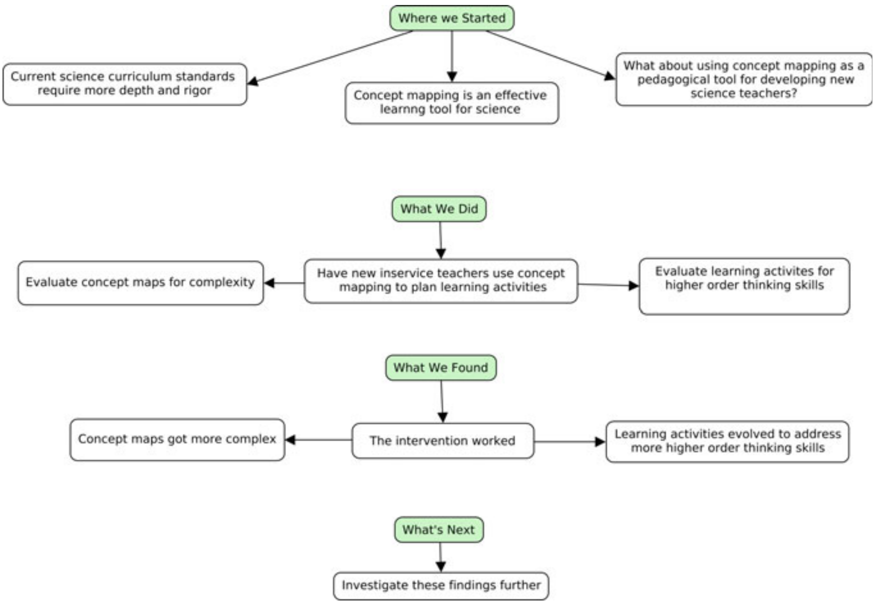
N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_21

Graphical Abstract/Art Performance



Concept mapping: a tool for adolescent science teachers to improve learning activity design.

Keywords

Adolescence · Concept mapping · Life science · Science education · Teacher education

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

Teaching science to adolescent students requires being able to walk a tightrope between layers of abstractions. In order to introduce novice students and/or younger adolescent students to core science concepts, the level of abstraction must be low enough to allow entry to the topic by all students but also fluid enough to provide opportunities for deeper and more precise levels of understanding.

2 Increasing Expectations for Complexity, Depth, and Rigor in Science Teaching and Learning

In recent years in the United States, calls for standards reform, such as those that resulted in the Next Generation Science Standards (NGSS), have left teachers with more and more abstract science content to deal with while simultaneously requiring higher levels of abstraction, independent of prior knowledge or experience on the part of students [1]. Figure 1 depicts a sample of the NGSS standards for middle school life science.

This sample section demonstrates that the levels of complexity and abstraction in science education have been increased through the inclusion of science and engineering practices (key practices that describe how scientists investigate phenomena and how engineers design solutions to problems) and crosscutting concepts (key ideas that cross different science content areas, such as to cause and effect) alongside the disciplinary core ideas. It is worth noting that these disciplinary core ideas constituted a vast majority of the content in most previous science curriculum standards documents.

This situation has left some teachers and teacher educators, particularly those working in urban areas with highly diverse student populations, with a serious dilemma. Too often, rigor in the adolescent science classroom has been associated with larger amounts of concepts and increasing levels of abstraction. New tools are required in science education and science teacher preparation to support new and in-service teachers to work their way through this dilemma/opportunity and to address the enhanced expectations in the teaching and learning of science.

Students who demonstrate understanding can:

MS-LS2-5. **Evaluate competing design solutions for maintaining biodiversity and ecosystem services.*** [Clarification Statement: Examples of ecosystem services could include water purification, nutrient recycling, and prevention of soil erosion. Examples of design solution constraints could include scientific, economic, and social considerations.]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Engaging in Argument from Evidence
Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world(s).
- Evaluate competing design solutions based on jointly developed and agreed-upon design criteria.

Disciplinary Core Ideas

LS2.C: Ecosystem Dynamics, Functioning, and Resilience
- Biodiversity describes the variety of species found in Earth's terrestrial and oceanic ecosystems. The completeness or integrity of an ecosystem's biodiversity is often used as a measure of its health.

LS4.D: Biodiversity and Humans
- Changes in biodiversity can influence humans' resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on—for example, water purification and recycling. *(secondary)*

ETS1.B: Developing Possible Solutions
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. *(secondary)*

Crosscutting Concepts

Stability and Change
- Small changes in one part of a system might cause large changes in another part.

Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology on Society and the Natural World
- The use of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time.

Connections to Nature of Science

Science Addresses Questions About the Natural and Material World
- Scientific knowledge can describe the consequences of actions but does not necessarily prescribe the decisions that society takes.

Connections to other DCIs in this grade-band:
MS.ESS3.C

Articulation of DCIs across grade-bands:
HS.LS2.A ; HS.LS2.C ; HS.LS4.D ; HS.ESS3.A ; HS.ESS3.C ; HS.ESS3.D

Common Core State Standards Connections:
ELA/Literacy -
RST.6-8.8 Distinguish among facts, reasoned judgment based on research findings, and speculation in a text. (MS-LS2-5)
RI.8.8 Trace and evaluate the argument and specific claims in a text, assessing whether the reasoning is sound and the evidence is relevant and sufficient to support the claims. (MS-LS2-5)
Mathematics -
MP.4 Model with mathematics. *(MS-LS2-5)*
6.RP.A.3 Use ratio and rate reasoning to solve real-world and mathematical problems. *(MS-LS2-5)*

Fig. 1 Sample section from the NGSS middle school life science curriculum

3 Concept Mapping and the Teaching and Learning of Science

Concept mapping has proven to be a useful tool in developing student understanding of complex science concepts and supporting the student in navigating increasing levels of precision and abstraction. Novak defined concept maps as:

> graphical tools for organizing and representing knowledge. They include concepts indicated by a connecting line linking two concepts. [2, p. 1].

He established concept mapping as a productive analog to the ways that young children learned science [3].

This work has been extended to include other fields of science, including biology [4]. These benefits include deeper learning of science as well as more effective retention of science concepts [5]. Additionally, students' critical thinking skills have been enhanced through concept mapping [6]. Others have suggested that the documented benefits to increased learning are reflected of concept mapping serving as cognitive support for rehearsal of new and prior knowledge:

> The process of construction should be a continuous questioning between the student and the educator, a higher-order thinking skill [7]

Some research has investigated the potential benefits of concept mapping in the development of nurses and accountants [8, 9]. However, this tool has been only infrequently used in the development of teachers [10, 11]. Hence, this case study was designed to investigate the following research questions:

1. How can concept mapping be used in training new adolescent science teachers in an urban setting?
2. How does concept mapping improve the development of curricular materials by new teachers and teacher candidates?

4 Methods

We followed a case study methodology [12]. Twelve in-service life science teacher candidates in an alternative teaching certification program in an urban setting participated in a science methods course. The focus of this graduate class was to have these in-service teaching candidates develop proficiency in the pedagogical methods and strategies effective in teaching science to adolescent students. The unit described in this chapter occurred near the beginning of the semester and was designed to provide a framework and context for all the work that followed.

During this initial unit, these life science in-service teachers were asked to do the following:

i. *identify* a topic of study within their specific grade level and content area;
ii. *develop* a concept map for this topic of study and learning activity for their students appropriate to this topic of study (round 1);
iii. *read* some research on concept mapping in science education; and
iv. *revise* their concept maps and learning activities (round 2)

At the end of the two rounds of concept mapping and curriculum development, these artifacts were analyzed for complexity, depth, and rigor. We will discuss the findings of this analysis in the next section.

5 Findings

This case study investigated the use of concept mapping by in-service teacher candidates and its effect on the types of learning activities developed by them. It was designed as a pilot study into the efficacy of concept mapping as a training tool for novice educators, especially these alternative certification in-service life science teacher candidates. This section discusses the findings of this investigation.

5.1 Concept Map Organization and Complexity

These in-service teacher candidates identified a topic to teach within their adolescent biology certification area and developed two rounds of both concept mapping and curricular development. Figure 2 depicts both rounds of concept mapping by one teacher candidate in this study, whom we will call Janet (pseudonyms used throughout). Janet's concept maps depict the evolution of her conception of a unit called "renewable energy."

Concept maps are defined as having concepts/key ideas (e.g., deforestation) connected by linking phrases (e.g., is part of the question) [13]. The complexity of concept maps can be determined by examining their:

- *organization*, the structure by which the concepts in the map are depicted; and
- *complexity*, the number of concepts and linking phrases depicted in the map [13, 14].

Through this side-by-side comparison of this renewable energy concept map, we can see that Janet's map for this unit has increased in both *organization* and *complexity*.

We performed a similar analysis on the full set of 12 life science concepts maps to observe and identify trends between the two rounds of concept mapping these in-service teacher candidates performed.

This analysis showed that 2 of the 12 (17%) concept maps reflected an increase in organization between rounds 1 and 2 and that another 6 (50%) concept maps reflected an increase in complexity between rounds 1 and 2. Overall, 8 of the 12 concept maps (75%) reflected an increase in either organization or complexity between rounds 1 and 2.

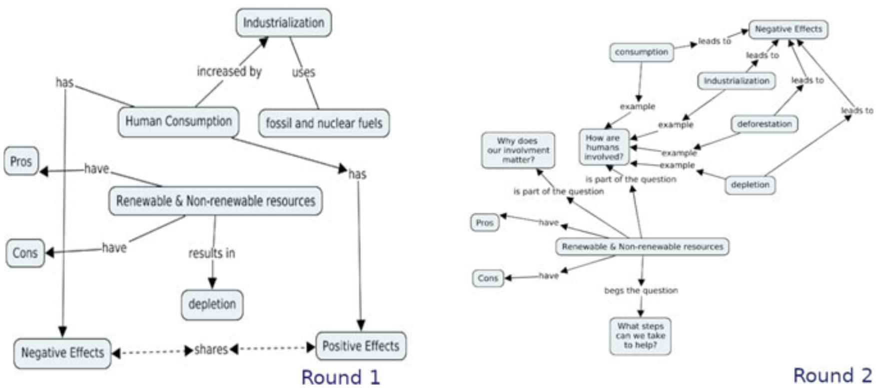


Fig. 2 Rounds 1 and 2 of one concept map for renewable energy

Table 1 Characteristics of linking phrases used in both rounds of concept mapping

	Round 1	Round 2	Difference	%difference (%)
#words	295	351	56	19.0
#unique words	61	97	36	59.0
%unique words (%)	20.7	27.6		

5.2 Textual Analysis of Linking Phrases

The changes between the two rounds of concept mapping were also examined through textual analysis using Voyant-Tools software [15]. For this analysis, the linking phrases for each round of concept mapping formed a corpus. This corpi were then analyzed in Voyant-Tools to determine two characteristics of this writing: word counts and unique work usage. Table 1 depicts this analysis.

This analysis demonstrates a 19% increase in both word counts (295–351) and a 59% increase in the usage of unique words (61–97). Additionally, the percentage of unique words within all linking phrases increased by more than 7%. These measures strongly suggest an increased complexity across the two rounds of concept mapping.

Next, Voyant Tools was used to visualize collocations of words within the linking phrases used in each round of concept mapping. Collocations depict the linkages between groups of words in a text. Figure 3 depicts this analysis and presents the collocations from rounds 1 and 2 side by side.

In round 1, we can see that "leads" connects to (meaning, has been used in connection with) the terms "lead," "invent," "results," "example," "change," and "causes." Additionally, the thickness of the connecting line indicates the number of connections between those terms in the various documents involved in this corpus. A thicker line indicates more connections.

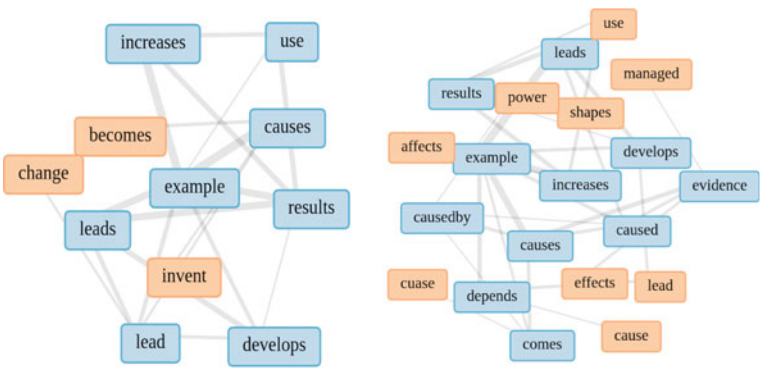


Fig. 3 Visualizations of word collocations from concept map linking phrases

We can see that the network of terms created from the sets of linking phrases from the second round of concept mapping is both larger and more interconnected. The variety of terms used in round 2 is much larger than in round 1, which is also indicated by the corps characteristics depicted in Table 1. Additionally, the increased number of connections in round 2 reflects the increased complexity in the second round of concept mapping and shows the trend observed in Fig. 2.

5.3 Learning Activity Development and Bloom's Taxonomy

As a part of this concept mapping experience, these 12 life science in-service teacher candidates also prepared two rounds of a learning activity that would be connected to the concept maps they developed. For each round of the concept mapping, these participants first created and then revised a correlated learning activity. An example of such a set of learning activities is depicted in Fig. 4.

Revised Renewable and Nonrenewable ENERGY activity

Round 1:

Hook Activity: Give students a "Scientist ___________________ Data" paper. On this sheet is a list of hints and a category of "Evidence" that breaks up into two columns

First column: we identified that energy was present because….

Second column: Energy Source (wind? electricity? sun? other?)

The students are given 3 hints:

1. "Heat" comes from energy
2. "Movement" comes from energy
3. Energy has the ability to make things change

Their goal is to investigate in the classroom the answer to the question "What is energy?" With the given hints they search for evidence that will help them find the answer.

After they have collected their evidence on energy around them, each person in their group makes up in their own words a definition for energy. They write their definition on the second handout in the spaces below which will have two columns as well. First column says: Scientist Name, second column says: Definition of Energy. Afterwards, as a group they collaboratively choose one of those definitions to represent their group answer to "What is Energy?"

Round 2:

This is what I thought can improve and expand the activity and push my students' thinking:

Post Activity/Class Collaboration:

After this activity, as a class, my students and I can develop a concept map based on their collective knowledge of factors in the topic of ENERGY starting with the most inclusive, most general concepts at the top of the map and as you go down it becomes more specific, and general concepts become specified in sub-units.

Independent Work: Expand student thinking and allow them to pick one problem they can identify in the concept map we created together, and let them examine how methods of fixing that problem can have rippling and unintended consequences throughout the map.

Fig. 4 The evolution of learning activity from the two rounds of concept mapping

This example clearly shows the participant's changes in the learning activity in response to the further development of their concept map. This teacher/teacher candidate added some independent work that he felt would help the students expand their thinking on *renewable energy*.

To identify trends in the evolution of this work, the learning activities were analyzed using Bloom's revised taxonomy. Formulation allows researchers and educators to classify cognitive work performed by students [16]. In this revised version of Bloom's taxonomy, there are six categories of cognitive work, such as *remembering* or *evaluating*. Each component of Bloom's revised taxonomy was converted into a code for this analysis. This codebook is depicted in Table 2.

Each learning activity was evaluated for the presence or absence of each of Bloom's revised taxonomy components. Once the coding was complete, the learning activities were investigated to reveal any possible trends that arose. The results of this coding are presented in Table 3.

One essential trend arises from this analysis: at the beginning of the concept mapping/curricular design process, most of the learning activities addressed Bloom's lower-order thinking skills, namely: *understand*, *remember*, and *apply* (80% vs. 20%). Then, after the second iteration of the concept mapping/curricular design process, a majority of the learning activities indicated the presence of

Table 2 Codebook developed from Bloom's revised taxonomy

Blooms components	Definition*	Thinking skill type
Remember	Retrieving relevant information from long term memory	Lower order
Understand	Determining the meaning of instructional messages	Lower order
Apply	Carrying out or using a procedure in a given situation	Lower order
Analyze	Breaking material into its constituent parts and detecting how these parts relate to one another	Higher order
Evaluate	Making judgments based on criteria and standards	Higher order
Create	Putting elements together to form a novel, coherent whole	Higher order

*from Krathwohl [16], p. 215

Table 3 Summary of the results coding two rounds of learning activity development

	Round 1			Round 2		
Blooms skill	#	%	LO/HO (%)	#	%	LO/HO (%)
Understand	11	55	80	3	21	21
Remember	3	50		0	0	
Apply	2	10		0	0	
Evaluate	2	10	20	5	36	79
Create	2	10		1	7	
Analyze	0	0		5	36	
	20			14		

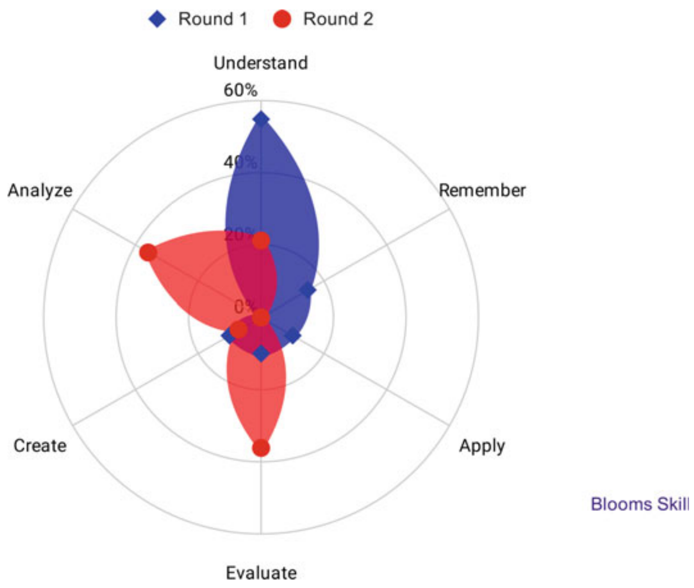


Fig. 5 Visualization of learning activities coded for Bloom's skills

Bloom's higher-order thinking skills, namely: *evaluate*, *create*, and *analyze* (79% vs. 21%). These results are visualized in the chart depicted in Fig. 5.

While there are some indications of *evaluating* and *creating*, the section of the diagram corresponding to round 1 depicts a concentration of *understanding* and *remembering*, two of the lower order thinking skills. In contrast, the portion of the diagram depicting round 2 is bimodal, with concentrations in both *evaluation* and *analysis*. If we think of this visualization as a clock, round 1 correlates with noon through 6 pm, and round 2 correlates with 6 pm to midnight.

5.4 Networks for Codes

We also analyzed the coding of the two rounds of learning activities developed by these in-service teacher candidates using *Epistemic Network Analysis* (ENA). ENA is a quantitative analysis method that allows the research to investigate relationships between codes in rich, qualitative ethnographic data [17, 18]. This tool allowed us to investigate these coding differences and trends differently and more granularly. The results of these analyses are depicted in three visualizations. Figure 6 depicts the coding networks revealed via the ENA Webkit in the first round of learning activities [19].

This visualization depicts strong connections between the codes LO-R (*remember),* and LO-A (*apply*), and LO-U (*understand*). The thickness of the line between these sets of codes represents the strength of the connection. Additionally,

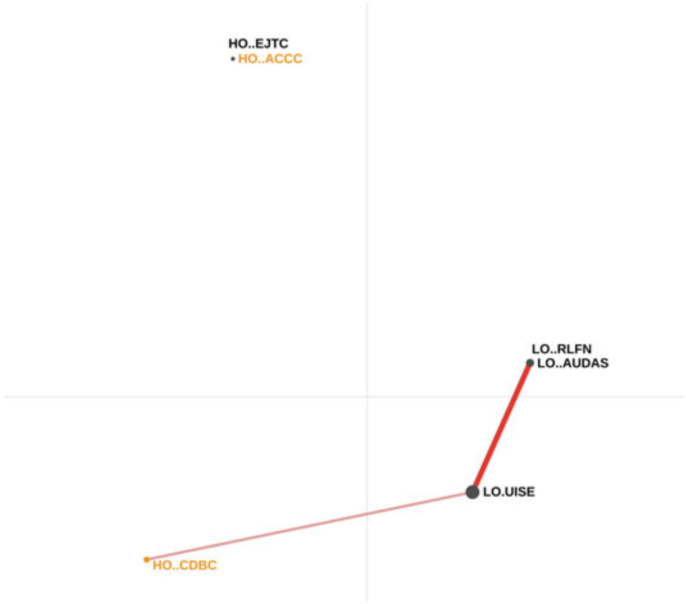


Fig. 6 Network of codes revealed in the first round of learning activities

we can see another connection between LO-R (*understand*) and HO-C (*create*). This connection is depicted with a thin line, indicating a much weaker connection than the LO codes.

The second ENA visualization, Fig. 7, depicts the coding networks revealed via the ENA Webkit in the second round of learning activities.

This visualization also depicts strong connections, but in this case, these are, for the most part, between higher-order (HO codes). We can see that the codes HO-E (*evaluate*)/HO-A (*analyze*) are connected with both HO-C (*create*) and LO-U (*understand*).

Finally, the third ENA visualization, Fig. 8, depicts the coding networks revealed via the ENA Webkit across both rounds of learning activities.

Reading this last visualization of networks of Bloom's taxonomy codes discovered in both rounds of learning activities from right to left depicts the evolution of a network of mostly LO codes (in red) to a network of mostly HO codes (in blue), hence depicting the evolution of the learning activities across the two rounds. Given the small n in this case study, it is impossible to determine these differences' statistical significance.

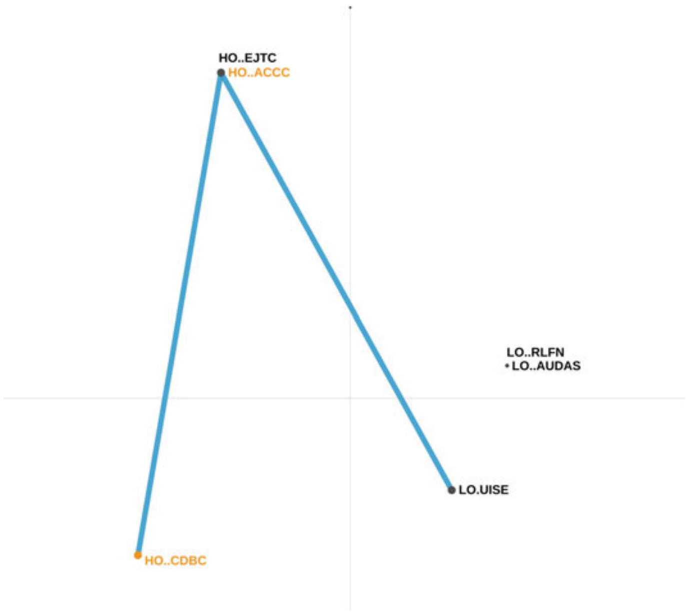


Fig. 7 Network of codes revealed in the second round of learning activities

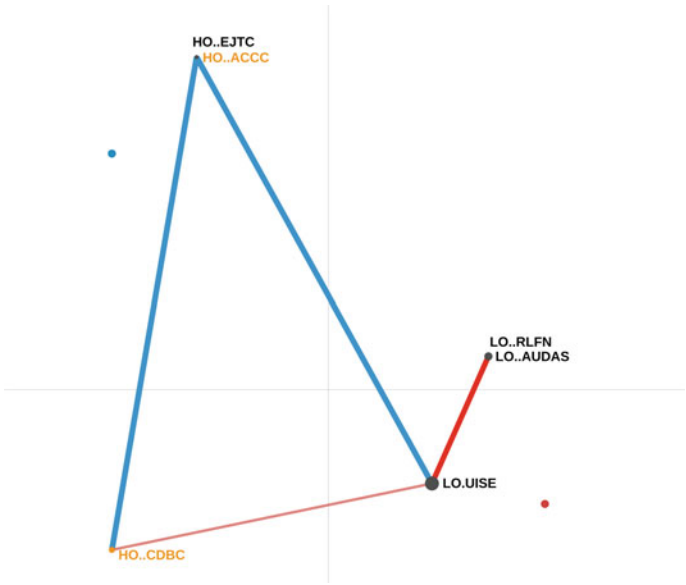


Fig. 8 Network of codes revealed in both rounds of learning activities

6 Discussion

This case study sought to explore concept mapping as a tool to develop new adolescent life science pre-service teacher candidates in the important teacher education area of planning. The participants identified a topic within their life science grade-level standards as part of this work. They did two rounds of concept mapping and learning activity design focusing on that topic. The previous section discussed the findings of this work. This section will discuss these findings to determine trends and patterns.

6.1 Concept Map Evolution

The concept maps developed by these 12 teacher candidates evolved towards increased complexity between rounds 1 and 2. Eight out of twelve of these concepts' maps (75%) increased in either structure or organization (see Fig. 2). A textual analysis of the linking phrases used in the round 2 concept maps utilized a 59% increase in unique phrases over those in round 1, another measure of concept map evolution (see Table 1). Lastly, textual analyses of these concept map linking phrases demonstrated more elaborate networks of word collocations in round 2 (see Fig. 3). Taken together, these observations indicate an increase in complexity across the two rounds of concept mapping.

6.2 Learning Activities and Bloom's Revised Taxonomy

According to Bloom's revised taxonomy, the learning activities developed by these 12 teacher candidates evolved towards addressing more higher-order thinking skills across rounds 1 and 2. Both rounds of each learning activity were coded using Bloom's Revised Taxonomy. The data presented in Table 3 and Fig. 4 indicate that the first round learning activities were primarily associated with Bloom's lower-order thinking skills–*understand*, *remember*, and *apply* (80% in total), and that the second round of learning activities was primarily associated with Bloom's higher-order thinking activities*evaluate*, *create*, and *analyze* (79%).

Additionally, Epistemic Network Analysis (ENA) was used to investigate and explore the relationships between these codes (see Fig. 8). These analyses validate this evolution of the learning activities from lower-order to higher-order thinking skills.

6.3 Co-evolution of Concept Maps and Learning Activities

The primary trend observed from these various analyses of the two rounds of concept mapping and development of learning activities suggests that these two artifacts are co-evolving. As the concept maps became more complex, the associated learning activities addressed higher-order thinking skills.

6.4 Implications and Suggestions for Further Research

It is not possible to assign a causal relationship to this co-evolution. However, the pattern is clear and occurs consistently across the cohort of these 12 teachers. Further research would need to be conducted to explore this pattern in greater detail and depth with a larger cohort of teachers. It is entirely possible, for example, that while the concept mapping might have helped have teachers clarify their understanding of the relationships between key concepts comprising the topic chosen for the learning activity, it is also possible that the process of developing the learning activities over multiple iterations itself may be sufficient for this type of development.

Independent of this study's limitations, we believe it would be fruitful to continue exploring concept mapping as a tool for planning and teacher professional development. Additional work on this is currently underway.

7 Conclusion

This chapter described a case study where novice in-service adolescent teachers were trained to use concept mapping as a curricular planning tool and strategy. These novice teachers were asked to create a concept map for a part of a unit of study along with a learning activity for their students. Then, they were exposed to research documenting the benefits of concept mapping in science learning by adolescent students. Finally, they were then asked to repeat the concept map and learning activity design process. The findings of this case study suggest that this intervention was effective for these new teachers. The second round of concept mapping demonstrated increased complexity in structure and organization. The second round of learning activity development displayed activities that addressed Bloom's higher-order thinking skills. This work seems promising to support new teachers, and additional research is currently underway.

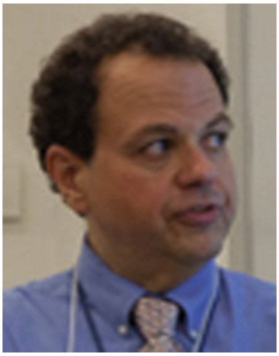
Core Messages

- New science curriculum standards require increased levels of *depth and rigor* in the teaching and learning of science.
- New science teachers must be developed to allow them to meet this need for depth and rigor in their teaching.
- This case study explored the use of concept mapping to develop this depth and rigor in science in new in-service teachers.

- These novice teachers designed learning activities to address the higher-order thinking skills in Bloom's revised taxonomy.
- Future work should expand and deepen these findings.

References

1. Next Generation Science Standards (n.d.) https://www.nextgenscience.org/. Accessed 8 July 2020
2. Novak JD, Cañas AJ (2008) The theory underlying concept maps and how to construct and use them. Technical report IHMC CmapTools 2006-01 Rev 01-2008, Florida Institute for Human and Machine Cognition, 2008, p 1. http://cmap.ihmc.us/Publications/ResearchPapers/TheoryUnderlyingConceptMaps.pdf. Accessed 8 July 2020
3. Novak JD (2005) Results and implications of a 12-year longitudinal study of science concept learning. Res Sci Educ 35(1):23–40. https://doi.org/10.1007/s11165-004-3431-4
4. Kinchin IM (2000) Concept mapping in biology. J Biol Educ 34(2):61–68. https://doi.org/10.1080/00219266.2000.9655687
5. Freeman LA, Jessup LM (2004) The power and benefits of concept mapping: measuring use, usefulness, ease of use, and satisfaction. Int J Sci Educ 26(2):151–169
6. Wheeler LA, Collins SK (2003) The influence of concept mapping on critical thinking in baccalaureate nursing students. J Prof Nurs 19(6):339–346
7. Cañas AJ, Reiska P, Möllits A (2017) Developing higher-order thinking skills with concept mapping: a case of pedagogic frailty. Knowl Manage E-Learn 9(3):348–365
8. Gul RB, Boman JA (2006) Concept mapping: a strategy for teaching and evaluation in nursing education. Nurse Educ Pract 6(4):199–206. https://doi.org/10.1016/j.nepr.2006.01.001
9. Leauby BA, Brazina P (1998) Concept mapping: potential uses in accounting education. J Account Educ 16(1):123–138. https://doi.org/10.1016/S0748-5751(98)00006-2
10. Cliburn JW Jr (1986) Using concept maps to sequence instructional materials. J Coll Sci Teach 15(4):377–379. https://doi.org/10.1039/C6RP00069J
11. Martin DJ (1994) Concept mapping as an aid to lesson planning: a longitudinal study. J Elem Sci Educ 6(2):11–30
12. Yin RK (2013) Case study research: design and methods. Sage Publications, New York
13. Hay DB (2007) Using concept maps to measure deep, surface and non-learning outcomes. Stud High Educ 32(1):39–57. https://doi.org/10.1080/03075070601099432
14. Kinchin IM, Hay DB, Adams A (2000) How a qualitative approach to concept map analysis can be used to aid learning by illustrating patterns of conceptual development. Educ Res 42(1):43–57. https://doi.org/10.1080/001318800363908
15. Sinclair S, Rockwell, G (2016) Voyant tools. http://voyant-tools.org/. Accessed 8 July 2020
16. Krathwohl DR (2002) A revision of Bloom's taxonomy: an overview. Theor Pract 41(4):212–218. https://doi.org/10.1207/s15430421tip4104_2
17. Shaffer DW (2017) Quantitative ethnography. Cathcart Press, Madison, WI
18. Shaffer DW (2018) Epistemic network analysis: understanding learning by using big data for thick description. In: Fischer F, Hmelo-Silver CE, Goldman SR, Reimann P (eds) International handbook of the learning sciences. Routledge, New York, pp 520–531
19. ENA App (n.d.) http://www.epistemicnetwork.org/. Accessed 17 June 2020



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Measuring, Assessing and Evaluating Thinking Skills in Educational Settings: A Necessity for Twenty-First Century

22

Yalçın Dilekli and Erdoğan Tezci

Education is not learning of facts, but training of mind to think.

Albert Einstein

Summary

The twenty-first century is very different from other centuries as mobilization of the people is very rapid, and the spread of knowledge has reached unbelievable levels, which has caused rapid changes in all disciplines. Under these circumstances, the traditional educational philosophy cannot meet the needs of the twenty-first century. The modern approach advocates that education should aim to raise thinking generations. A thinking generation means that individuals should be competent in terms of analytical, critical, and creative thinking, decision-making, and problem-solving. The transition from the traditional educational approach to the modern one has resulted in some problems called barriers in teaching thinking skills. These barriers can be summed up as attitudes of schools' administrators, teachers, and parents. The major reason for this attitude is the difficulty of measuring and assessing these skills. The skills cannot be measured and assessed by traditional ways that measure remembering and memorizing. However, 21st-century skills are higher-order analysis, evaluation, and creation. These skills are measured and assessed using multiple-choice and open-ended questions and

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N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_22

performance-based works. Furthermore, the evaluation process is not from a single perspective; instead, it is from multiple perspectives as self-evaluation, peer evaluation, and teacher evaluation. This chapter focuses on how teachers can measure and evaluate students' thinking skills by focusing on concrete examples.

Graphical Abstract/Art Performance

Thinking skills.

Keywords

Analytical thinking · Creative thinking · Critical thinking · Decision-making · Education · Problem-solving · Teaching · Thinking · Thinking skills

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

According to Onosko [1], the main barriers in teaching thinking skills are that

- societies undermine these skills;
- school administrations and teachers undervalue them;
- business sectors expect other qualities from their employees other than such skills; and
- it is burdensome and problematic to assess and evaluate students' mastery of these skills.

In the last 30 years or so, the literature on thinking skills has indicated that societies, schools, and business sectors need to put a great emphasis on these skills more than ever [2–4]. However, the most significant problem in teaching thinking skills remains the issue of measuring, assessing, and evaluating students' thinking skills. Additionally, the issue of teaching thinking skills requires a practical approach rather than a theoretical dwelling. Therefore, the main purpose of this chapter is to discuss measuring, assessing, and evaluating thinking skills by examining concrete examples from real educational settings.

2 Thinking Skills

21st-century Skills are like a motto in the educational era. Many countries have made reforms in their curriculums to teach these skills [5]. What makes this century different from other ages are developments in sciences and the changes in people's needs. When job posts are analyzed, the terms creative, collaborative working, critical thinking, and problem-solving skills have been aroused 70 times in the last 20 years [6]. The main reason for this increase in these terms is the rapid change in the labor market demands. New working life is "technology-rich, problems are frequently ill-defined and people work in teams, often multidisciplinary teams," [7] to solve these problems. The number of problems is constantly increasing in the production processes because of the new methods which enable producers to produce cheaper and faster. These new demands have resulted in changes in the philosophy of education because the traditional educational philosophy cannot assist educators in raising people with high-order thinking skills. Traditional approaches give importance to remembering or memorizing all the knowledge given by the school, and the students were supposed to answer the questions by memorizing. However, the world is so complicated that its problems are constantly changing. For example, think of two factories producing glasses. Both of them sell two hundred glasses per week and get similar profits. People do not buy new glasses unless their glasses break down. However, one day, one of the factories hired an artist to draw figures on the glasses, which increased their monthly sales. Then, this factory's profit and production rate dramatically increased since people liked these ornamented glasses and bought them. The owner of the factory now employs more artists for drawing. At this time, production costs of the factory also increase. For solving this problem, the factory uses machines. The artist has to know or learn computer-based programs for designing new models suitable for machine production. Here in the scenario, lifelong learning comes into the picture. Meanwhile, new kinds of paints are needed to use in these machines. The factory owner has to hire a chemist and an engineer for other systems in the factory. Totally, a team of workers comes together for cheaper production. All of them should be able to work collaboratively to solve problems during the production of the creative items. New rival factories are also established during this time, and consumers have to decide which one to buy. When consumers try to collect data for making decisions, they face a huge amount of input, making it difficult to make the right decision. They have to think critically.

The 21st-century society and its production processes may be better understood by examining the previous example. Not only producers but also consumers need new skills in this century. According to Griffin, Care, and McGaw [8], a group of 21st-century skills is related to thinking skills, which cover "creativity and innovation, critical thinking, problem solving, decision making, learning to learn and metacognition" [8]. These are also called thinking skills or higher-order thinking skills [9–11].

Since the importance of skills skyrocketed, the main aim of education has changed, and many different projects like Smart School in Malaysia or Odessay Program in Venezuela were applied. Later, school programs have radically changed to teach thinking skills in many countries, from North Korea to the USA [6]. Despite these efforts, Sternberg [12] has asserted that our students do not know how to think even in this century. The main problems in teaching thinking skills are teachers' behaviors, social acceptance of the skills, central examinations applied countrywide, and difficulty assessing these skills [1, 13]. In his study, Bruer [13] found that teachers insisted on teaching 3R (Reading, Writing, Arithmetic), which is the main traditional education philosophy. According to the traditionalist, educational goals should be assessed objectively; otherwise, they are not worth teaching since a teacher cannot decide whether her students achieve the goals or not if she does not employ an objective assessment approach. Ngang and Nair [14] found that teachers are eager to teach these skills; however, their success is assessed by the students' grades taken by the central examinations designed to evaluate lower ordering thinking. Similarly, teachers have lower self-efficacy levels in assessing thinking skills than teaching these skills [6, 15]. Therefore, teachers may abstain from teaching high-order thinking skills. However, this trend has changed because of content changes in central examinations. In this contemporary context, although teachers include new questions trying to assess thinking skills, they assign more homework to students, which does not promote students' mastery of thinking skills [16, 17].

3 Dimensions of Thinking Skills

Up to the 1990s, there was no exact definition of thinking skills or which skills should be accepted as thinking skills. Some scholars such as Costa [9], Swartz and Parks [10], and Mc Guinness, Eakin, Curry, Bunting, and Sheehy [18] defined the term and the skills constituting thinking skills. Although there are some small discrepancies related to the skills in some cultures, they are almost the same [7]. Swartz and Parks [10] and McGuinness [11] indicated that thinking skills have five main domains as "searching for meaning (analytical thinking), critical thinking, creative thinking, problem solving and decision making" [19]. At first glance, it seems these terms are not too different. However, they are different, and there is a strict relation between them. The last point that one wants to reach defines the route in her thinking process.

Thinking skills generally constitute five dimensions. Understanding the meaning, critical thinking, and creative thinking skills are in the first row. These skills are needed for decision-making or problem-solving. For example, before problem-solving, one should compare the information and classify them according to his/her aim. These activities are a part of understanding the meaning. Later, one should check the validity of the information given that is critical thinking. Then, she should try to find other alternatives, which is called creativity. After completing all these steps, the last point is solving problems. Sometimes, one may prefer a usual way of solving the problem and sometimes devise a creative alternative. Whichever she chooses, her main aim is to solve a problem. If she chooses how to solve the problem, she first decides what to do and then solves the problem [10, 11].

3.1 Understanding the Meaning (Analytical Thinking)

Much of the fallacies in problem-solving or decision-making processes are caused by the lack of understanding of the problem [20]. Understanding the real problem or the factors affecting the solution(s) is important. For understanding the meaning, students should know some basic skills under this dimension. According to Swartz and Parks [10], these skills are comparing and contrasting, classifying, constructing part and whole relationships, sequencing, and finding reasons/conclusions. In traditional education philosophies, teachers should ask open-ended or multiple-choice questions with specific answers that can be easily found in books to assess these skills. Having certain answers means that students are expected to learn lower thinking skills. Yet, in modern educational philosophies that constitutes thinking skills, students are supposed to have higher-order thinking skills to solve problems. Examples 1 and 2 illustrates this point.

Example 1 (multiple-choice question)
Which of the following item is conductive?
(A) Copper (B) Plastic (C) Rubber (D) Wood.

Example 2 (open-ended question)
Please write down five conductive and five non-conductive items?
…………
Examples 1 and 2 are based on classification skills and prepared in accordance with the traditional aspect. Students should memorize conductive and non-conductive items to answer these questions.

Example 3 (multiple-choice question)
Roger is working at a hardware store. He classified some items that are different sizes into boxes. Some items are made of rubbers, wood, and plastic in the first box. Some items are made of copper, steel, and iron in the second box.
Which one of the below is right about this classification?

(A) Items in the first box are more expensive than the second one.
(B) Items in the first box are lighter than the second one.
(C) Items in the first box are non-conductive, and the items in the second box are conductive ones.
(D) Items in the first box are flexible, but items in the second one are inflexible.

Example 3 is based on assessing, comparing, and contrasting skills. Therefore, students have to apply the criterion for classification. Furthermore, in this example, we know nothing about the weightiness or prices of the items. To deal with this problem, students must think about the features of the items and make a table for defining mutual points for all.

Example 4 (open-ended question)
In a hardware store, some items are classified into two boxes. There are rubbers, woods, and plastic in the first box, and in the second box, there are copper, steel, and iron. Today is your first working day in this store, and you have a piece of ceramic item. Which box should you store and why?
Example 4 also employs the same perspective. Students should also explain his classification with reason and result relationships.
The third way to assess thinking skills is project-based activities, also called performance-based assessment [20]. Performance-based assessment is exemplified in Example 5.

Table 1 Assessment rubric for classification skills

	4 (exemplary)	3 (good)	2 (satisfactory)	1 (needs improvement)
Data	All needed about conductive and nonconductive items were collected. Tables and figures were also included	Most of the needed conductive and nonconductive items were collected. Some tables and figures were missed	Some of the needed data were collected. Tables and figures were not included	Data were collected roughly or not collected. There were imitated or taken away directly from some pages. There are not any figures or tables
Design (if a design is needed)	A good design was made, and the design had all the requirements to be operable	A good design was made, and the design had most of the requirements to be operable	The design had some defects and not very operable	There was no design, or designed material was not operable one
Presentation	The presentation was understandable. It also included why and which these materials were preferred. Students have also answered the questions	The presentation was understandable. It mostly included why and which these materials were preferred. Students also answered most questions	The presentation was not very clear. Some points were identified about which and why these materials were preferred. Students also answered some questions	The presentation was not clear, or there is no presentation. The presentation about material selection was wrong, or there is no explanation. Students did not answer questions

Example 5 (performance-based work)
The teacher may ask students to design protective gloves for an electrician for performance-based assessment. During this design process, the teacher may give students both conductive and non-conductive materials or let students decide to choose the material for protective gloves. Students should also prepare a presentation on which items they use and why. In performance-based assessment, teachers should prepare rubrics for assessment. For this project work, a sample rubric may be prepared (see Table 1).

3.2 Critical Thinking

Norris and Ennis [21] stated that "critical thinking is reasonable, reflective thinking that is focused on deciding what to believe or do" (p. 3). The critical point in this definition is deciding what to believe or do. There are many different data from the outside world, such as TVs, newspapers, or social media, even on an ordinary day. Which of the data are right and which are not? Especially there are many advertisements and news on the internet and social media. Furthermore, there are some facts checking network systems on web pages about news on the net. To think critically, one needs to be able to analyze, evaluate, and synthesize [22]:

- the ability to analyze is used to examine and detect within an argument or written document;
- the ability to evaluate is used in assessing reliability, relevance, logical strength in the argument; and
- the ability to synthesize is referred to as "the collection of reliable, relevant and logical evidence based on the previous analysis and evaluation of existing evidence to draw a reasonable conclusion" [23].

Swartz and Parks [10] indicate that critical thinking involves the accuracy of the observation and reliability of the resources, causal explanation, prediction, generalization, deduction, and reasoning by analogy skills. In educational settings, students should learn these skills to be critical thinkers. From a traditional perspective, students should accept data as true when presented to them. However, today, the only resource is not course books, and the internet has become the main resource for collecting data. With the development of internet technologies, people produce content on the web. Thus, students should have evaluation skills. In the traditional assessment approach, it is difficult to mention the credibility of the sources. However, in the modern approach, the credibility of the resources can be assessed by multiple-choice questions, as exemplified by Example 6.

Example 6 (multiple-choice question)
On a TV program, Professor Millen, a medical expert, indicated that 'Global warming is not because of human activities; it is because of the natural cycling of the world.' When you consider this explanation, which is one of the following options true?

(A) It is true because he is an expert.
(B) It is true because it was on TV.
(C) It is false because human activities are the main source of global warming.
(*D) It is false because the professor is a medical expert, not natural sciences.

The second way to assess the credibility of the resources is performance-based assessment. A performance-based assessment example can be seen in what follows after Example 7.

Example 7 (open-ended question)
Teacher: Your duty is to analyze three different web pages giving information about global warming and compare them, decide which one(s) presents more reliable information and why?
In this assessment, students are supposed to examine: writers' field of expertise, when it is updated, whether there are the photos, whether figures and tables are

coherent with each other, whether it includes official reports, whether it is a scientific article or only personal ideas.

For causal explanation, teachers can prepare multiple-choice questions. In such questions, students are asked to connect reasons and results (see Example 8).

Example 8 (multiple-choice question)

Our civilization is established on plastic. Look around; our clothes are produced from plastic; this morning, you drink your coffee from a plastic cup; most of your car is made of plastic. When these are old, we throw them away. Later, they turn into microplastic, which is very small plastic particles. Most of these microparticles reach oceans and are eaten by fish at the end. When you eat these fish, you also eat plastic. Plastic is also one of the main causes of cancer. When you check statistics about the number of people dying because of cancer, you can easily notice the dramatic increase.

According to this passage which of the following can be said:

(A) All of the cancer types are because of plastic.
(B) Fish that eat plastic are the main cause of cancer.
(*C) Plastic eaten by fish may be a cause of cancer.
(D) People should give up using plastic.

In this question, students should find the passage's main idea without making the wrong generalization. Making too wide a generalization may cause to connect wrong causal explanation.

Prediction is another skill under critical thinking. For predicting, students have to evaluate the data, propose some future alternatives, and decide which has the highest possibility of turning into reality. Teachers may prepare multiple-choice exams for students' prediction skills (see Example 9).

Example 9 (multiple-choice question)

In global warming, people's changing diet has an important role. Especially in developing countries, the middle-class population is getting bigger. This new class consumes more meat, and most of the meat is supplied from cattle grown up in poultries. Cattle's waste is one of the sources of methane gases.

Which of the sentence given below best concludes this passage?

(A) So, we should reduce methane gases rate production.
(B) As the number of middle-class people increases, the methane rate seems to increase.
(C) People should give up consuming too much meat.
(D) To decrease methane production, vegetarianism should be promoted.

In this passage, the main point is that people are changing their diet because of their increased income. Students are supposed to see this detail from the passage as evidence to make a logical prediction.

Example 10 (multiple-choice question)
In the last 20 years, more than five parrot species got extinct in Salmon Island. Although many reasons are mentioned for this, the main reasons are building hydroelectric power plants which prevent parrots from reaching water sources, deforestation of the area, and increasing usage of pesticides in farms. Parrots are easily affected by the changing conditions in nature. Furthermore, the human population is getting higher because of the tourism on the island.
According to the passage, which can be said given below?

(A) There were too many animal species on the island in the past.
(B) Tourism is the main economic activity on the island.
(C) Tourism has caused deforestation on the island.
(*D) If it goes on like this, some other parrot species may become extinct.

Students are supposed to collect data from the passage and predict possible consequences in the future. There are two important pieces of information in the passage: the increasing population and the second one is the incapability of parrots to adapt to new situations. These two pieces of evidence show that some other species most probably disappear.

Example 11 (open-ended question or performance-based work)
For an open-ended question or performance-based assessment, the teacher may give students some graphics indicating people's educational level from different cities and their participation rate in the elections (People with higher education are more eager to participate in elections than others). The teacher may want students to predict which cities will have the highest participation rate in the next election and why? Students may prepare a presentation or a report about their prediction. A rubric should be prepared for evaluating their reports/presentations.
Generalization is another basic skill under critical thinking. By generalizing, we reach general rules. Generalization is also one of the main factors that affect our beliefs or attitudes. For example, we might think that a brand produces the best goods. However, our belief, a gross overgeneralization, does not necessarily mean that every brand's product is the best by itself. As this example indicates, the fallacy in generalization may cause problems even with many fraud incidents. These incidents are called Monte Carlo fraud. In a criminal event, a thousand people got e-mails about football results. The criminals divided those thousand victims into three categories. Criminals send e-mails about the result of the football match. For the same match, the first group gets an e-mail indicating team A will win, the second group gets an e-mail team B will win, and the last group gets an e-mail indicating draw. In the second run, the victims who get true predictions are divided

into three groups. This process has taken three weeks, and in the end, at least 15% of the people will always get true predictions about the results of the matches. In the last turn, criminals want these people a thousand dollars for the next matches. 10% of all send the money as they have taken the right prediction. For teaching generalization, students should ask questions such as what the proposed generalization is. For generalization, do we have a big enough sample group, and can that sample group represent the whole, and is there additional information to get other resources? [10]. Like other skills, multiple-choice exams can be used to assess generalization skills.

In the traditional approach, to teach geographical features and their effect on social and economic activities, students must memorize the cities' names and economic activities. For evaluation questions, they generally remember the cities or their economic activities. The following example question is prepared based on the traditional approach.

Example 12 (multiple-choice question)
Which of the cities given below are industrial cities near the seaside?

(A) Edinburgh.
(B) Bangkok.
(C) Lisbon.
(*D) Stuttgart.

However, in the thinking skills approach, teachers prepare such questions both for teaching generalization and the aim of the lesson.

Example 13 (multiple-choice question)
Most of the cities near the seaside are more crowded than the other ones. Industrial districts are generally established on sea sides because of easy and cheap transportation of the goods. As industrial districts offer many job opportunities, people settle down in such cities for better jobs. In the end, these cities turn into metropoles. According to the passage, which of the following can be said?

(A) All metropoles are near the seaside.
(B) Industrial districts established near the seaside.
(*C) Easy and cheap shipping make seaside cities attractive places.
(D) People migrate to seaside cities for only better job opportunities.

In Example 13, students are supposed to make generalizations by analyzing the information given in the text. Options A and B may be true answers if they make wrong generalizations. Generalization skills can also be assessed by open-ended questions or performance-based work.

Example 14 (open-ended question)
Teacher: Please analyze five big cities near the seaside. What are the main economic activities? Are they historical places or industrial districts? Explain why cities near the seaside are more crowded than the other cities in that countries?
In this project, students are supposed to analyze many seaside cities and choose five. They have to check some statistics about them and even their history. In the end, they compare them and reach some general rules.
In conclusion, higher-order thinking, namely thinking skills, can be assessed by multiple-choice exams, open-ended questions, and performance-based works. Some main approaches can be used to assess students' critical thinking skills. Firstly, students can be asked to analyze a given argument to find the main problem, idea or explain the reasons. Secondly, students can be asked to find the author's purpose and try to persuade us and what evidence is given for this purpose. To evaluate the credibility of sources, students should evaluate what piece of the information is reliable and why. Last are some cognitive activities to "draw a logical conclusion and explain their reasoning, select a logical conclusion from a set of choices, and identify a counter-example that renders the statement untrue" [20, 22, 24–26].

3.3 Creativity/Creative Thinking

Creativity can be described as the skill of generating new possibilities or new alternatives for a problem. Teachers want students to be creative, but do they know what "creative" means? Are all ideas creative, or are all unusual ideas creative? At this point, creative and critical thinking should not be confused. Creative thinking and critical thinking are reasonable; however, the former is productive and non-evaluative, while the latter is reflective and evaluative. Both of them are reasonable. Yet, creativity is a part of the problem-solving skill, and therefore, it is reasonable. However, creativity is not evaluative. After creative solutions are proposed, critical thinking comes into use to evaluate which alternative(s) is better than others. On the other hand, it can be possible to mention other kinds of creativity for artists. Their creativity is a kind of inspiration [21]. The other point which needs to be illustrated is the difference between creativity and creative thinking. Creativity is a thinking skill, but it may not result in tangible materials, yet creative thinking results in a tangible one [3, 27]. Although some think that only intelligent ones are creative, many studies [28, 29] showed a weak correlation between creativity and intelligence. As Tezci [30] states, creativity tests are based on divergent thinking, but intelligence quotient (IQ) tests are based on convergent thinking. Sweller [31] indicates that creativity requires creating thoughts, readjustment of thoughts, trial and error, and a depth in knowledge. He highlights the necessity of having fresh thoughts and utilizing various structural techniques to merge and operate the thoughts for solving problems. Creative people are open-minded to new ideas and willing to acquire new knowledge and skills continually. They also look for new sources such as media, peers, or new events to get new ideas. Creativity is not a skill when one wants to see it; creativity is generally performed while solving a problem. There are two ways to solve a problem. The first one is applying others' solutions to the problem. The second one is creative problem solving which means combining many different ways or reordering materials or actions and adopting them into the problem. For example, a bus company wants to raise its profit, yet people do not want to use buses as they think they are too slow and boring. However, driving faster may increase the risk of an accident. The solution is finding something that people can enjoy during the trip. Companies reassemble TV units today so that passengers can watch videos or listen to music during the trip. Although understanding the meaning (analytical thinking) and critical thinking skills can be assessed in three ways (multiple-choice questions, open-ended questions, and performed-based works), creativity or creative thinking is assessed by performance-based works. Another approach is that creativity is a skill that cannot be reduced to a number in the end [32]. However, if one thinks creativity includes having fresh thoughts and judging their worth, it is practicable to grade a performance-based work [20]. Examples of social science and science lessons are given in Examples 15 and 16.

Example 15 (open-ended question, social science lesson)
After visiting a local museum, a teacher wants students to write a legend about an object in that museum. This legend must be related to the selected object in that museum.

Example 16 (open-ended question, science lesson)
After watching a documentary about people's increasing demands for energy and the destruction of nature to produce energy, a teacher asks students to find ways to protect nature while producing energy.
The first step of creativity is brainstorming. Students are supposed to brainstorm and evaluate the ideas found in this brainstorming. They may combine different ideas for creative ideas. For grading the ideas, teachers can use rubrics. This rubric should contain the main aim of the problem and the feasibility of the originality of the proposed ideas.

3.4 Decision-Making Skills

Decision-making is a complex process that results in choosing one or more options. Decision-making skills generally are a part of problem-solving. During problem-solving, we decide on one or more options for the solution. According to Swartz and Parks [10], sometimes we make wrong decisions because we make quick decisions, collect restricted information, or fail to predict the decisions' results. According to Lee [33], personal values and beliefs are more important in decision-making than understanding the real problem. For making the right decisions, one should consider why this decision is necessary, what the options are, what the likely consequences are, and when the consequences are compared to which option is better. Namely, for right decision making, one should think analytically and critically. Later, decisions should be made. Decision-making skills can generally be assessed in multiple-choice questions, open-ended questions, and performance-based works. Example questions are no. 17–19.

Example 17 (multiple-choice question, mathematics)
You bought a new house, and there are no trees in its yard. The yard is 100 m^2, and at least ten trees from more than one species should be planted. Tree species and their features are given below. Which ones should you plant?

- Poplar (zones 6–15 m^2): A tall tree with aggressive roots known for causing sewer and foundational damage.
- Weeping willow (zones 6–10 m^2): A large shade tree commonly invades sewer lines.
- Crabapple (zones 7–10 m^2): A short, flowering tree matures about 20 feet tall. It is generally preferable in city center parks as its roots do not damage infrastructure.
- Japanese maple (zones 8–10 m^2): A popular scarlet-colored tree is ideal for planting at a curbside or near a patio.
- Flowering dogwood (zones 8–10 m^2): A delicate, flowering tree great for planting near walls.

  (A) Ten crabapple trees.
  (B) Five flowering dogwood trees and seven Japanese maple trees.
  (*C) Five flowering dogwood trees and five Japanese maple trees.
  (D) Four poplar trees and four weeping willow trees.

When the question is analyzed; poplar, weeping willow are not favorable trees near the houses, so options including these two are not right. Secondly, at least two species should be planted; for this reason, A is not the right option. When it is calculated, option B is not also the right answer.

Example 18 (open-ended question, science)
An open-ended question can be used for assessment for decision-making skills. While experimenting with a science lesson, the teacher may ask what the possible consequences of the chemical reactions are and why?

Example 19 (performance-based question, guidance)
Your close friends continually break the school rules. But, this time, there is a serious event. He stole some money from your classmate's bag, and you think you are the only witness to the crime. Now, the school administration is investigating the crime. What should you do? Your options are telling a lie or telling the truth. Perform a drama session with your group about the decisions and the possible consequences of your decision.
Performance-based assessment again needs a rubric for grading.

3.5 Problem-Solving Skills

Problem-solving is “a cognitive-behavioral process that includes identifying a problem, transforming a problem into a goal state, and finding and implementing alternative approaches to achieve the goals” [34]. In the traditional approach, memorizing formulas and content in the book is the only way to solve a problem. But today’s problems are not very simple. To deal with problems, it is necessary to identify the problem itself, locate possible hindrances of potential solutions, and judge which solutions might prove fruitful for solving the problem. Problem-solving skills include different cognitive activities, which are components of thinking skills. For example, while defining a problem, one uses analytical, critical thinking, and later for finding possible solutions, creative thinking and decision-making skills are used. One needs to create procedures to utilize knowledge to resolve real-world problems and combine knowledge for idea generation and solution investigation [35]. Problem-solving falls into five stages: defining the problematic situation, proposing the problem, suggesting alternative solutions, applying possible solutions, and evaluating them [36]. In school settings, problem-solving skills should be taught as they are needed in daily life. Many students fail to solve a problem. The main reasons for failing during problem-solving are failure to define the exact problem, generate possible solutions, select or apply unsuitable strategies, and use similar ways to all problems. Asking too structured questions, including an explicit definition of the problem and having one way to solve it, does not promote thinking skills. They appeal to lower-order thinking. But, in a modern approach, for assessing problem-solving skills, real-life problems can be developed, which are more complex and appeal to higher-order thinking skills. Structured problems seem to be easier to be graded, and they let the instructor manage the subject matter of learners’ studies, yet such too structured problems have less way of solutions than less structured ones. Teachers should be careful while preparing for such activities. While multiple-choice questions are generally more structured, performance-based and open-ended questions are less structured. Problem-solving skills can be assessed in three ways: multiple-choice questions, open-ended questions, and performance-based questions. The results and the stage of defining the problem can be assessed (see Example no. 20–22).

Example 20 (multiple-choice question)
When analyzing the precipitation regime graphic, which of the following cannot be said?

(A) Summertime is very dry.
(B) This area is located in the northern hemisphere.
(C) December, January, February, March, and April are rainy months.
(*D) This area is located in the southern hemisphere.

Example 20 is based on formulating or analyzing the given data, namely defining the problem. For defining real problems, students should refine data (Fig. 1).

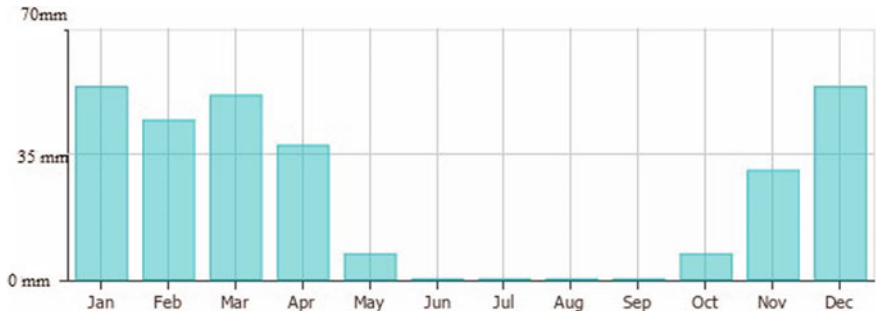

Fig. 1 Chart for example 20

Example 21 (open-ended question)
Approximate water waste per person is dramatically increased especially in city centers. Managing this wastewater is becoming a great problem, and also water resources are getting decrease. Explain how you would solve this problem?
For this problem, students are supposed to find applicable solutions. The teacher should also prepare a rubric for grading. This rubric should include a clear thesis about what students learned about himself/themselves, compatibleness of proof, reasonability of rationale, clearness of explanation, and feasibility, scientificity, and reasonability of the solution.

Example 22 (performance-based question)
Your uncle has a big cornfield where crows damage the corn. Your uncle's scarecrow is not functional anymore to keep crows away from the field. Design a new scarecrow for the field and explain why you did such a design.
In studying Example 22, students should first analyze why the scarecrow is not functional anymore. Then, they should look for alternative designs to develop a more functional one. For example, they might add a sound function to their design to scare the crows. Or, they may add a movement function to the scarecrow.
The change in the demand for a new workforce has caused educational aims. The new workforce should be creative. Moreover, problem-solvers need to meet the required thinking skills. It is inevitable to evaluate and assess the results of education and teaching thinking skills. Teaching thinking is not a product of the traditional approach; it cannot be evaluated and assessed in traditional ways.
Three important factors affect the assessment process during the assessment:

i. who makes the assessment? In the modern approach, assessment is not done by only teachers; it can be done by peers and in the form of self-assessment;
ii. what the purpose of the assessment is?; and

iii. what is assessed? It corresponds to learning outcomes and how they are assessed, such as multiple-choice questions, open-ended questions, or performance-based works. All these should be considered.

For all of them, there are some general principles for the assessment of teaching thinking skills [10, 20]:

i. *The alignment principle,* which refers to coherence with learning objectives of the lesson and assessment criteria*;*
ii. *The specificity* principle, which refers to the clear and exact definition of the assessment task and demands from the students, for example, decision making or predicting the possible consequences; and
iii. *The standards principle* refers to what characteristics of the students' work will be taken as evidence for grading. For example, while teachers may teach reliability of the sources in critical thinking for lower graders, teachers may teach generalization skills in higher graders.

Furthermore, a teacher may teach the same skill in different grades; the expected perfection level of the skill may vary from grade to grade.
As shown in Table 2, all the components of thinking skills are related to each other. The final point is problem-solving. This means that while evaluating and assessing problem-solving, some other skills are analytical, critical, and creative thinking and decision-making. If students fail, the teacher should diagnose where they did wrong and help students improve diagnosed skills.

Table 2 The relationship between thinking skills components

Dimensions of thinking skills	Aim	Needed basic cognitive skills	Main relationships among the dimensions
Understanding the meaning (analytical thinking)	To clarify the meaning of the problem	Comparing and contrasting Classification and definition Parts and the whole relationship Sequencing Finding reason/s or conclusions Uncovering assumptions	This is the first step for all dimensions of thinking skills. For example, in order to solve a problem, one should define the problem. In order to do that, the data should be analyzed by classifying or comparing
Critical thinking	To reach a critical judgment	Defining aim Evaluating options Establishing cause and effect relationships Making inquiry Distinguishing fact from opinion Concluding, logical thinking	Problem solving: to evaluate possible solutions Decision making: to check and ensure reliability of the data and other alternatives Creativity: to decide and formulate the aim

(continued)

Table 2 (continued)

Dimensions of thinking skills	Aim	Needed basic cognitive skills	Main relationships among the dimensions
Problem-solving	To reach one or more solution/s for the problem	Critical thinking, data processing, creative thinking, implementing of the planed actions, generating alternatives	Critical thinking: collecting data, formulating problems, establishing cause and effect relationships Creativity: creating new options for the problem Decision making: deciding which of the options are effective
Creativity/creative thinking	To reach original idea/product	Critical thinking, flexibility, defining options, collecting data, analyzing the problem, generating ideas and possibilities, seeing multiple perspectives	Critical thinking: evaluating new ideas or products, establishing new relationships among the patterns Problem-solving: creativity starts from problem-solving Decision making: Selecting one of the original products or ideas
Decision-making	To select one or more of the alternatives	Critical thinking, creative thinking, problem-solving, generating options, predicting likely consequences	Critical thinking: collecting data and evaluating options Problem-solving: formulating and analyzing the problem Creativity: proposing new alternatives

Teaching Thinking with Activities, Pegem Publishing [5], p. 12

4 Conclusion

Education systems must raise rational individuals who can understand, reinterpret, and transform the complex world we live in, think freely, be free from prejudices, effectively solve complex problems they encounter, and make correct and effective decisions clear. Education systems can fulfill this obligation by giving importance to learning contexts to increase the need for thinking skills and develop thinking skills. For this purpose, it is imperative to evaluate these skills as well as to define thinking skills comprehensively, revealing the approaches and strategies for teaching thinking skills in detail and presenting them to the practitioners because it is the assessment and evaluation of thinking skills that are often neglected or pushed into the background in learning contents. Within this context, this chapter aims to sweep away the question marks in the minds regarding assessing and evaluating thinking skills and to explain the assessment and evaluation of thinking skills with concrete examples.

Core Messages

- Thinking skills can be assessed and evaluated in many ways, such as open-ended, multiple-choice, etc.
- Creative thinking or creativity can be assessed and evaluated by open-ended questions and performance-based work.
- Teachers should predefine skills of interest before deciding which tools are used for assessment.

References

1. Onosko JJ (1991) Barriers to the promotion of higher-order thinking in social studies. Theor Res Soc Educ 19(4):341–366
2. Baumfield V, Oberski I (1998) What do teachers think about thinking skills? Qual Assur Educ 6(1):44–51
3. Dilekli Y (2015) The relationship among teachers' classroom practices for teaching thinking skills, teachers' self-efficacy towards teaching thinking skills and teachers' teaching styles. Unpublished Doctoral Dissertation, Balikesir University, Balikesir, Turkey
4. Hashim R (2003) Malaysian teachers' attitudes, competency and practices in the teaching of thinking. Intellectual Discourse 11(1):27–50
5. Dilekli Y (2019) Teaching thinking skills with activities. Pegem Publishing, Ankara, Turkey
6. Dilekli Y, Tezci E (2016) The relationship among teachers' classroom practices for teaching thinking skills, teachers' self-efficacy towards teaching thinking skills and teachers' teaching styles. Thinking Skills Creativity 21:144–151
7. Dilekli Y (2019) What are the dimensions of thinking skills in Turkish literature? A content analysis study. Int J Eval Res Educ 8(1):110–118
8. Care E, Griffin P, McGaw B (2012) Assessment and teaching of 21st century skills. Springer, Melbourne, AU
9. Costa AL (2001) Developing minds: a resource book for teaching thinking. ASCD, Melbourne, AU
10. Swartz RJ, Parks S (1994) Infusing the teaching of critical and creative thinking into content instruction: a lesson design handbook for the elementary grades. ERIC, Critical Thinking & Software Pacific Grove CA
11. McGuinness C (1999) From thinking skills to thinking classrooms: a review and evaluation of approaches for developing pupils' thinking. Department for Education and Employment London, Nottingam, UK
12. Sternberg RJ (1987) Teaching critical thinking: eight easy ways to fail before you begin. Phi Delta Kappan 68(6):456–459

13. Coffman DM (2013) Thinking about thinking: an exploration of preservice teachers' views about higher order thinking skills. Unpublished Doctoral Dissertation, University of Kansas, USA
14. Nair S, Ngang TK (2012) Exploring parents' and teachers' views of primary pupils' thinking skills and problem solving skills. Creat Educ 3(01):30–36
15. Tebbs TJ (2000) Assessing teachers' self-efficacy towards teaching thinking skills. Unpublished Doctoral Dissertation, University of Connecticut, USA
16. Jürges H, Schneider K (2010) Central exit examinations increase performance... but take the fun out of mathematics. J Popul Econ 23 (2):497–517
17. Kızkapan O, Nacaroğlu O (2019) Science teacher science teachers' opinions about central exams (LGS). Nevşehir Hacı Bektaş Veli Üniversitesi SBE Dergisi 9(2):701–719
18. McGuinnes C, Sheey N, Curry C, Eakin A (2003) ACTs II Sustainable thinking in classrooms: a methodology for enhancing thinking across the curriculum. Materials available from Professor C McGuinness, School of Psychology, Queen's University, Belfast, Northern Ireland
19. Dilekli Y, Tezci E (2019) Adaptation of teachers' teaching thinking practices scale into English. Euro J Educ Res 8(4):943–953
20. Brookhart SM (2010) How to assess higher-order thinking skills in your classroom. ASCD, Melbourne, Australia
21. Norris SP, Ennis RH (1989) Evaluating critical thinking. The practitioners' guide to teaching thinking series. Critical Thinking Press & Software Pacific Grove, CA
22. Dwyer C, Hogan MJ, Stewart I (2011) The promotion of critical thinking skills through argument mapping. Nova Science, Australia
23. Facione PA (1990) Critical thinking: a statement of expert consensus for purposes of educational assessment and instruction. Research Findings and Recommendations. The Delphi Report Millbrae, California, USA
24. Anderson LW, Krathwohl DR, Airasian PW, Cruikshank KA, Mayer RE, Pintrich PR, Raths J, Wittrock MC (2001) A taxonomy for learning, teaching, and assessing: a revision of bloom's taxonomy of educational objectives, abridged edition. Longman, White Plains, NY
25. McMillan JH, Myran S, Workman D (2002) Elementary teachers' classroom assessment and grading practices. J Educ Res 95(4):203–213
26. Sasson I, Yehuda I, Malkinson N (2018) Fostering the skills of critical thinking and question-posing in a project-based learning environment. Thinking Skills Creativity 29:203–212
27. Perry A, Karpova E (2017) Efficacy of teaching creative thinking skills: A comparison of multiple creativity assessments. Thinking Skills Creativity 24:118–126
28. Jaušovec N, Jaušovec K (2000) Differences in resting EEG related to ability. Brain Topogr 12 (3):229–240
29. Royer JM, Feldman RS, Chase P, Schulze K (1984) Instructor's manual for educational psychology: applications and theory. Random House, New York, USA
30. Tezci E (2002) The effects of constructivist instructional design on the success and creativity of fifth-year students in primary schools. Unpublished doctoral dissertation Fırat University, Elazığ, Turkey
31. Sweller J (2009) Cognitive bases of human creativity. Educ Psychol Rev 21(1):11–19
32. Azzam AM (2009) Why creativity now? A conversation with Sir Ken Robinson. Educ Leadersh 67(1):22–26
33. Lee YC (2007) Developing decision-making skills for socio-scientific issues. J Biol Educ 41 (4):170–177
34. Lee B, Lee Y (2020) A study examining the effects of a training program focused on problem-solving skills for young adults. Thinking Skills Creativity 37:100692

35. Runco MA, Acar S, Cayirdag N (2017) A closer look at the creativity gap and why students are less creative at school than outside of school. Thinking Skills Creativity 24:242–249
36. Bransford JD, Stein BS (1993) The IDEAL problem solver. W. H. Freeman, New York, USA

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Developing Computational Thinking Skills to Foster Student Research: Contemporary Scientific Education Through Modeling and Simulations

23

Vladimiras Dolgopolovas, Valentina Dagiene, Sergei Pozdniakov, and Alexander Liaptsev

I don't know what's the matter with people: they don't learn by understanding, they learn by some other way—by rote or something. Their knowledge is so fragile!

Richard Feynman

Summary

This chapter presents a view on modern K-16 education fostering students' research activities. The role of computational thinking (CT)-based pedagogy is discussed, and a model of corresponding educational settings incorporating modeling and simulations into the teaching and learning process is provided. We consider modeling and simulations in a broader sense not only from the perspectives of educational technology but also as a part of an epistemological approach aimed at grounding the learner cognitive structures and the final cognitive and long-time

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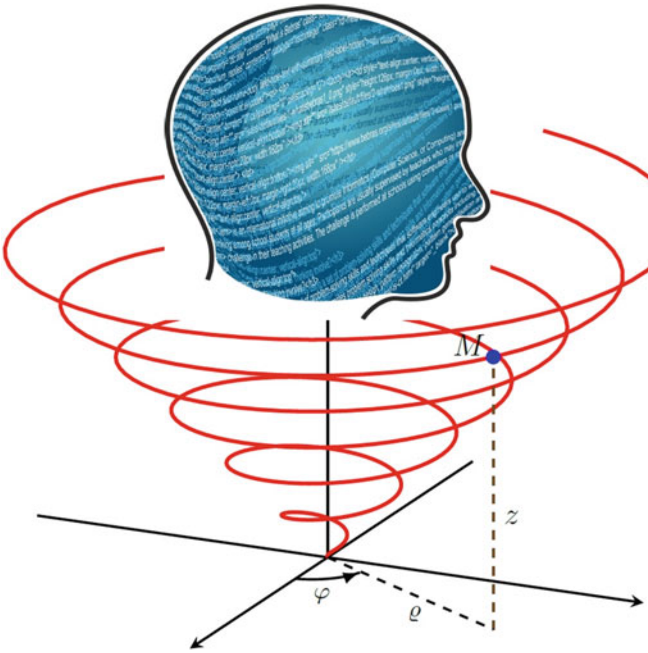
N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_23

sustainable development of knowledge. At the same time, we provide a detailed description of the practical educational environment based on the conceptual understanding of educational research as a "mirror image" variant of real scientific research activities. Besides this, the chapter provides some philosophical and methodological discussion. In addition, a practical example of a model-based educational environment for discrete mathematics education is introduced.

Graphical Abstract/Art Performance



Simulation of the mental or the mental simulation?

Keywords

Computational thinking · Mathematics education · Modeling · Scientific education · Simulation · STEM

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

How do people learn? The traditional approach is mentalistic [1]. Passive or active, lecture or project-based, "pure" or supported by technology, but still mentalistic. The student's brain is the primary purpose and the main target of educational efforts. Students sit, listen, read, write, watch, solve problems and participate in various forms of activity, improving their knowledge and understanding, and as a result, their knowledge is fragile. How do we improve this? How do we make such knowledge fundamental and understanding deep? What about skills? Could we consider skills as pragmatic "islands" in this "ocean" of mentalistic education? What should we focus on–on knowledge or skills? Could we deploy an educational strategy that will incorporate the synergetic development of both knowledge and skills and how they relate to each other, or if there exist dichotomies and contradictions? Obviously, there are more questions than answers. This is even more complicated when one considers the requirement of modern science. What is modern scientific education? And is the perfect scientific mind resulting from our educational efforts the solution?

This chapter aims to encourage discussion on the role of modeling and simulation in modern scientific education. Our general idea is that computational thinking (CT) pedagogy could be positioned as a kind of grounding [2] that allows different educational activities to be combined into one practical educational solution, passing from the purely mentalistic approach to its grounded counterpart. This is extremely important for such a traditionally seen as mentalistic field as, for example, mathematics education. We will not debate the importance of mathematics in the context of science, technology, engineering, and mathematics (STEM), considering this an obvious must, but will nevertheless emphasize the importance of a pragmatic direction in mathematics teaching, stressing the significance of applied implications and related modeling (scientific modeling) skills. Modern science is about modeling [3]; therefore no doubt that education in modeling is important for STEM and science education [4, 5].

The next aspect to discuss is the step from modeling to simulation. The following important remark needs to be made. We do not support in any way a mechanistic view on a simulation, a tool that improves a person's mental abilities, a kind of cognitive artifact after Norman [6] that enhances students' understanding. This would be just another "improvement" of the mentalistic approach we try to avoid. In this regard, we consider simulation as a kind of epistemological tool that allows us to move to the implementation as grounding in educational approaches and provides a kind of computational grounding [7] in connection with the settings of the computational modeling environment. The advantage of such considerations is the following: now we have an opportunity to utilize a broader vision of simulation, focusing on understanding its neuroscientific, cognitive, and reasoning backgrounds [8–10]. This includes mental modeling and simulation as one of the approaches to simulation-based learning in science education [11] and on which this chapter focuses.

Different approaches and applications of CT are presented, including CT-focused modeling and simulation environments [12, 13]. The main focus of this approach is developing computational abstractions and conceptualizing the phenomena under study [12]. In general, we are determined to avoid (or at least minimize) the influence of empirical tradition in science and corresponding scientific education, which is based on two main fundamentals: analyticity and reductionism. The reason for this is not only that empiricism (at least in its classical meaning) is "[…] rather suspicious with respect to any kind of abstract entities […]" [14], but also that we have the ambitious goal for providing the prerequisites for epistemological grounding, which is hardly possible in the framework of a "purely" empirical tradition. In general, following Quine [15], we do not intend to abandon analyticity on stage but to put it on a level with synthetic reality. Not the opposition; it is a reasonable connection–this is our solution. It is important to emphasize that our synthetic truth has a contingent nature. That is why it is essential to design a contingent educational environment, or, in other words, an inherently contingent environment in nature [16]. In this sense, we consider the scientific activity as "continuation of common sense, and [it's continuation of] the common-sense expedient of swelling ontology to simplify theory" [15].

It is these ontologies, the process of their design and verification, that we place at the heart of modern scientific education. Our orientation to the pragmatic process of verification, in particular for the sake of synthetic verification, and not just solely for the purpose of confirmation (or rejection) of analyticity, allows us to declare a paradigm shift from reductionism to pragmatism to fit our "continuing sensory promptings" [15] into the rational stance of our pragmatic considerations. How do we link the presented theoretical stance to the pragmatic vision we proclaim, or, in other words, how do we “design” such “pragmatic” ontologies? A number of practical recommendations can be formulated as follows:

- to show complexity not only as a structure but also in interrelationship, as well as causes and consequences;
- to educate to synthesize, rather than absolutize analyticity (for example, to reduce the number of parameters for the sake of understanding in favor of accuracy);
- to understand and support the human in its relationships and interactions with the environment; and
- to consider human and non-human (as a kind of “inscription devices” [17]) as equal participants in relevant educational settings

The chapter is structured in the following way. In this section, “Introduction,” in addition to motivational aspects, some backgrounds and topics covering CT-based pedagogy approaches are discussed. The section “CT For Research And Modern STEM Education” highlights some aspects of CT related to science education in general. Further, in the section “Mathematical Modeling In Education As A Learning Model For Scientific Research,” we consider a general view on modeling and simulation for scientific education and provide connections to the pedagogy of CT. In the section “Mathematical Modeling In The Course Of Discrete Mathematics,” we provide a practical example of the approach to the field of applied mathematics education. The analysis of the modeling process is presented when making formal grammar by students based on informally described language. Grammar, in this case, acts as a model for formalizing a set of words, which students generate themselves based on the proposed samples. This generation plays the role of simulation and tests grammar for its correspondence to the language. It is shown how, with the help of a teacher and group discussion, an adequate model is progressively created, which ends with the creation of a syntactic analyzer and provides students with intellectual satisfaction with the results of their mental simulation done. The chapter ends with “Conclusion,” “Acknowledgments,” and “References” sections. The section “Authors biographies” ends the chapter.

2 CT for Research and Modern STEM Education

Today’s post-industrial world is becoming increasingly complicated. Post-industrial society gains new opportunities and, at the same time, faces new challenges. On the one hand, technology is constantly evolving, more complex, and challenging to learn and interact with. On the other hand, the digital world is penetrating all spheres of personal and social life; digital devices are becoming ubiquitous, always and everywhere, following with the individual and directly influencing their personal life and determining their social behavior and social status. In fact, the modern world could be described as a man-machine, or more precisely, an environment where society and technology are constantly interacting. In this respect, the socio-societal context is as important as the technological one in this interaction. How do we interact with this advanced world? We need new knowledge and competencies: digital competencies and competencies in relevant contextual areas and so-called “soft competencies” such as CT. A reform of STEM education, targeting both primary and university education, is consequently required. The overall approach is based on reforming and innovative approaches to STEM curricula, including hands-on, real-world, research-based, and information and communication technology-enhanced learning methods, collaborative practice with a transdisciplinary focus, and the use of extracurricular activities to teach a wider range of skills that encourage innovation and creativity and foster initiative and entrepreneurship [18].

It is important to note that such a reform is comprehensive and stipulates a number of requirements for the nature and settings of the educational environment, including practical requirements for upgrading STEM curricula. Such requirements, in addition to the specification of modern educational technologies, involve requirements for educational content and related digital competencies. Here, the interdisciplinary nature of STEM should be taken into account, as well as the fact that STEM curricula cover all stages of the educational process, including pre-school and secondary education [19, 20]. Therefore, in addition to the classic CT skills associated with computer science, additional skills such as problem-solving, communication, and teamwork skills need to be developed [21].

The model of a holistic approach to STEM education that we advocate is based on the integrative nature of CT. In this way, scientific thinking enables scientific experiments to be carried out within the STEM educational environment, which is particularly important for subsequent careers as a scientist and for carrying out scientific experiments directly in a real scientific environment. In addition to disciplinary knowledge and subject matter expertise, skills in generalization, logical inference, experimentation, and data processing are as well important here. The development of creative thinking enables activities in a context-sensitive learning environment, taking into account social and environmental aspects, and supports student interaction in real-world project-based learning activities. In this respect, CT could be positioned as an integrative skill set that enables the development of universal competencies, a universal language for modeling and interaction in the holistic STEM environment.

Modern scientific practice is based on the extensive employment of digital tools, such as computational models, which enable computer experiments and simulations. Consequently, training in developing mathematical and computer models, conducting computer experiments and simulations from the earliest ages is particularly important. Another important point is that, as mentioned earlier, aspects of modeling the social environment and human-machine interaction are crucial as well as technical aspects. Therefore, in addition to content-oriented knowledge, students should also have the skills to learn in a modern digital learning environment and to design and conduct educational, scientific experiments and simulations. Such skills include core CT skills such as generalization, decomposition, algorithmic, automation, and systems thinking skills. On the other hand, CT skills are needed to enable effective interaction with the social environment. In this context, although CT has its origins in computer science, it is becoming a skill far beyond this [22]: a skill for everyone, an important tool, and a subject of social knowledge regardless of learners' technical background. Consequently, it is important to ensure that the holistic teaching of CT skills is integrated into a modern educational environment.

As already discussed, CT skills and a holistic approach to teaching such skills, including CT as a subject of study both within integrated STEM and directly in subject-specific curricula, will prepare students to meet the challenges of the changing Information Age paradigm shift [23]. The key here is to organize an effective teaching process, as the teachers will play the main role in ensuring effective teaching of CT in the framework of such integration. It is important to note the following point in this respect–this integration process takes place against the background of constant changes in requirements, content, and context of learning, so the role of developing relevant competencies and skills in teaching CT is of primary importance. However, as our practical experience shows, computer science teachers have little awareness of the specifics of STEM pedagogy related to CT education. This is all the more relevant for teachers of individual STEM subjects. In our opinion, teacher training programs in CT teaching need to be revised.

All this makes it necessary to improve and develop innovative programs and educational approaches to STEM education based on the broad use of methods and concepts of CT. Such programs should be linked to and consider the transdisciplinary nature and holistic perspectives of STEM education. We consider a pragmatic approach to teaching CT skills understood as a holistic set of tools, approaches, and methods to enable a painless transition from younger students' playful activities to learning and applying digital technologies, computers, and digital modeling by high school and undergraduate students. At the same time, as stressed earlier, it is important to emphasize the development of teacher training programs and methods aimed at teaching CT skills within such an integrated STEM program.

3 Mathematical Modelling in Education as a Learning Model for Scientific Research

At a more general level, the process of scientific research can be illustrated using the diagram depicted in Fig. 1. At the first stage, the accumulation and systematization of experimental facts occur. Then a hypothesis is constructed explaining such facts and giving some predictions (consequences). Such predictions are checked (if possible) by setting up an experiment or making additional observations. New facts contribute to developing a hypothesis or constructing a new hypothesis if the old one is not confirmed. This results in new predictions and repeated cycles. As experienced facts become available, the hypothesis becomes a common theory if confirmed by experience or discarded if new data does not confirm it.

One of the leading mathematicians, academician of the Russian Academy of Sciences A. A. Samarskii, who made a great contribution to the development of education in the field of mathematical modeling (see, for example, [24]), formulated the following thesis “Education is a learning model of science.” In particular, the process of teaching mathematical modeling can be illustrated in Fig. 2. This scheme corresponds to the method embedded in the notion of CT as the “three As” iterative process (see for example [25]):

i. at the first stage (**A**bstraction), a problem is set;
ii. at the second stage (**A**utomation), solution development; and
iii. at the third stage (**A**nalysis), solution execution and analysis.

The process is quasi-cyclical. It means that after the successful completion of the initially planned research, the new information gained is the basis for the next research stage, just as it happens in scientific research. If the decision on some criteria does not meet the set task, it is necessary to return and develop a model that meets the obtained discrepancies. It should be noted that at each of the stages when solving a concrete problem, the main characteristics corresponding to the methodology of CT are manifested to some extent.

3.1 Formulation of the Research Problem

At this stage, a general formulation of the problem takes place. When the problem is first addressed, the initial information that may be more or less specific in the learning process is analyzed. Sometimes, to simplify the process, a training task is presented in a concrete form, such as some physical task. The initial information may be presented as a set of some experimental facts and theoretical provisions, which may be disordered and not directly related. At this stage, such peculiarities of CT as *using abstractions and defining templates for new and different ways of presenting the problem, logical organization and analysis of data, breaking down*

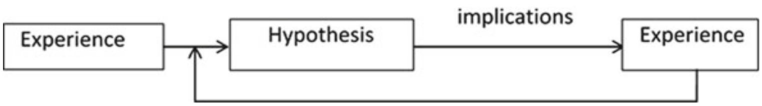


Fig. 1 The process of scientific research

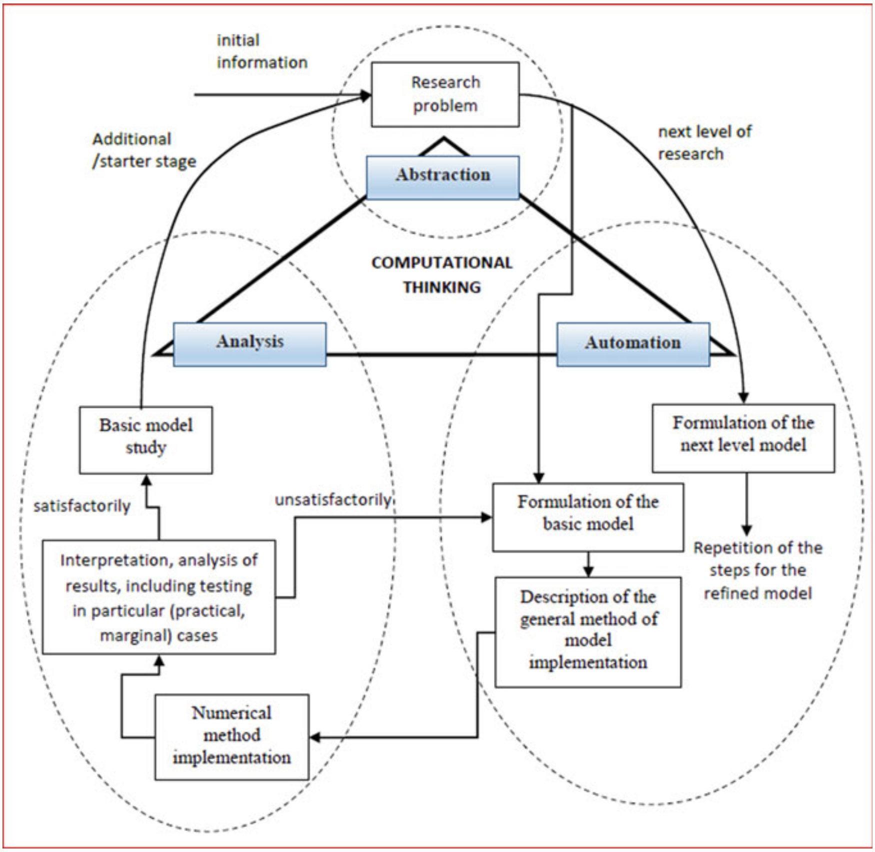


Fig. 2 The main steps of teaching mathematical modeling

the problem into smaller parts can appear (Fig. 2). In the next cycle, the problem is expanded when students have additional information obtained from the simplest model. Here, in particular, such characteristics of CT as a *generalization of the process of solving one problem for a wide range of similar tasks* can be useful. It should be noted that at this stage, the mathematical model as such may not be formulated; that is, the research formulation may remain at the verbal level.

3.2 Formulation of a Mathematical Model

A mathematical model corresponding to the research problem is formulated at this stage. The set of variables characterizing the system under study and the set of parameters on which the system evolution can depend is determined. When a certain physical system is considered, the basis of the equations may be formed by physical laws describing these phenomena. Modeling is based on some heuristic positions for phenomena and processes in the "non-physical" domains [26].

At the end of this stage, mathematical equations or some mathematical prescriptions must be obtained, which can then be implemented by numerical methods. At the same stage, it is necessary to formulate special and limiting cases, which will allow testing the model. Some requirements for the selection of an educational model:

i. the model should motivate students to research. This motivation may be due to the nature of the topic chosen, which is related to the specialization students are learning. Another possibility is relevance–connection with phenomena and processes currently taking place in nature and society (e.g., pandemic);
ii. the model should correspond to the students' level. Pupils should be able to understand the phenomenon being studied and, with the help of the teacher (to a greater or lesser extent), obtain some solution within the time allocated for the discipline;
iii. the model should contain some computational experiments in its implementation. It cannot be a task that can be solved without calculations by analytical methods (even if it is a complicated olympiad task);
iv. while implementing the model, some qualitatively new peculiarities of the phenomenon under study must appear (for example, it is inexpedient to put the problem on the calculation of gravity force between two homogeneous balls. Of course, a force different from the law of gravitation will be obtained, but something qualitatively new will not occur); and
v. the model should contain simple solutions (for example, analytical) in some extreme cases. This will make it possible to test the model.

At this stage, such characteristics of CT *as breaking down the problem into smaller parts and identifying, analyzing, and executing possible solutions to achieve the most effective and efficient combination of resources and steps may manifest themselves.*

3.3 Description of the General Method of Model Implementation

At this stage, it is not the algorithm that is being formulated but some general provisions regarding a possible solution. For example, a mechanical problem can be solved by solving dynamic equations or minimizing some functionality. It is necessary to realize model limits and the possible accuracy of calculations at this stage. If iteration methods are used, estimating the number of iterations is probably necessary. If the model is formulated as a set of some subtasks, it is necessary to think over the relationship of subtasks and the sequence of their implementation.

At this stage, such characteristics of CT *as representing the problem in the form of a series of sequential steps (algorithmic thinking) and the approach to the* *problem using algorithmic methods such as cycles, logical operations, and symbolic representation can manifest themselves.*

3.4 Numerical Implementation of the Method

Only for the simplest models can be formulated algorithms that can be immediately programmed in a high-level language. Any “interesting” models must possess computational methods. These include various numerical methods and solutions, including numerical approaches to the integration and solution of ordinary and partial derivative differential equations, methods of linear algebra, Fourier transform, etc. Students are not always familiar with these methods, let alone possess them. However, nowadays, numerical methods are implemented in many computing environments (Mathcad, Mathematica, Matlab, Maple, Octave, etc.). For students who are not familiar with the numerical methods necessary for the model implementation and do not have any disciplines in the educational program familiarizing with these methods, it is reasonable to acquaint them with the idea of the necessary method and teach them to address the corresponding procedure in the chosen computational environment. For example, in an environment such as Matlab, you can quickly create applications that allow you to conveniently conduct various numerical experiments in the created window (GUI, graphical user interface).

The numerical implementation also implies a visualization of the results obtained. The results can be two-dimensional and three-dimensional graphics and animations of the processes under study. There are possibilities to create animations in different formats (gif, avi, etc.). Such visualization, carried out under changing external parameters, is a simulation of some investigated processes. We define simulation as “performing goal-directed experimentation or gaining experience under controlled conditions by using dynamic models; where a dynamic model denotes a model for which behaviour and/or structure is variable on a time base” [27].

3.5 Analysis of Results, Including Testing for Particular (Marginal) Cases

Testing the software is an important step in the study of the model. To conduct testing, students must be familiar with approximate methods (e.g., linearization of differential equations near a particular point) and analytical research methods. It is the combination of analytical and computational methods that can give, firstly, the guarantee of correctness of numerical algorithms and, secondly, help to understand the process under study. At the same stage, the “reasonableness” of the results obtained should be assessed. At the initial formulation of the model, some hypothesis is formulated, predicting the consequences of the model. The results obtained from a numerical experiment must either “fit” into this hypothesis or be somehow explained in terms of inconsistency with the predictions made during the model formulation. If model testing has yielded unsatisfactory results, or if the results obtained are completely out of line with the expected qualitative effects of the model, a return to the previous stages is required up to the first stage of formulating the new model. With a satisfactory test result and "reasonable" results obtained for some model parameters, you can move on to the stage of the model investigation.

At this stage, such characteristics of CT as *logical organization and data analysis and identification, analysis, and implementation of possible solutions to achieve the most effective and efficient combination of steps and resources* may be manifested.

3.6 The Study of the Simplest Model

Any model, even the simplest one, contains some set of parameters. Model research consists of obtaining the model properties' dependence on the given parameters. In this case, it may be important to obtain both quantitative characteristics that can be compared with experimental data or known theoretical studies and qualitative types of dependencies.

When the model implies simulation, the model study allows demonstrating the qualitative features of the model and the results of the numerical experiment. At this stage, such characteristics of CT as *logical organization and data analysis and identification, analysis, and implementation of possible solutions to achieve the most effective and efficient combination of steps and resources* may appear.

3.7 Formulation of the Next Level Model

It is important to educate for mathematical modeling. V. I. Arnold wrote [28], "The ability to make adequate mathematical models of real situations should be an integral part of mathematical education. Success brings not so much the application of ready-made recipes (rigid models) as a mathematical approach to the phenomena of the real world. For all the great social importance of computing (and computer science), the power of mathematics is not in them, and teaching mathematics should not be reduced to computational recipes." In Arnold's terminology [28], "rigid" models are the simplest models containing a minimum of parameters. The "softening" of the model is that some of the parameters are replaced by functions from the task variables. The functions themselves can be different, taken from some theoretical considerations, or selected in such a way as to ensure the best match with the experienced facts (a detailed discussion with examples can be found in the book cited above). The introduction of such functions can be stepwise so that at each stage, a higher level of research on the model obtained would give a new qualitative result. Thus, the research process is similar to Hegel's spiral.

4 Mathematical Modeling in the Course of Discrete Mathematics

The emergence of the concept of CT was a consequence of changes in human habitats. The appearance of the digital environment, significant for human life activity, gradually changes the structure of human thinking: now he can rely not only on his knowledge, but also on the knowledge that is in his environment, easily extractable from there, and can also take into account the possibility of expanding his operational capabilities through computer means. Let us consider how these changes influence the process of a person's comprehension of new mathematical ideas. Let us analyze this process from the point of view of the interaction of human experience with creating a new product. We will consider a product in two aspects: as an intellectual product (in the sense of how the product was understood by Max Wertheimer [29]) and as a product of the human activity, which can be alienated from the person and have social significance. For our purposes, we can divide human thinking into two different processes:

i. the first is similar to the work of a neural network formed since childhood and possessing knowledge that this network itself can neither realize nor structure; and
ii. the second is the conscious structuring of knowledge that this neural network possesses.

Let us keep in mind that these two described processes occur in conjunction with human interaction with the external digital environment. This interaction can be considered as two interrelated forms of modeling and simulation approach [30]: on the one hand, it is the creation of mental models and simulation on the human neural network; on the other hand, it is the creation of external computer models and work with them. Building internal models is based on unconscious knowledge, which initially has no formed internal mechanisms for working with it and inclusion in new constructions, but allows you to verify the created consciously thought structures quickly. At the same time, the construction of external models can be considered the use of the mechanism of interiorization (translation from the external plan to the internal), developed based on the works of Vygotsky and Leontiev [31–33]. This activity also has a social aspect–creating a mathematical model that can be presented to the mathematical community.

It is worth mentioning that the emergence of computer mathematics has given rise to a new direction in teaching mathematics itself–mathematical modeling. For example, compilers of mathematical olympiad problems use dynamic geometry environments to find or try out new geometric patterns between the various parameters of geometric shapes. At mathematical programming olympiads in test procedures, the efficiency of the algorithm used for the solution is taken into account.

One of the projects on applying mathematical modeling in a course on discrete mathematics, which reveals important features in the study of material on "formal languages and grammar," will be presented below. These features can be briefly described as follows:

- the student is assigned an informally described assignment, that at the same time allows the student to use his basic concepts (described by the structure of a similar neural network) to verify partial solutions;
- the student proposes solutions in the form of a model, which is designed for implementation on a computer, that is, performing mental operations related to the sphere of CT;
- this model is then verified on his basic concepts, as well as on the ideas of the students of the study group (it can be formalized as verification on a system of neural networks built on different principles) and the differences of this purposefully constructed mathematical model with its informal image, which is presented by the condition of the problem, are determined;
- this process, which consists of computer modeling and computerless mental simulations, continues until these differences are no longer identified by the student community; and
- at the last stage, the final computer model is implemented as software and is simulated by external—computer—means. This stage is analogous to software testing, but because task definition was carried out based on the informal representation of the task in the student's information system, this stage acts as a reward in the form of a finished product for the work done.

Thus, the student's activity is an example of CT, when a computer is an intermediate–a tool in terms of Vygotsky, allowing to establish a connection between informal knowledge (experience) and the mathematical model of the subject area.

4.1 Mathematical Modeling in the Development of Formal Grammar of an Informally Given Language

The project was inspired by the material presented in N. Wirth's "Algorithms+Data Structures=Programs" [34]. Wirth shows how to build a program that converts formal grammar described in a certain way into a parsing algorithm. The main idea of our project is to combine this algorithm as the last (routine) part of the project–as an experiment–with the search for a description of an informally given language (given a set of examples and counterexamples) grammar that satisfies a number of limitations that ensure applicability of the algorithm as mentioned above by Wirth.

Let us analyze the application of mathematical modeling on the example of building grammar for a very simple language. The following is a reconstruction of the process of interaction between the teacher and students in practical classes with a group of sophomores in the subject "Mathematical Logic and Algorithmic

Theory" (Saint-Petersburg State Electrotechnical University "LETI," Faculty of Computer Technology and Informatics).

Example (*the language of inflexible algebraic formulas*) As an alphabet, consider small Latin letters {a; b; c} and two characters of arithmetic operations: addition (+) and multiplication (×). For example, the formulas a + b × c, b, a × a × a are correct formulas, and the wrong formulas are + b, ×, a + × b.

Beforehand, students are introduced to context-free grammars and its subtypes. The first attempts of the students to solve the problem are connected with the "operational" meaning of the language presented. At this stage, students cannot abstract from semantics–the meaning of these expressions and perceive them simply as some text with certain syntax. Therefore, the first solutions are usually of the following kind:

4.1.1 Model 1[1]

<formula>::=<operand>+<operand> | <operand>×<operand>
<operand>::=a | b | c

This variant of grammar is quickly disproved by other students, as it does not allow setting one-letter formulas. The following edition of the grammar appears:

4.1.2 Model 2

<formula>::=<operand>+<operand> | <operand>×<operand> | <operand>
<operand>::= a | b | c

But before the student can correct the grammar, it turns out that expressions with three or more letters cannot be written with this grammar, even corrected. At this point, students begin to feel the difference between finite and infinite language. Initially, many students associate the words of the language with its alphabet (and such errors are also found later in some students). There is a problem situation that is first tried to solve with "ellipsis," i.e., to copy records of infinite rows from mathematical analysis when the beginning of a row is written, and the formula ends with ellipsis. At this moment, an important concept is formed, which is that the infinite language can be described by finite grammar! Now students understand that the tool they need to use is recursion and begin to see recursive descriptions, for example:

[1] The following entries use the Backus-Naurus description form, with non-terminal characters—syntactic language concepts—taken in angle brackets, and a vertical line is used for alternative transcriptions of non-terminal characters.

4.1.3 Model 3

<formula>::=<formula>+<operand> | <formula>×<operand> | <operand>
<operand>::=a | b | c

None of the students can refute this grammar, and the discussion moves on to the next stage–grammar restrictions. Note that it is impossible to prove that the constructed grammar describes a given language in this activity. Why not? Because the language is not formally defined. Thus, the student's activity corresponds to the modeling scheme: hypothesis–experiment–hypothesis–correction–experiment, etc. For mathematical courses, this situation is not yet standard, as it does not assume "correct" in terms of the proof of the answer. At the same time, the set of initial examples makes it possible to check the constructed grammar on them (formal part) and use the general aesthetic conceptions to estimate the result. This brings the problem closer to applied problems and shows the possibilities of the indirect influence of digitization on changes in mathematics teaching.

At the second stage a constraint—belonging to the class of grammars LL(1)—is imposed on the grammar, which informally can be formulated as unambiguity of branching on the first symbol. In other words, when terminal symbols are "decrypted" by different alternatives, the result cannot begin with the same terminal symbols. So in our example, the second rule satisfies this condition, and in the first, each of the three alternative transcriptions can start with any letter.

This restriction is already more difficult to satisfy, and the constraint is "superfluous" semantics. The problem of "cleansing" the mathematical model is an important step in the use of modeling and simulation in learning. Here are what R. Feynman writes about it [35] "To what extent do models help? It is interesting that very often models do help, and most physics teachers try to teach how to use models and to get a good physical feel for how things are going to work out. But it always turns out that the greatest discoveries abstract away from the model and the model never does any good. Maxwell's discovery of electrodynamics was first made with a lot of imaginary wheels and idlers in space. But when you get rid of all idlers and things in space the thing is O.K. Dirac discovered the correct laws for relativity quantum mechanics simply by guessing the equation." The attempt to avoid ambiguity of the branching leads to the idea of "put the general part out of brackets," i.e., to combine the first two alternatives into one:

4.1.4 Model 4

<formula>::=<formula><continuation> | <operand>
<continuation>::=+<operand> | ×<operand>
<operand>::=a | b | c

This variant of grammar "brings the problem closer to solving." The presence of mechanisms to assess the approach to solving the problem is called the "principle of progress" by Minsky [36]. This way is also discussed by Poya [37], which suggests at the beginning of the problem solution to compare what is known with the goal to be achieved. At the same time, various implicit criteria automatically appear, which allow a person to estimate the "approach" to the problem solution. In this case, there is unambiguousness of branching by the first symbol in the second and third rules. In the first rule, the ambiguity remains because both <formula> and <operand> in the decoding can start with one letter, but before, it was in two places, and now it remains only in one. We can assume that there will be students who will look at recursive definition differently and offer such a model instead of Model 4:

4.1.5 Model 5

<formula>::=<operand>+<formula> | <operand>×<formula> | <operand>
<operand>::=a | b | c

Now we can take the common <operand> symbol out of all three alternatives "out of brackets". But then what is left of it in the third alternative? If we perceive the derivation operation as multiplication, then a unit–a neutral element–should remain. Thus, we need to introduce a neutral symbol for actions with words (gluing words–concatenation). Let us call this symbol an empty string symbol and designate it with a capital letter of the Greek alphabet "lambda:" Λ.

4.1.6 Model 6

<formula>::=<operand><continuation>
<continuation>::=+<operand> | ×<operand> | Λ
<operand>::=a | b | c

This model already satisfies all the required limitations, and further, we can build an algorithm of syntactic analysis by literally translating grammar into a parser. Table 1 presents the parsing program to show the correspondence of the grammar rules to the parsing operations:

Having received recursive programs, it is natural to raise the question of the existence of iterative ones. And at this point, you can draw students' attention to a simple arrangement of "words" of our language. Any formula can be considered a repetition of the "letter-sign operation" pairs and ends with a letter. Let's introduce the meta-symbol of iteration in the following way: A*:: = Λ | AA | AAA …. In these terms, grammar will take the form:

4.1.7 Model 7

<formula>::=<symbol-operation sign>*<symbol>
<symbol-operation sign>::=<symbol><operation sign>
<symbol>::=a | b | c
<operation sign>::=+ | ×

Table 1 Corresponding grammar rules to syntactic analysis operations (recursive syntactic parsing algorithm)

Rule of grammar	Syntax analysis program function
<formula>::=<operand><continuation>	**function** FORMULA **begin** OPERAND CONTINUATION **end**

<continuation>::= + <operand> | ×<operand> | Λ	**function** CONTINUATION
	begin
	if symbol = "+"
	then read(symbol)
	OPERAND;
	else
	if symbol = "×"
	then read(symbol)
	OPERAND;
	end

<operand>::=a | b | c	**function** OPERAND **begin** **if** symbol ∈ {a; b; c} **then** count the symbol; **else** error **end**
Main Program	read(symbol) FORMULA

The model is abstracted from its superfluous elements introduced by interpretation at this stage. What Feynman [38] calls the transition from model to theory and throwing away of the model, it is more correct to represent the transition from the simulation model, or in other words, from the interpretation of model in representations accessible to the student to mathematical model when in it only elements essential for model and connections are kept. At the same time, on the psychological level, this model abstracted from the interpretation will still be related to the initial interpretation but will include additional knowledge about which elements of interpretation are essential and which are not. This is achieved by combining different interpretations. So in our case, it was an "operational" interpretation of the language and its "syntactic" interpretation.

Attentive students will notice at once that as <letter-symbol of operation>* can by definition be both an empty symbol and begin with a letter, the rule contains ambiguity of branching on the first symbol. Then you can pay attention to another iterative way of structuring the words of the language: start with a letter, and continue with the repetition of the pair "sign of operation—letter." The corresponding grammar will be like this:

4.1.8 Model 8

<formula>::=<symbol><operation sign - symbol>*

<operation sign - symbol>::=<operation sign><symbol>

<symbol>::=a | b | c

<operation sign>::=+ | ×

Again, there is an algorithm of direct translation into the software program (Table 2).

Some summarising practical examples of informal language descriptions for building grammars and syntactic analyzers [39] are presented in Table 3.

4.2 Pedagogical Experiment

Based on the idea described above, an experiment with the course students at the Faculty of Computer Technologies and Informatics of Saint-Petersburg State Electrotechnical University "LETI" was conducted. Students were offered an

Table 2 Corresponding grammar rules to syntactic analysis operations (iterative syntactic parsing algorithm)

Rule of grammar	Syntax analysis program function
<formula>::=<symbol><operation sign - symbol>*	**function** FORMULA **begin** SYMBOL **while** symbol ∈ {+; × } OPERATION SIGN - SYMBOL **end**

<operation sign - symbol>::=<operation sign><symbol>	**function** OPERATION SIGN - SYMBOL
	begin
	    OPERATION SIGN
	    SYMBOL
	end

<symbol>::=a | b | c	**function** SYMBOL
	begin
	    if symbol ∈ {a;b;c}
	    then read(symbol)
	    else error
	end

<operation sign>::=+ | ×	**function** OPERATION SIGN
	begin
	    if symbol ∈ {+; × }
	    then read(symbol)
	    else error
	end

Main Program	read(symbol) FORMULA

Table 3 Examples of informal language descriptions for building grammars and parsers as assignments for students

No.	Description	Examples	Incorrect solution
1	Formulas of temporal logic LTL	Gq, (Fp), (trueUq)	()Fp
2	A set of chains above the alphabet {a;b} in which, if there is a subchapter ab, there is also a subchapter bb	abbb, bbab, bbaaa	ababab, aaab
3	The language of arithmetic expressions given priority	(a + b)*c, a + b*c	a + (b*c), (a + b) + c
4	Predicates with quantifiers and two variables x and y (generality and existence quantifiers are denoted for convenience A and E)	Ax(EyP(x;y) v Ax (Q(x;y)	AxExP(x)
5	Binary sets that define self-contained functions of 1, 2, and 3 variables	(10), (1010), (11,101,000)	(1110), (101,010)
6	Bracket expressions determining the matrix multiplication sequence	((AB)(C(DA))	ABC, (AB)C
7	Arithmetic examples with rational numbers	(2/34 + 17,000/ (5 + (12 + 7/130)/ 22))	12/0, 12,300/1
8	Complete bracketed records with multiple bracketed levels: each level has the same bracketing type and alternates when moving to a new level	[(([(a + b)*(c + d)]/ [a + c]) + (a* [c + d])]	[(a + b)* [c + d]]

informal description of the language they had to use first to build formal grammar, to experimentally justify its correspondence to the examples by making a parse of a typical example. Then it was necessary to test the grammar on the property of unambiguousness of the branch on the first symbol and, if it is not executed, build a new grammar. After the theoretical modeling stage, the resulting model was "implemented," i.e., the parser was built according to the algorithm developed by Wirth [34] and using a convenient programming language.

After the lecture and one practical lesson, students were offered to go through all the modeling stages and build a parser for a simple language (Table 3). The work was considered not as programming work but as work on discrete mathematics, which should be a mathematical model of the parser. At the same time, students built a program of syntactic analysis on a model with which they could work and make sure that it meets the requirements. The peculiarity of this work was that the program was built "automatically" with the right model and worked without errors with a 100% guarantee. The last phrase seemed surprising to most students who were used to the process of testing and error correction. They could understand the true meaning of this phrase only after the work was done.

Three groups of students can be classified in the work process:

i. students easily perceived the idea of preliminary construction and modification of the model. These students carried out their tasks quickly. The parser turned out immediately and without errors. You can conventionally call such students "mathematicians;"

ii. students for whom building a model turned out to be as new as solving tasks. The individual task was done long, with errors and corrections after the teacher's remarks. Some steps were performed formally; and

iii. students who, in principle, did not want to start with a model and built a syntactic analyzer first. It worked correctly in simple cases and with errors in more complicated ones. By no means, the students did not want to take the position that building a model allows you to automate the process of program development and avoid errors in it and, therefore, to avoid the testing stage. Grammar was often built by such students after building a parser, and it usually turned out to be inadequate to the program of syntactic analysis. These students were asked to formulate rules to move from grammar to a program of syntactic analysis for ANY grammar from the LL(1) class. Only then could students in this group move from a straightforward software development process to a pre-modeling process.

4.3 Summarising Remarks

The presented theoretical analysis shows that applying the approach from the point of view of mathematical modeling is possible not only for such classical areas as the description of processes by differential or difference equations but also for areas of discrete mathematics. The main features of this approach that have been identified are the following:

- the presence of an informally described problem, the solution of which cannot be verified by the usual method "by the answer," but only by the degree of conformity of the solution to the specified conditions;
- the possibility of implementing the general approach to the problem presented by Poya [37], using the principle of "progress," associated with the informal evaluation of intermediate solutions, to assess the effectiveness of progress; and
- the possibility to conduct mental or computer-based experiments to verify the conditions to be met by the solution

The main in applying the approach to the problem from the point of view of mathematical modeling is much more conformity with the psychological mechanisms of formation of new concepts at the student compared with the traditional deductive presentation of the theory with the formulation of definitions and theorems. Thus in the resulting example, it is shown what problem situations lead to the formation of such important ideas as "description of infinite language by final grammar," "recursive definition," "empty string symbol," "iteration." As a further step, It would be possible to compare the definition of the algorithm through Markov's normal schemes with the description of the grammar language, which clearly shows the difference between the description of the problem and the algorithm for its solution (D. Knuth wrote in the preface to [40] that he considers this definition of the algorithm the most convenient).

This practical experiment has highlighted one interesting category, which can be conditionally called “hacker programmers” who begin to work without building a model. Their results are always distinguished by many errors and corrections, which suggests that the approach to teaching through the model building is useful not only for learning mathematics but also for teaching programming. Grammars were not chosen as an example by chance. Indeed, grammar provides a way to describe many objects, and the algorithm of syntactic analysis is based on it. At modeling any process, the attention also addresses the description of a problem instead of its decision, which is already the next stage and is now carried out by systems of support of modeling automatically. Thus, the construction of grammar with some properties is a modeling element. Replacement of one grammar by another is the iterative process corresponding to the circular scheme of stage-by-stage modeling. The process of model verification of each stage, by its conceptual focus, includes the process of mental simulation. This learning activity is supported by CT-based pedagogy, which provides a set of tools to enable the process of computational grounding.

5 Conclusion

This chapter is about models and simulations. Usually, models and simulations are presented in the form of mathematical or software constructions and can be considered cognitive artifacts that enhance human mental abilities [6]. Using models and related simulations could enhance students’ understanding and provide foundations for solid and consistent knowledge. However, such an approach considers the model or simulation as a kind of cognitive enhancer, which is not always true in general. Thus the impact of the cognitive artifact on students’ understanding in an educational environment is not as straightforward as it might seem at first sight. It can be analyzed from different points of view: the system view and the personal view. Since educators are usually keen to improve teaching, the motivation to incorporate the most effective educational tool is always present. If we consider simulation as a software-based educational tool, if it is viewed as a cognitive artifact, then obviously, from the educator’s perspective, because such a tool enhances students’ abilities, the educator is usually willing to include it in the learning process. If considered from the learner’s perspective, such a cognitive artifact is merely an additional activity for the learner, and the view of its effectiveness is usually biased.

The following illustrative example ([6] as cited in [41]) explains the point. Consider the checklist. Aircraft pilots, as an example, use it for pre-flight consultation and, if viewed as a cognitive artifact, it enhances their performance. From a system perspective, it clearly enhances the cognitive abilities of pilots, as it makes the flight preparation process more efficient. On the contrary, the pilot himself sees it as just another duty requiring attention. If one does not use a checklist, one must do the work required to complete the task and learn and memorize in advance. The process of using the list is different, as the list has to be considered and prepared in advance (performed by a third party), firstly the pilot has to be instructed, and secondly the pilot must remember to read and perform the tasks on the list before the flight. To summarize, we see that from the system's (read: teacher's) point of view, the list is a very effective tool. At the same time, from the pilot's (read: student's) point of view, because the set of activities is limited and the pilot only has to remember to read the list, there is no improvement of cognitive abilities as a result of such activity, but instead, there is the degradation of mental abilities and memory deterioration.

To solve the described contradiction, it is essential to apply a broader perspective on modeling and simulation, paying attention to epistemological and sociological foundations of educational modeling and simulations. Such epistemological focus enables a set of CT skills in the form of relevant abstractions and conceptualizations to be developed. At the same time, introducing the "realistic" model of scientific research into the educational practice provides a kind of cognitive grounding and, consequently, the corresponding formation of knowledge and skills of students on a solid and long-time basis. This is important for such traditionally "theoretical" fields as mathematics. In addition to being important per se, mathematics and its education are also important and an applied discipline within the STEM curriculum, as it provides foundations for mathematical modeling and computer science. The difficulty here is that mathematical constructs tend to be abstract and difficult to understand, thus decreasing students' motivation.

The CT-based educational environment, presented in this chapter, provides a practical example of how modeling and simulation (in the epistemological sense) enable the practical transformation of existing and new cognitive structures, enhancing student understanding of complex abstract concepts. At the same time, some sociological aspects are highlighted. While maintaining a pragmatic stance, one could practically observe how such the CT based educational environment, following Latour [42], provides a field for a number of "inscription devices," such as ideas, artifacts, humans, and social groups to destroy, emerge, transform, develop, and ultimately formalize in the form of new structures that influence and impact the behavior, foresight, and fate of all the participants. However, it is worth mentioning that this study focuses on methodological and epistemological aspects of CT as related to modeling and simulation for scientific education. The detailed study of the described sociological aspects is positioned as further research.

Core Messages

- The pedagogy of computational thinking is aimed to provide a framework for grounding students' cognitive processes.
- Computational thinking is positioned as an integrative skill for enhanced STEM education.

- Mathematical modeling and simulations in science education are positioned as learning models for scientific research.
- The instructional approach in teaching discrete mathematics is based on conducting mental and computer simulations.
- A computational thinking-based educational environment impacts students' behavior, foresight, and fate.

Acknowledgements One of the article authors, Sergei Pozdniakov, works on this topic within the framework of the Russian Foundation for Fundamental Research (grant no. 19-29-14141).

References

1. Macedonia M (2019) Embodied learning: why at school the mind needs the body. Front Psychol. https://doi.org/10.3389/fpsyg.2019.02098
2. Barsalou LW (2010) Grounded cognition: past, present, and future. Top Cogn Sci 2:716–724. https://doi.org/10.1111/j.1756-8765.2010.01115.x
3. Gelfert A (2016) How to do science with models: a philosophical primer. Springer, Berlin
4. Callahan BE, Dopico E (2016) Science teaching in science education. Cult Stud Sci Educ 11:411–418. https://doi.org/10.1007/s11422-015-9703-7
5. Gilbert JK (2004) Models and modelling: routes to more authentic science education. Int J Sci Math Educ 2:115–130. https://doi.org/10.1007/s10763-004-3186-4
6. Norman DA (1991) Cognitive artifacts. Des Interact Psychol Hum-Comput Interface 1:17–38
7. Pezzulo G, Barsalou LW, Cangelosi A et al (2013) Computational grounded cognition: a new alliance between grounded cognition and computational modeling. Front Psychol. https://doi.org/10.3389/fpsyg.2012.00612
8. Thagard P (2010) How brains make mental models. In: Studies in computational intelligence. Springer, Berlin, pp 447–461
9. Magnani L, Casadio C (2016) Model-based reasoning in science and technology. Springer
10. Barsalou LW (2008) Grounded cognition. Annu Rev Psychol 59:617–645. https://doi.org/10.1146/annurev.psych.59.103006.093639
11. Landriscina F (2014) The role of mental simulation in understanding and in creating scientific concepts. Innov nella Didatt delle Sci nella Sc primaria e dell'infanzia al crocevia fra Discip Sci e Um 3:141–165
12. Basu S, Dickes A, Kinnebrew JS et al (2013) CTSiM: a computational thinking environment for learning science through simulation and modeling. In: CSEDU 2013 - Proceedings of the 5th international conference on computer supported education, pp 369–378
13. Sengupta P, Kinnebrew JS, Basu S et al (2013) Integrating computational thinking with K-12 science education using agent-based computation: a theoretical framework. Educ Inf Technol. https://doi.org/10.1007/s10639-012-9240-x
14. Carnap R (2011) Empiricism, semantics, and ontology. In: The pragmatism reader: from Peirce through the present, pp 249–264
15. Quine WVO (2016) Two dogmas of empiricism. In: Clarity is not enough: Essays in criticism of linguistic philosophy, pp 110–132
16. Taber KS (2009) Progressing science education. Springer
17. Blok A, Jensen TE (2011) Bruno Latour: hybrid thoughts in a hybrid world. Routledge
18. EACEA (2018) Call for proposals EACEA 36/2018. Key action 3: support for policy reform —initiatives for policy innovation European Forward-Looking Cooperation Projects in the

fields of Edu-cation and Training. Guidelines for Applicants. https://eacea.ec.europa.eu/sites/eacea-site/files/call_guidelines-en.pdf. Accessed 25 Aug 2020
19. Weintrop D, Beheshti E, Horn M et al (2016) Defining computational thinking for mathematics and science classrooms. J Sci Educ Technol. https://doi.org/10.1007/s10956-015-9581-5
20. Bers MU, Flannery L, Kazakoff ER, Sullivan A (2014) Computational thinking and tinkering: exploration of an early childhood robotics curriculum. Comput Educ. https://doi.org/10.1016/j.compedu.2013.10.020
21. Barr D, Harrison J, Conery L (2011) Computational thinking: a digital age skill for everyone. Learn Lead with Technol 38:20–23
22. Angeli C, Giannakos M (2020) Computational thinking education: issues and challenges. Comput Hum Behav 105:1–3. https://doi.org/10.1016/j.chb.2019.106185
23. Huitt W (1999) Success in the information age: a paradigm shift. Educ Psychol Interact 1:1–18
24. Samarskii AA, Mikhailov AP (2001) Principles of mathematical modelling: ideas, methods, examples. CRC Press
25. Rich PJ, Langton MB (2016) Computational thinking: toward a unifying definition. In: Competencies in teaching, learning and educational leadership in the digital age: papers from CELDA 2014, pp 229–242
26. Bordovskij GA (2017) Physical fundamentals of mathematical modelling: textbook and workshop for undergraduate and graduate students. Jurait (in Russian)
27. Ören T, Mittal S, Durak U (2019) Modeling and simulation: the essence and increasing importance. In: Modeling and simulation of complex communication networks
28. Arnold VI (2004) “Rigid” and “soft” mathematical models. Moscow Publishing House MCNMO (in Russian)
29. Wertheimer M, Wertheimer M (1959) Productive thinking. Harper, New York
30. Mittal S, Durak U, Ören T (2017) Guide to simulation-based disciplines: advancing our computational future. Springer, Berlin
31. Vygotsky LS (1980) Mind in society: the development of higher psychological processes. Harvard University Press
32. Kozulin A (2004) Vygotsky’s theory in the classroom: introduction. Eur J Psychol Educ 19:3–7. https://doi.org/10.1007/BF03173233
33. Classman M (1996) Understanding vygotsky’s motive and goal: an exploration of the work of A.N. Leontiev. Hum Dev 39:309–327. https://doi.org/10.1159/000278505
34. Wirth N (1985) Algorithms & data structures. Prentice Hall
35. Feynman R (1968) The character of physical law. Sci Educ 52:513–513. https://doi.org/10.1002/sce.3730520572
36. Minsky M (2014) The society of mind. Simon and Schuster
37. Poya D (2010) How to solve the problem. Librokom (in Russian)
38. Feynman RP, Leighton RB, Sands M (2011) The Feynman lectures on physics, vol. I: the new millennium edition: mainly mechanics, radiation, and heat. Basic Books
39. Karpov YG (2010) Model checking. Verif parralel Distrib Syst SPb Bhv-peterbg
40. Knuth D (2011) The art of computer programming, vol 1. Addison-Wesley Professional
41. Dolgopolovas V, Dagienė V, Jasutė E, Jevsikova T (2019) Design science research for computational thinking in constructionist education: a pragmatist perspective. Problemos. https://doi.org/10.15388/Problemos.95.12
42. Latour B (2005) Reassembling the social—an Introduction to ANT. Oxford University Press

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24 Contemporary Artists' Work: A Critique of the Possible in STEAM Education

Laura Felleman Fattal

> *The question is not what you look at, but what you see.*
>
> *Henry David Thoreau*

Summary

Arts integration in PreK-high school classrooms has initiated a multidimensional approach to education learning and practices. This chapter focuses on: i, documentation of advocacy for the curricular practice of Maker Space to STEAM (science, technology, engineering, the arts, and mathematics) teaching and learning; ii, exploration of exemplar practices; and iii, investigations of contemporary artists' work as a valuable platform for expanding analogous aesthetic understanding. Intertwined with critical inquiry, arts integration and its imprint in Maker Space and STEAM lessons place itself as a further innovation pedagogy. The hands-on transdisciplinary basis of arts integration learning permeates project-based and problem-based learning and other frequently implemented classroom practices to advance student learning. The revisited curricular constructs speak to the interdependent twenty-first-century educational goals to build a sustainable future.

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N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_24

Graphical Abstract/Art Performance

Pine cones.

(Adapted from Wikimedia Commons, the free media repository, licensed under the Creative Commons Attribution 3.0 Austria, https://upload.wikimedia.org/wikipedia/commons/3/31/Kiefer_Zapfen%2C_Pine_cones_02.JPG).

Keywords

Art · Contemporary artwork · Curricular constructs · Education · Integration · Learning · STEAM · Transdisciplinary

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

Arts integration in PreK-high school classrooms has stimulated multidimensional educational research and implementation practices. This chapter focuses on: i, documentation of advocacy for the curricular approach of Maker Space to STEAM (science, technology, engineering, the arts, and mathematics) teaching and learning; ii, exploration of exemplar practices; and iii, investigations of contemporary artists' work as a valuable platform for expanding analogous aesthetic understanding. Intertwined with critical inquiry–a process through which information and ideas that have their roots in multiple sources and domains come to be experienced together–arts integration and its imprint in Maker Space and STEAM lessons places itself as a pedagogy for further innovation. The hands-on transdisciplinary basis of arts-integrated learning permeates project-based and problem-based learning and other frequently facilitated classroom practices to advance student learning. The revisited curricular constructs speak to the interdependent twenty-first-century educational goals to build a sustainable future.[1]

The historical background of the goals of art education is a study in itself. In the newly formed United States of America, art education centered on the practical skills needed for nation-building seen in silversmiths, carpenters, woodworkers, and saddle-makers with honed attention on well-designed tools for farming and building. By the early nineteenth century, the first academic art school, The Philadelphia Academy of the Fine Arts (1805), provided instruction in oil painting and classical sculptural techniques in emulation of British, French, and Italian art schools. Regional folk styles in the growing United States intertwined aesthetic inventiveness with indigenous and traditional materials and subjects. The invention of photography employed by journalists and artists by the mid-nineteenth century captured domestic political conflicts alongside the expanse and diversity of the country's landscape and inhabitants. With growing economic growth, the Grand Tour of Europe by wealthy and/or adventurous American artists in the late 19th and early twentieth century provided first-hand encounters with classical archaeological histories as well as burgeoning stylistic changes to traditional academic teaching methods. The country's economic, political, and aesthetic needs depicted, at times, controversial ideas of manifest destiny, democracy, and economic prosperity. The global reach of the United States in the twentieth and twenty-first centuries has deeply informed the aesthetic proclivities and perspectives of working artists. Educators in all content areas acknowledge the interdisciplinary necessity of global understanding, have re-constructed curricular paradigms to address global challenges, particularly climate change, pandemics, borderless technologies, and food insecurity. The all-embracing language of the arts represents a communicative humanitarian strategy to dialogue with and generate possible solutions to contemporary problems.

[1] https://www.un.org/sustainabledevelopment/education/.

2 Advocacy for STEAM

The Ted Talk (2002) "teach art and science together" by Mae Jemison, an astronaut, a physician, and earlier in life, a dancer, reveals her equal passion and love for dance and the sciences. She finds it critical and vital to reintegrate the sciences and the arts in schools and questions what are people contributing to society right now if we do not understand that science and the arts should be taught hand-in-hand? Dr. Jemison debunks mistaken thinking that science is analytical, not creative, and the arts are creative but not analytical. Science is a universal experience, while the arts are a way to share individual experiences. She underscores this way of thinking by saying art and science require an intuitive leap, and both can be creative and analytical. Dr. Jemison's talk bolsters self-awareness and encourages people to take risks and put ideas into action.

John Maeda (2012), technologist, designer, executive, and past president of the art college Rhode Island School of Design (RISD) (2008–2013), speaks to how a world-class science, technology, engineering, and mathematics (STEM) workforce aims for "economic prosperity, international competitiveness, a strong national defense, a clean energy future, and longer, healthier, lives" for our citizens.[2] As an educator, he is keenly aware of competitive academic and political initiatives. As president of RISD, Maeda understood the school's culture as one of the makers, an idea articulated through something made with your hands, a dialogue between eye, mind, and hand. This leads to ideas about design that creates innovative products and solutions in and outside of the art studio. He initiates STEAM thinking where the arts are catalysts to fostering creative solutions to everyday problems [1].

Empowering students through design thinking is part of Maker Spaces, STEM, and STEAM classes. A Pennsylvania school district, for example, created a framework called launch with cyclical thinking: "look, listen, learn, ask tons of questions, understand the process or the problem, navigate ideas, create a prototype, highlight, and fix."[3] The program led students to make a "hybrid skateboarding park model" that created a ranking of roller coasters worldwide and solved graffiti problems by painting a mural accompanied by a digital launch [2]. STEM to STEAM thinking evolved with the continued goal of collaboration amongst disciplines so that subjects that were previously taught in isolation are now taught in an integrated curriculum.

3 Divergent Goals of STEAM

The tension in a STEM + the arts classroom [3] has side-stepped around whose creativity is being enhanced, engineering or visual art students. How does arts-based innovation further our national goal for economic well-being in creating

[2] https://www.energy.gov/diversity/office-economic-impact-and-diversity.
[3] https://mainlineparent.com/exploring-ancient-egypt-with-the-haverford-schools-third-grade/.

new industries? "Cultivating creativity for the primary purpose of promoting economic growth" has been questioned by STEAM practitioners [3]. The practitioners noted how aesthetic problems and project-based hands-on learning were embedded in the design studio activities of the study. The study recognized that personally relevant connections were being made among "materials, design, society, and the natural environment" for engineering and art students [3]. Nonverbal and intuitive thinking were parts of the engineering design process connecting to a "higher-order understanding of specific points of congruence" with the art students [3]. Art should not be looked at "as a panacea for increasing the creative abilities of STEM students" [3]. Indeed, STEAM learning leads students to think about their professional identity in a critical manner where creativity, as noted by Jemison, is understood to be part of all individuals' capabilities.

STEAM classes' goal is to increase school participation to ensure all students are engaged and involve more students of color and women in traditionally male-dominated academic areas. STEAM forwards the idea of connected learning, drawing on students' interests in authentic, real-world problems, and taps into outside-of-school learning through technology such as video production, digital sketching, and diverse and creative visual art materials [4]. Technology is understood as a social process, a communicative tool of everyday life. STEM and STEAM stress to make these connections, most insightfully, that art education, engineering, science, math, and technology are conceptualized as a social practice [5]. Social practice in STEAM classrooms is mainly concerned about how to engage the community is essential and can be facilitated and how ecologically sustainable development is achieved. For this matter, STEAM is learning of thinking through materials and considering the audience.

Educators, Sousa and Pilecki [6], have promoted in their book *STEM to STEAM: Using Brain-compatible Strategies to Integrate the Arts* the need to underline how the arts pave the way for the development of cognition, social aspects, creative thinking, and long-term memory, as well as stress management. By combining divergent and convergent thinking, scientists and artists have an expansive way of investigating problems. STEAM projects bypass standardized assessments utilizing new-found skills in problem-solving and our ever-evolving technology to serve critical issues best. The authors address the multifaceted nature of the visual arts – printmaking, photography, painting, sculpture/wood, stone, glass, metal, film, graphics, media arts, animation, environmental and industrial arts, urban space, landscape design, folk art, jewelry, and fiber arts highlighting the scope of the materiality of the visual arts addressed in the national arts standards. Closely examining the range and multiple forms of the materiality of art-making introduces non-art teachers to the scope of the visual arts and the benefits it might confer in other content areas. Through the social interaction of educators by incorporating the arts into the classroom, teacher collaboration benefits from each person's expertise.

4 Maker Spaces

Maker Spaces are a child's introduction to tool-based problem solving through tinkering, making, and engineering in early childhood education settings. "Tinkering" has been used to explain the engineering cycle of asking, imagining, planning, creating, and improving. This cycle establishes the pedagogical anchor that continues to be a part of elementary, middle, and high school classroom learning. Maker Spaces have been part of the design of STEM education for young learners; it has shown to be a catalyst for engagement and participation for students. The process of building and taking things apart in Maker Spaces is more important than the final product. Collaboration, communication, and experimentation are inherent components of a Maker Space environment. Reusing and repurposing parts of tools and machines are common practices to advance problem-solving skills, creativity, and risk-taking. The early childhood classroom Maker Space poses design challenges so that children make prototypes to see if they work or need revisions. Some design challenges are creating floating boats, birdhouses for different size birds, pet carriers, roller coasters, chairs, and shoes.

Heroman [7] provides a design challenge planning template for Maker Space projects:

- Identify a picture book where the characters have a problem;
- What is the problem in the story?;
- What are materials required for dealing with this problem?; and
- How do you encourage children to tinker with the materials?

An example of a Maker Space lesson required students to re-envision fairy tale plots such as Cinderella, Hansel and Gretel, and Three Billy Goats Gruff while also focusing on climate change issues. One of the design problem-based lessons described an alternative expedient escape route for Rapunzel from the tall tower where she was sequestered to the ground to avoid the notice of the sorceress. Rapunzel devises another way to escape with her prince instead of her long hair (or the rope she is weaving) being the ladder that her prince and the sorceress climb to reach her. She has watched how rainbows appear as arcs in the sky after heavy rains. She imagines a rainbow sliding down to the Earth from her high tower. Since life on the ground is engulfed by polluted air accentuated by burning wood causing atmospheric changes (dating from the eighteenth century when the fairy tale was written), people will not be able to see Rapunzel escape. People see "rainbows when sunlight passes through raindrops," which become "tiny prisms that bend the rainbow's seven different colors—red, orange, yellow, green, blue, indigo and violet in white light so the light spreads out into a band of colors that can be reflected back for a person to see" [7]. The rainbow arc becomes Rapunzel's arc-shaped slide down to Earth, enabling her to escape from the tower.

The Maker Space design problem allowed the children to create a multicolored rainbow out of ribbons or pipe cleaners and measure the distance of the prismatic arc. Rapunzel used the rainbow to slide on (the hypotenuse of the triangle) versus how far the prince or sorceress had to go (two legs of the triangle) to climb up or down the tower. The anticipated quandaries by students on the lesson were how high the students would want to build the tower to add to the excitement of the escape with the math problem and solution remaining the same. Additional discussions would focus on how water vapor forms which causes rain, the dissipating mist after a rainstorm, and how to diminish air pollution to see rainbows. This lesson is a building block towards a STEAM lesson where science, technology, engineering, art, and math are more developed and aligned with the Next Generation Science Standards (NGSS) and national math and art standards.

5 Contemporary Artists' Work: A Critical Resource for Transdisciplinary Teaching and Learning

"In the Impressionist artist Claude Monet's painting La Gare Saint-Lazare (1877) billowing clouds of steam emerge from the locomotives entering and departing from the busy Parisian train station. The steam from the trains blur the outlines of other train cars, the curved tracks, and triangular roof of the station" [7]. Monet's painting technique revolutionized aesthetic tradition, from valuing a work of art for its exact reproduction of imagery to that of a personal, often ephemeral, impression of an image or object. The curricular and pedagogical construct of STEAM aims to expand ideas of creativity. By students transcending the limitations of any singular content area, STEAM lessons widen their thought processes grasping analogous relationships in various content areas to empower learning. The following examples of STEAM practices align with selected contemporary artists' work and science and math K-12 standards to broaden aesthetic understanding.

6 Local and Global Geology

One's immediate surroundings form an initial understanding of geography. In NGSS, identifying both the geography and geology of the environment is critical. A landform lesson for second graders, working in groups of three, moved from their regular classroom to a separate room to create various landforms on sand tables. The temporary structures showed how the students molded shapes of sand into trapezoid/plateaus, valleys between mountains, and gullies from flash floods in deserts. The discipline-based vocabulary of scientific terms, direct manipulation of materials/sand, and the discussion of visual observations of the causes of physical changes due to erosion, platonic shifts, wind, ice, and rain were essential parts of science and art learning.

A landform lesson for 3rd–4th graders required additional cause-effect learning, new vocabulary. It prompted students to invent hand-drawn imaginary maps about the Earth's surface, e.g., bays, peninsulas, mesas, volcanos, deserts, and canyons. The students transformed the contour lines of their topographic maps into three-dimensional (3D) terrains using corrugated cardboard, glue, papier mache, rulers, and foam core. All were created to scale with the hands-on components of painting, measuring, stacking, and gluing. Rollings [8] understands this lesson as an example of embracing the synergy of science, technology, engineering, art, and math.

Advancing visual literacy about landforms can be enhanced by including the study of photographs and understanding the work of the British artist Richard Long.[4] He walks to create his work. The land is the fodder for artistic thinking and shapes his understanding of life. Long has said that he makes.

> Art about mobility, lightness and freedom.
> Simple creative acts of walking and marking
> about place, locality, time, distance and measurement.
> Works using raw materials and my human scale
> in the reality of landscapes.
>
> Richard Long

His photographs are of the places he has walked. They are documentation of the Himalayas, the Adirondacks, the Sahara, upland in Devon, United Kingdom, and other paths. He constructs linear and circular forms built with grass, rocks, snow, sticks, mud, and sand on his walks. He brings the outside into his large installations with vertical and/or horizontal orientations. Art is in concert with time and space for him, seeing motion and stillness sharing the same moment. His work is associated with land art and performance art. The artist's visceral and spiritual connection to the land augments the formal academic constructions of landforms' labeling.

7 Finding Space

A 4th-grade class examined modern paintings of the De Stijl movement by Theo Van Doesburg (1883–1931) and Piet Mondrian (1872–1944) to create a map of their local community generating visual fraction models to explain equivalent fractions. The instruction used fraction bars with real-world urban situations. Sketching on grid paper and observations of the inner-city landscape of the school were essential parts of the lesson. Assembling felt pieces to the paper created equivalent fractions that depicted an alignment with the Van Doesburg or Mondrian painting and the cityscape using fractional thinking. This lesson can extend to agricultural space where farmers need to divide acres of land for specific crops.

[4] www.richardlong.org.

The rectangular shapes and fractional thinking essential to the above-described lesson has resonance with the work of the contemporary artist Fred Sandback[5] (1943–2003), who has been said to carry his art in his pocket. He makes art with pieces of string. He is consumed with the physical details, the angle of vision, and the natural lighting of the architecture of his almost invisible work of outlining space with string. He is eager to understand the viewer's movement when seeing these more than life-size string contours of planes of space. Space is something we create and can be seen as illusionary; the most comfortable of perceptions, Sandback has said, are shadows. He has taken great effort in his planning of the measurements and ratios of the planes formed by his colored yarn or elastic. The materiality of installations is ephemeral and will be discarded after use; the titles of all his work are 'untitled.' Like a Van Doesburg or Mondrian painting, the idea behind the work is to experience space is a planar illusion.

8 Bones—The Skeletal System

A 4th-grade science lesson explains how the human skeletal system of 206 bones supports an individual and allows for intricate bodily movement. The Life Science lesson is aligned with the NGSS objective, how interactions of human/systems carry out everyday activities. Identifying the major bones of the human body presented and reinforced through an educational video and diagrams provided the necessary visual information for the students to start to create their own 30-s stop-motion animation with an accompanying soundtrack. The skeletal figure with movable limbs and torso were cut from cardboard and attached with split pin fasteners. The stop-motion animation was created by photographing the movements of the cardboard human skeleton on an iPad and importing them into the animation application. The images needed to be paced with the speed of the music. As student choreographers had to calculate beats per minute for their chosen musical score to figure out the number of frames per minute were required for their cardboard skeletal dancers. Students' verbal explanation of animation presentations assisted their comprehension of the elaborate skeletal structure of the human body. An extension to the skeletal lesson can look at the long-standing academic practice of studying and drawing the human form in visual art schools, academies, colleges, and universities.

The modern artist Nancy Graves[6] (1939–1995) was both a painter and sculptor. She had a youthful fascination with flora and fauna that evolved into a mature natural world investigation. She created "camel, fossil, totem, and bone sculptures that were hand formed and assembled from unusual materials such as fur, burlap, canvas, plaster, latex, wax, steel, fiberglass and wood." In 1970, her installation *Variability of Similar Forms* made of wax, steel, marble dust, and acrylic paint on

[5] www.lissongallery.com.
[6] www.nancygravesfoundation.org.

wood was a sculpture of several bent and straight leg bones and feet of large animals; the imagined grouping of the large leg bones of ostriches, giraffes, or prehistoric creatures are positioned as if the animals are standing around a watering hole. It appears as an unusual archaeological excavation site since the bones defied gravity by standing upright. A fascination with the structure of living forms and the intersections of art and science informs many of her paintings and sculptures.

9 Chemistry of Color/Pigments

Essential to scientific and aesthetic observations is how color/pigments are formed based on chemical reactions. An academy for 4th–6th grade girls conducted a physical science "investigation to determine whether mixing two or more substances results in new substances;" the young women were to develop a multi-colored palette for painting [9]. They experimented with acids/vinegar and bases/baking soda to change the color of vegetables, mixed soil and water to make mud, and added bubble solutions or dishwashing liquid to paints to make new colors. The students mixed, heated and/or cooled various ingredients in a kitchen to question when a new substance has been formed based on a chemical reaction indicated by a change of color, texture, odor, and/or density of a plant's parts. The students employed "commercial indicator strips to measure the pH (a scale used to measure acidity or basicity) of their painting materials" [9]. The students organized their findings by filling out a table tying observations of chemical reactions with argument-based reasoning to the various possible paint mediums.

The students then painted a multicolored design with their assembled tested substances. The gallery of student artwork showcased the results of chemical reactions with different substances. The aesthetic component of this STEAM lesson enabled students to generate design solutions based on observations of chemical reactions of acid and base elements to pigments. Measuring and observing the quantity of acid and base ingredients and the density of the pigments augmented the dual science and maths learning. The engineering cycle of planning, creating, improving, asking, and then further employing the new pigments was intrinsic to the design process of the lesson. Further research into the development of pigments and pigment sources can be explored through changes in paint bases and technology chemistry.

Color is essential to many visual art forms besides painting. Sheila Hicks[7] is a fiber artist who started her career in tapestry. She has lived in Guerrero, Mexico, and Paris, which has influenced the materials and coloration of her weavings and fiber sculptures. Colors such as saffron, forest-green, metallic tints, and deep blues are interwoven into her patterns of textured and thick and thin lines of the sculptural textiles. Hicks' predominately large weavings twisted and stretched often are assembled, appearing as bundles, or vertical waterfalls, or thick fibers spilling out of

[7] www.sheilahicks.com.

tightly tied ends. They are often made with durable synthetic fibers placed in interiors and outdoor landscapes. With polychromatic inclinations, Hicks' sculptural work squirms across a floor, climbs a wall, dangles from numerous hooks, and intermingles air and space with natural materials and dyed fibers.

10 Heat and Sand = Glass

A STEAM collaboration on volcano simulation, Earth and Space Sciences, through a glass-making experience with middle and high school students in Newark, New Jersey [10], highlights the inspiration and importance of understanding place-based natural settings. The unique collaboration with GlassRoots, a non-profit glass art studio with two glass furnaces, included hands-on geoscience:

- "learning about the heat of a volcano and lava, lava flows and the dangers they pose, forms of falling volcanic bombs, volatiles in lava, and interaction of lava with water;"
- "to give students an appreciation of the heat involved in igneous processes and an understanding of the properties of molten glass as a proxy for magma and lava, as well as solid and solidifying volcanic rock;" and
- "to give students an understanding of the fluidity and mechanical properties of lava, the results of interactions between lava with gases and lava with water, the mechanical properties and processes of hardening and crystallizing lava, and the geologic formations produced during a volcanic eruption" [10].

In the GlassRoots' studio, the "torch shop exercise" enabled students:

- "to learn the mechanics and form of falling volcanic bombs by producing Pele's tears (also known as Apache's tears in geology and Prince Rupert's drop in glass art), and Pele's hair out of glass;" and
- "to see how the acetylene torch can heat the end of a glass rod enough to melt it. Once the glass melts, it drips downward in a teardrop shape with a trailing, thread-like tail of glass while hardening. As the glass rod is pulled away from the flame, the thread connects the droplet with the rod and must be detached" [10].

Liquid droplets of the glass fall due to the force of gravity, making the teardrop shape. The size and texture of the glass drops are called Pele's tears because of their similarity to the lava drops from real volcanos. Obsidian and glass, stored in the cold shop of the studio, had conchoidal smooth curving fractures after being hit with a hammer. These features are similar to the shapes from the cooling of the glass observed in real-time during the glass studio experience. The dynamic interaction of water to cool the lava/molten glass and the factors controlling the speed of the volcanic lava were incorporated into the students' knowledge base. The multifaceted aesthetic outcome of the STEAM lesson was the effect of heat to change the shape of the glass, to see the infusion of color in the glass, and the excitement in making a glass necklace of Pele tears.

Glass as an art form can be readily accessed by examining the artist's work, glassmaker Dale Chihuly.[8] Higher-order Bloom questioning based on exploring Chihuly's work can

- advance students' transdisciplinary learning;
- describe the process of glass-making;
- compare one of the artist's bowls to a sea animal; and
- enable students to alter the color or texture of glass and do the glass-making process as a collaborative art.

Such questions are, for example:

- what is a blowpipe?;
- how does glass take on different shapes?;
- how does the artist use centrifugal force, gravity, and fire?; and
- do you look at glass objects in your own home differently than before studying the art of glass sculptures?

Dale Chihuly's work has been seen as public art through temporary exhibitions in Jerusalem, Israel (1999–2000), Venice, Italy (1996), and many installations in parks. The artist's wide range of coloration and organic forms echoes and advances the use of glass as both functional and artistic, as seen in his chandeliers, bowls, and varied-sized sculptures.

11 Curricula Constructions

Distinctions between interdisciplinary, multidisciplinary, and transdisciplinary curricula constructs are often not differentiated and thought to have the same meaning. An interdisciplinary approach is more directed towards learning through collaborative activities and interactions between different disciplines (art and science, math and art, science and math) and is best implemented in schools when there is organizational support from the school administration. Multidisciplinary is defined as "a combination of various disciplines and separate components of learning, which allows students to work within discipline specific parameters and attain discipline specific goals" [11]. Communication between the specific disciplines in multidisciplinary learning occurs but not necessarily collaborations. Through a transdisciplinary approach, learning leads to benefits similar to those an interdisciplinary approach can offer. This learning encourages students to learn and acquire knowledge and skills to produce new knowledge. STEAM teaching and

[8] www.chihuly.com and YouTube videos.

learning has developed a multidimensional perspective attempting quality interactions amongst disciplines with the added transdisciplinary aspect of problem-solving, forming new knowledge. In this way, the United Nations sustainable development goals (SDGs) mentioned at the onset of this chapter support a transdisciplinary perspective resulting in quality global education.

The alignment of contemporary artists' work with the STEAM-designed lessons detailed in this chapter is motivated by the intellectual desire to inform and expand educators' aesthetic purview. The inclusion of challenging and distinctive artists' perspectives is intended to enable transdisciplinary thinking to integrate new conceptual and theoretical models and extend discipline-based specific thinking. The Project Zero educator, Mansilla [12], has suggested the need for a fulfilling life is to nurture synthesizing minds. Curricular resources rarely delve into new aesthetic perspectives, particularly by contemporary artists. However, these individuals address critical issues, such as climate change, food insecurity, industrial innovation, responsible consumption, and production. Transdisciplinarity is a dynamic form of inquiry demanding corrigibility and the ability to create analogies in a range of academic disciplines.

12 Clay-Making Processes and Products

Critical cultural teaching and learning culminated in a seminal ceramic art-making experience near Puget Sound in the state of Washington during two summers to mobilize non-dominant community youth's everyday interests and practices with ways of making knowledge from storytelling, walking, and clay-making [13]. Indigenous artists discussed design principles and past, present, and future technologies in clay-making and weaving. Indigenous scientists engaged with the participants on the need to walk and observe the land, clay, and beach deposits and water-acidity of the tidal pools and its living inhabitants to critically understand the timelessness of intergenerational communal activities of molding and working clay.

Clay-making became a type of cyclical storytelling, elaborating on the process of making clay and reading the land and waters that inform its design and pattern. The youthful participants noticed how impermeable clay is and how dependent a good aquitard with chemical changes is on the embedded minerals. The animate and agentic nature of clay holding onto a spirit embedded in the clay was reinforced through storytelling. Clay's role in the ecosystem and its relationship to land and water manifest in its materiality was central to the STEAM workshop. The participants needed to make intentional decisions in their object-making with clay channeling ancestral stories and ecological systems. Plants and sea life (starfish) and trees and animals, e.g., otters and wolves, were potential inspirational designs to be part of the clay sculptures. Students formed incense burners that evoked the shapes of animals and the spirits of nature, and the elders. The life story of endangered animals was infused into some of the sculptures re-conceptualizing the life source of art-making. Clay-making is a science by understanding its properties as part of an ecosystem. It is also infused with human interactions recalling indigenous ancestral stories.

The American artist Betty Woodman[9] (1930–2018) understood that forming pottery and inventive sculptures using ceramics employed her intellectual, technical, physical, and aesthetic skills early in her life. She performed ambitious experiments with clay that greatly enhanced her work's color, shape, and scale. The long history of creative uses of clay as an artistic medium was reinforced by Woodman's travel to Italy (Etruscan), Spain (Majolica), and Greece (Minoan). Her fascination with Minoan pottery's inherent movement and design and the glazes of diverse cultures influenced her own work. She is inventive not only by disturbing the function of the pottery but also by creating sculptural pieces that exude a sense of humor and display unique coloration and juxtapositions. Her experiential investigations of the locale where the clay has been employed as an artistic medium create a new art history of the medium.

13 Evolution and the Dinosaur Fossil Record

"Are birds dinosaurs" is a provocative question for any child over the age of four when dinosaurs become an animal of great fascination? Since the 1990s in northern China, fossil records have been found indicating feathered imprints in an avian animal's rock with otherwise dinosaur features. The DNA sample suggests that the feathers had various colors. Hollow bones, hip sockets that let an animal stand on two legs, wing structures, beaks that take the place of teeth, claws that appear at the end of wings, three-toed feet with leathery skin like chickens, and giant eggs found in clusters of nests are some of the shared characteristics of birds and dinosaurs that roamed the Earth at one time. Fifth-grade students became novice paleontologists studying the evolution of avian dinosaurs and birds through the American Museum of Natural History website.[10] The website has videos, text, and interactive activities to guide students through the timeline of animal life on Earth, the Big Bang theory of the destruction of the dinosaurs and the adaptive changes to food sources, climate, and the structural and chemical bodily capabilities of avian and non-avian dinosaurs. As amateur paleontologists, students were given clear straws (hollow bones of legs, body, wings, colored feathers, clay, and textured plates/leathery skin), cardboard (beak, claws, and teeth), and tape and glue to design and assemble a prototype of one of the stages of imagined evolutionary development of avian dinosaurs with an eye on current bird species. The group project required careful investigations into the timeline of various groups of dinosaurs, the conjectures of past paleontologists during their discoveries, the actual fossil record, and the structure of various birds today. The iterative steps of the engineering cycle of ask, imagine, plan, create, and improve is part of this STEAM-based lesson on avian evolution.

[9] www.salon94.com.
[10] www.amnh.org.

The Chinese artist Xu Bing[11] destroys preconceived notions of historical truths. He used a lightbox of found natural materials such as grasses and tree branches to mimic a classical Chinese landscape painting. He created a social commentary on tobacco use by constructing a 40' simulated tiger-skin rug made of over half a million cigarettes generating a conversation about the appeal of tobacco and its deathly effects. One of his most monumental works are two phoenixes made from construction debris sourced from a Beijing high-rise building site. He rethinks what cast-offs are, human exchanges, and social connection is. He is in constant dialogue with the past as artistic and cultural history. The Phoenix Project (2007–2010) is 26' × 93' and 26' × 100' and was commissioned for a lobby for a new high-rise building in Beijing. When Xu Bing visited the site, he was appalled by the living conditions and sacrifices made by the migrant laborers working on the building and changed the direction of the art installation. The "discrepancy between these workers' plight and the luxurious lifestyle"[12] of the to-be inhabitants of the new building became the aesthetic, conceptual basis of the artwork and concurrently the harmful effects of China's expeditious urbanization. The Phoenixes were assembled using industrial tools and the cast-off building materials from the construction site, e.g., "pipes, shovels, tire rims, jackhammers, saws, pliers, and drills" conforming to the ornithoid anatomy and fastened together with great precision. The birds' talons are steel claw scoops, and the body includes hard hats, fire extinguishers, fans, and goggles [14]. The work of collective labor is evident in the building of the enormous sculptures and the work of the Beijing high-rise apartment building. The intention of Xu Bing's work signifies hope and unity to build a better world. The reimagining of the conceptual direction of the sculpture is an example of the rethinking of established understandings that can be extrapolated into social, aesthetic and/or scientific investigations.

14 Fibonacci and the Golden Ratio

"In mathematics, the Fibonacci numbers, commonly denoted F_n, form a ***sequence***, called the Fibonacci sequence, such that each number is the sum of the two preceding ones, starting from 0 and 1."[13] The Fibonacci spiral is referred to as "an approximation of the ***golden spiral*** created by drawing ***circular arcs*** connecting the opposite corners of squares in the Fibonacci tiling."[15] Fibonacci numbers closely correspond to the ***golden ratio***, which is represented by the Greek letter phi: It is called the golden ratio since it appears so often in nature. We can see the Fibonacci numbers as tree branching patterns, ***leaf arrangement on the stem***, pineapple growing, ***artichoke flowers***, an uncurling ***fern***, bract–scale structure of a pine cone, and sunflower petals.

[11] www.xubing.com.

[12] https://brooklynrail.org/2014/12/artseen/xu-bing-phoenix-xu-bing-at-the-cathedral.

[13] https://www.geocaching.com/geocache/GC8BXP7_fibonacci-sequence-01-1?guid=a5f64d9e-da0b-4d34-b8f8-50156ed2827f.

The high school students need to “apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios.”[14] In a high school math lesson, students worked to identify the Fibonacci pattern and design formula. Students were shown visual images of the Fibonacci sequence in nature, underscoring the phenomena of the observed pattern. Students drew the golden rectangle part of the composition in Michelangelo’s painting *The Creation of Adam* 1508–1512. Students worked with a Golden Ratio template for designers using a 3D printer to understand works of art and patterns in nature.

Tara Donovan is an installation artist who evokes the natural world through the multitudinous use of everyday materials such as clear drinking straws, Styrofoam cups, clear buttons, silver-blue fish line, mylar, adding machine tape, plastic sheets, scotch tape rolls, metal slinkies, and toothpicks.[15] How light infiltrates through the often translucent materials adds to her site-specific installations’ natural and otherworldly quality. The repetitive use of her materials form clusters appearing, at times, like low-hanging clouds, undulating waves, and mountains experiencing entropy, mathematical formulae, and natural phenomena. The sculptures appear as examples of exponential growth, with the dimensions of the pieces accommodating the size of the gallery. Reminiscent of the Fibonacci occurrence in nature, many of Donovan’s installations are seen as mold growth, termite colonies, and strange crystal formations or pollution-caused haze; nature is paired, at times, with a sense of dread or foreboding. The intrinsic aesthetic of the work stems from its innovative use of the multitudes of clear or metallic quotidian materials creating analogies to unbridled consumerism and a deep connection to the precarious rhythm of our twenty-first-century world.

15 Bird Migration

Climate change was almost immediately noticed by ornithologists and citizen bird watchers, indicated by disrupted temporal sightings of flocks of migrating birds. Birds were leaving southern locations too early to find food and give birth to their young to nurture reproduction. Temperature and climatic changes were providing misleading seasonal signals for bird migrations. The birds were then confronted with a dangerous loss of seed production in different climes and changes of winds and rainfall inhospitable to their survival. The NGSS requires students to learn about the lifecycle of animals in several elementary grade levels with increased levels of synthesis of intervening factors in middle and high school. The study of migrating birds includes both life and physical sciences and a visualization of the Earth’s geography. Understanding and documenting the diverse migration routes of birds such as arctic terns, hummingbirds, pelicans, warblers, and hawks required

[14] https://tasks.illustrativemathematics.org/content-standards/HSG/MG/A/3.
[15] www.pacegallery.com.

students to employ Google Scholar and Google Earth research on the selection, timing, and geography of the migrating birds.

Visually conceptualizing singular birds' migration routes in the secondary education classroom was developed by constructing large balloon globes to represent the Earth. Each continent was cut out of different color paper and glued to the globe; students created origami birds (a generic bird form) that were taped to fishing wire or yellow, red, or green covered electrical wire and attached to the balloon globe indicating the seasonal flight paths of the researched birds. Students searched for apps of recorded bird songs animating the classroom discussion on bird migration. Bird chatter is often heard at dawn, and dust is an indicator of the daily passage of time. Migrating terns move longitudinally across the globe to both arctic poles while other birds like the warbler have latitudinal migrations from East to West, from Europe to the United States, while raptors fly from Eurasia to northern Africa. Scientists observe the semi-annual migration and have suggested that Earth's magnetic forces, thermal currents, and temperature have propelled the extraordinary journey. Viewing diving, swirling, and swooping flights of flocks of birds embodies an aesthetic of freedom and a marker of anticipated seasonal change around the world.

The artist James Turrell has created light installations understood as sculpture uniting volume and the picture plane as a space for contemplation.[16] The colors of his light installations range from lavender to shades of green and beyond. His work *Meeting*, 1986 uses natural light from above and opens up to the winter sky at dusk. The Roden Crater Project (an extinct volcano) near Flagstaff, Arizona, began in 1977. It is ongoing through a series of tunnels and apertures to heighten our sense of heaven and Earth. He often uses LED lights that refer to passageways and stages of consciousness and a primal connection to light. He speaks of bringing the light to Earth in his light installations and understands light occupying real space. He is a sculptor [15] whose media is the physical presence of light made manifest in sensory form with an aerial sensibility. Born a generation later, the artist Duke Riley[17] has a similar aesthetic intuition as he embraces the light where the land and water meet. In 2016, the sky at nightfall at the Brooklyn waterfront was the canvas for the orchestrated movement of 2,000 trained pigeons with LED lights attached to their legs; the performance was called *Fly by Night* in April–May 2016. The breed of pigeons included Ice pigeons, pigeons with delicate black wing tracings; Damascenes, white pigeons with blackheads; Russian highfliers, pigeons with silver heads; Rollers, brown pigeons collared and acrobatic; and red-beaked New York Flight pigeons who were all trained to return to their coops after their original 30-min choreography with leg castings of LED lights. The LED lights were controlled remotely, with the birds clued to return to their starting point by the turned-on light at their coop and a familiar musical soundtrack. *The New York Times* reviewer, Newman [16], compared the imaginative light bird display akin to a giant cluster of fireflies, constellations moving very fast, fireworks that change

[16] www.jamesturrell.com.

[17] www.dukeriley.info.

direction, or most arresting the idea of the lights in the New York skyline taking to the air. While bird migration is a scientific study, an aesthetic re-envisioning of a portion of the natural phenomena entreats more comparisons to the use of light, time, and nature in human space.

16 Further Implications

Art and science museums recognize the important and expansive reach of digital learning in our new virtual reality. At the Morris Museum in Morristown, New Jersey,[18] their collection of Murtogh D. Guinness Collection of Mechanical Musical Instruments and Automata (750 objects) is supported by text and videos of the examples of the charm and originality of luxurious automata produced in Paris in the late 1800s through the early twentieth century. Automata are small metallic or wood human figures depicting chefs, circus performers, waiters, girls, boys, famous personages such as Buffalo Bill, and animals who come alive through their mechanical movements. A century ago, the movements activated like a player piano with punch cards were a step forward in the marriage of art, technology, and entertainment.

Science museums, for example, the American Museum of Natural History[19] in New York City, have designed a particularly engaging website for K-12 learners entitled 'ology' taking the suffix of paleontology, geology, zoology, and archaeology to widen one's perspective of the sciences. Science centers, e.g., the Exploratorium[20] in San Francisco, The Liberty Science Center[21] in Jersey City, and the Field Science Museum[22] in Chicago, offer online videos and blogs as resources to further student STEAM learning. Art museums' websites focus on permanent and/or changing exhibitions and collections, entreating educators, students, and the general public to observe and apply critique methodologies to more fully understand the work of visual artists over time. The art museum websites such as the Museum of Modern Art in New York[23] provide cultural and historical information to engender meaningful interpretations of specific works of art. In this way, museum websites are digital resources of visual information essential for STEAM teaching and learning [17]. Students demonstrate greater motivation and involvement as well as "learn more deeply when they can apply classroom-gathered knowledge to real-world problems, and when they to take part in projects that require sustained engagement and collaboration" [18]. Student investigations can extend beyond the classroom walls to embrace local and global museums. Artists and scientists focus on authentic problems requiring collaborative transdisciplinary thinking and action in this often-overlooked resource.

[18] www.morrismuseum.org.
[19] www.amnh.org.
[20] www.exploratorium.edu.
[21] www.lsc.org.
[22] www.fieldmuseum.org.
[23] www.moma.org.

17 Conclusion

The alignment of contemporary artists' work with transdisciplinary teaching and learning in STEAM education provides apt analogies and possible metaphors to synthesize meaning from visual information to further intellectual, social and emotional understanding of our interconnected world. One can explain Richard Long's walking as a metaphoric contemplation of time on Earth; Fred Sandback's string sculpture as an aperture to spatial thinking, Nancy Grave's skeletons as a synecdoche of evolution, Sheila Hick's fibers as entanglement with natural pigments; Dale Chihuly's use of fire as a reconnection with the origins of sea and plant life; Betty Woodman's technical ceramic experiments to reimagine civilizations; Tara Donovan's translucent multitudes as an allusion to exponential growth in evolving Earth; Xu Bing's installations as a dually subtle and confrontational revelation on social inequity, and James Turrell and Duke Riley's manipulation of light as a spiritual and temporal sensor of time on Earth. Analogies and metaphors frame reality in terms of similarities between constructs of different realms [12]. Curricular constructs embedded in the interdependent twenty-first-century educational goals to build a sustainable future[24] are enhanced and realized through aesthetic analysis and research into exemplar educational practices.

> Who says that intuition is not data.
>
> Laura Fattal

Core Messages

- Educators' aesthetic purview is expanded through analogies intrinsic in contemporary art production.
- Synergistic practice is social and collaborative invigorating experimentation.
- The natural world with its lines, shapes, spaces, and colors is a perennial source of aesthetic inspiration.
- Materiality/media of art-making is a spiritual and individual calling resonating in its dialogue with global needs.

Acknowledgements The author would like to acknowledge Noelle Mironis and Grisela Pervisi, graduate students at William Paterson University, and Jacqueline Pisano, Jessica Romero, and Allison Thorn, undergraduate students at William Paterson University.

[24] https://www.un.org/sustainabledevelopment/education/ UN Sustainability Goals.

References

1. Maeda J (2012) STEM to STEAM: art in K-12 is key to building a strong economy. https://www.edutopia.org/blog/stem-to-steam-strengthens-economy-john-maeda
2. Spencer J (2017) The genius of design. Educ Leadersh 74(6):16–21
3. Sochacka NW, Guyotte KW, Walther J (2016) Learning together: a collaborative autoethnographic exploration of STEAM (STEM+ the Arts) education. J Eng Educ 105 (1):15–42
4. Quigley CF, Herro D (2019) An educator's guide to steam: engaging students using real-world problems. Teachers College Press
5. Guyotte KW, Sochacka NW, Costantino TE, Walther J, Kellam NN (2014) STEAM as social practice: cultivating creativity in transdisciplinary spaces. Art Educ 67(6):12–19
6. Sousa DA, Pilecki T (2013) From STEM to STEAM: using brain-compatible strategies to integrate the arts. Corwin Press
7. Fattal LR (2017) Into the Woods-environmental problem solving through STEAM lesson planning. STEAM J 3(1):8
8. Rolling Jr JH (2016) Reinventing the STEAM engine for art+ design education, vol 69. Taylor & Francis
9. Sullivan PT, Conner LDC, Guthrie M, Pompea S, Tsurusaki BK, Tzou C (2017) Colorful chemistry. Sci Child 54(8):34
10. Gates AE (2017) Benefits of a STEAM collaboration in Newark, New Jersey: Volcano simulation through a glass-making experience. J Geosci Educ 65(1):4–11
11. Park J-Y, Son J-B (2010) Transitioning toward transdisciplinary learning in a multidisciplinary environment. Int J Pedagogies Learn 6(1):82–93
12. Mansilla B, Learning VI (2017) A cognitive-epistemological foundation, vol 261. The Oxford handbook of interdisciplinarity
13. Barajas-López F, Bang M (2018) Indigenous making and sharing: claywork in an indigenous STEAM program. Equity Excellence Educ 51(1):7–20
14. Roniger T (2015) XU BING Phoenix: Xu Bing at the cathedral. https://brooklynrail.org/2014/12/artseen/xu-bing-phoenix-xu-bing-at-the-cathedral. Accessed 01 Jan 2022
15. Haber J (2013) The illusion of minimalism review of Pace Gallery/2007 and Guggenheim 2013 http://www.johnhaber.com/
16. Times TNY (2016) 2000 Pigeons will put on a light show in Brooklyn. https://www.nytimes.com/2016/04/29/arts/design/-duke-riley-pigeons-fly-by-night.html
17. Guzey SS, Moore TJ, Harwell M (2016) Building up STEM: an analysis of teacher-developed engineering design-based STEM integration curricular materials. J Pre-College Eng Educ Res (J-PEER) 6(1):2
18. Barron B, Darling-Hammond L (2008) Teaching for meaningful learning: a review of research on inquiry-based and cooperative learning. Book Excerpt. George Lucas Educational Foundation

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Entrepreneurial STEM for Global Epidemics

25

Sila Kaya-Capocci and Sedat Ucar

If opportunity doesn't knock, build a door.

Milton Berle

Summary

Entrepreneurship and STEM have become prominent on educators' agendas in the past two decades. Many countries included STEM in their education programs since it can develop society, economy, environment, and health. Similarly, entrepreneurship became one of the concepts extensively embraced in education programs as it offers individuals self-employment as a career opportunity and equips them with 21st-century skills, particularly problem-solving, risk-taking, and creativity. Studies show that when STEM and entrepreneurship are employed complementary to each other, higher social and individual benefits occur as educational outcomes than when they are employed independently. However, a limited number of studies argue why incorporating entrepreneurship into STEM education and promoting entrepreneurial STEM education brings durable or permanent innovative solutions to the issues in health, economy, and social relationships. This chapter elucidates how entrepreneurship and STEM are related, how to incorporate entrepreneurship into STEM education and its importance,

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N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3_25

particularly in global epidemics. To take a closer look at why we should achieve entrepreneurial STEM, we explore STEM education and entrepreneurship, discuss the link between entrepreneurship and STEM education, and the benefits and drawbacks of incorporating entrepreneurship in STEM education. This argument is followed by examples of practical STEM strategies and practices adapted to create entrepreneurial STEM students with scientific, economic, social, and environmental awareness. Furthermore, three levels of action are proposed to incorporate and implement entrepreneurial STEM education.

Graphical Abstract/Art Performance

Entrepreneurial STEM for global epidemics.

Keywords

COVID-19 · Education · Entrepreneurial STEM education · Entrepreneurship · Epidemic · STEM

QR Code

Scanning the QR code directs you to the word cloud of the chapter that is made up of the words we discussed throughout the whole book in relation to the chapter's keyword, which is intentionally not included in the word cloud. Find the keyword and put it in place in the puzzle according to the clues provided in Chap. 26. The mystery hidden in the puzzle is the quote of *Integrated Education and Learning*.

1 Introduction

Opportunities do not knock on the door. Agreeing with Milton Berle, "*If opportunity doesn't knock, build a door*." This might mean that we should create our own opportunities in this global world, or we should be receptive to the opportunities. However, how will we do this or, more importantly, why should we do this? The answer might lie in entrepreneurial STEM education.

Entrepreneurship education and STEM education have been studied extensively; however, there is still a limited number of studies that investigate the role of entrepreneurship in STEM education. The research focusing on STEM and entrepreneurship discusses the benefits entrepreneurship education confers with STEM students, examines the role of gender in entrepreneurs from STEM disciplines, and provides examples of implementing entrepreneurship in STEM programs. For example, Camesano et al. (2016) mentioned that Worcester Polytechnic Institute (WPI) is engaged in a program incorporating innovation and entrepreneurship into the curriculum for Ph.D. students researching STEM disciplines [1].

There are also projects implementing entrepreneurship into STEM disciplines. For example, the STEMitUP,[1] an Erasmus + project that was conducted with the partnership of five European countries between 2017 and 2019, aimed to increase interest in STEM entrepreneurship amongst European students. All these studies are highly important for entrepreneurship to be integrated into STEM education and inclusivity of the entrepreneurial STEM programs. Despite the significance of the

[1] See https://www.stemitup.eu for the project details.

research conducted in this field and the great impact of entrepreneurial STEM education on areas such as health, science, environment, and society, the explanation of why incorporating entrepreneurship into STEM education is important, and the link between entrepreneurship and STEM remains limited to its impact on the economy.

The recent global pandemic, COVID 19, deeply affected our lives, from how we work to what we need in everyday life, as well as impeding many things such as health, economy, and social relationships. There is an ongoing process of attempting to manufacture a vaccine and finding treatment procedures to bring the development of this virus to a halt and resuming where we left our lives. Every person in the world has suffered directly or indirectly for many months, and developing only a vaccine for the virus is not the solution to our problems. What is going to happen if there is another outbreak in the future?

If we want to bring a permanent solution to the problem, we need to go to the roots of the problem that underlies education, as explained in the following. Developing entrepreneurial mindsets should gain more importance in STEM fields during and after this process than before the pandemic. It is obvious that STEM is needed to discover a vaccine but what is not obvious is that entrepreneurship can facilitate the discovery process during and after by bringing a fresh, innovative perspective and helping realize what we have not realized before. Furthermore, after a vaccine is discovered, entrepreneurship can help apply the new STEM knowledge into different contexts and spread this knowledge and the product across the world. Similarly, through an entrepreneurial lens, students may realize STEM in everyday life easier and apply STEM competencies (i.e., knowledge, skills, and attitudes) into different contexts. These students with the entrepreneurial STEM perspective may realize the everyday issues, such as global pandemics, and bring solutions to them in a practical, economical, and innovative way. This may eventually support scientific, economic, and social development and prepare us for future outbreaks through increasing awareness.

Therefore, this chapter aims to elucidate how entrepreneurship and STEM are linked, how to incorporate entrepreneurship into STEM education, and its importance, particularly in times of global epidemics. More precisely, we initially explore what is meant by STEM and the reasons for promoting STEM education. This exploration is followed by a scrutinization of what entrepreneurship means in the formal field and the benefits and drawbacks of incorporating entrepreneurship in STEM education. How entrepreneurship links with STEM education and its importance are argued. This argument is followed by examples of practical STEM strategies and practices that would be used to create entrepreneurial STEM students with scientific, economic, social, and environmental awareness. Furthermore, three levels of actions are proposed to incorporate and implement entrepreneurial STEM education.

2 STEM Education to Develop the Society, Economy, Environment, and Health

During the last few decades, the required competencies for graduates' employment have been changing, and STEM education is becoming more prominent worldwide [2]. Yet, there is no formal agreement on what STEM education means. Perspectives to STEM education range from rudimentary descriptions of the four STEM disciplines to a unified collective of all four STEM disciplines [3, 4]. According to Bybee (2013), definitions of STEM education include:

- "science (or mathematics);
- both science and mathematics;
- science and the incorporation of technology, engineering, or mathematics;
- a quartet of separate disciplines of science, mathematics, engineering, and technology;
- science and mathematics that are connected by a technology or engineering program;
- coordination across disciplines;
- combining two or three disciplines;
- complementary overlapping across disciplines; and
- a transdisciplinary course or program" [3].

We believe that perspectives to STEM should be supported according to the main aim of education. However, we find it more useful and holistic to support all STEM disciplines. For example, if we are educating graduates in the health sector, even if we focus on science more, we should support it with:

- technology to conduct experiments;
- engineering to develop and use devices, such as MRI scanner; and
- mathematics to calculate the frequency or the dosage of a medicine.

Many countries, such as the USA, Austria, and Ireland, referred to STEM education curricula, policies, and government reports. For example, Costello et al. (2020) surveyed partners of an Erasmus + project from eight European countries [5]. The survey results showed that six countries/regions, i.e., Austria, Cyprus, Flanders, Galicia, Ireland, and Slovenia, have STEM policies directed at Pre-school and Secondary levels. Still, STEM for higher education, postgraduate and adult education was missing.

Various reasons are provided to justify the reason for promoting STEM education and referring to STEM in education systems. Some of these reasons include developing society, environment, and/or economy [6], creating innovative citizens [4, 7], increasing the low number of STEM graduates [8], and providing STEM graduates for the job market [8, 9]. Other than these reasons provided, STEM education provides many benefits and opportunities to students.

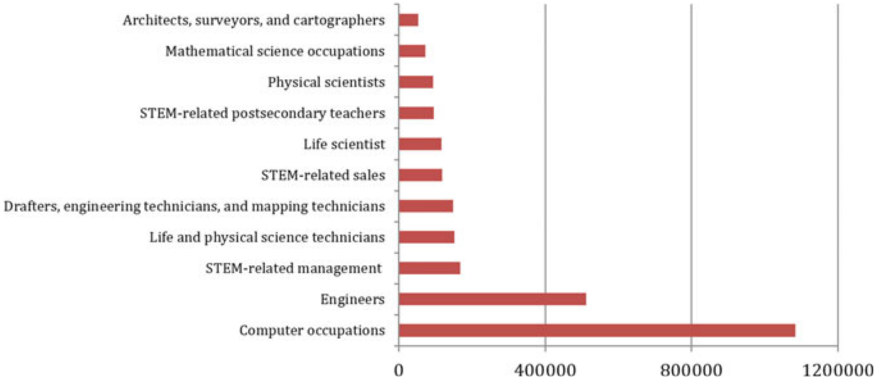

Fig. 1 Projected job openings for types of STEM occupations, 2014–2024 (*Source* the U.S. Bureau of Labour Statistics, [14])

The graduates embracing STEM competencies can analyze, synthesize, and evaluate the problems, develop and apply projects in practice, use numeracy to bring solutions to problems, acquire life skills such as leadership and citizenship and show technical ability to maintain engineering-related concepts. Due to being equipped with these STEM competencies, graduates can also realize their full potential and effectively face the challenges that come with higher education and career development [10]. Therefore, employers hire and provide more opportunities to graduates who are equipped with STEM knowledge, skills, and attitudes and can solve problems by combining these competencies better than STEM-illiterate graduates [11]. STEM-literate citizens can use, manage, understand, and assess STEM disciplines and their applications in everyday life. There is a great demand for STEM graduates due to technological advancements and the changes in the way that we live in this global world. For example, the need for 114,000 STEM graduates was reported in Germany in 2011, and the need for 380,000 to 700,000 ICT graduates was reported in Europe in 2015 [12]. Furthermore, "Europe faces a shortage of around 756,000 ICT professionals by 2020, with a lack of synergy between educational systems and the requirements of the labour market" [13]. Similarly, job openings for STEM occupations are projected by the "U.S. Bureau of Labor Statistics," as shown in Fig. 1 [14, p. 12]. Supplying more STEM graduates can help decrease the demand in the market and the number of unemployed citizens.

A decrease in unemployment improves the country's economy. In addition to its direct contribution to employment and indirect contribution to the economy, STEM fields are crucial to economic growth. STEM fields develop new devices and inventions in this direct role and export these new products and services to other countries. Also, these STEM products and services enhance the standard of living and provide social utility. Once economic development occurs, more funding can be provided for education, society, and the environment. For example, with the enhancement of sustainable development, companies and businesses aim to reduce carbon emissions and become more environmentally friendly. Additionally, STEM education helps develop the health sector.

When there is a global epidemic, people need vaccines and/or treatment, and STEM education can aid this process in many ways. STEM-literate citizens may be curious about the national and global issues and attempt to help solve them by inquiring about the nature of the issue, researching it, conducting relevant experiments, and innovating devices that can facilitate solving these issues. STEM education can help engineer devices for treatment, develop medicine, conduct tests to diagnose people, increase communication between people and scientists, inform the public through technology and increase their awareness of the conditions across the world. For example, a doctor can currently operate a surgery from a different country than the patient through a control panel connected to robot hands.

An approach referring to STEM-related concepts and theories at schools can support students to realize how school, society, economy, and environment are interlinked and how they can be developed together. Students need to be exposed to an effective STEM education program to achieve all these developments. For effective STEM education, students should be able to solve problems and use reasoning and be creative, innovative, self-confident, and technology-literate [15]. Developing graduates equipped with these competencies may be achieved by adopting innovative and entrepreneurial approaches.

3 Understanding Entrepreneurship: Business, Competence, Process, or More?

Recently, many studies have discussed entrepreneurship from different perspectives in different disciplines, for example, the formal field of entrepreneurship, education studies, and pure and applied sciences, including science, technology, engineering, and mathematics. The research shows how entrepreneurship education can positively influence the individuals' entrepreneurial perspective [16–20]. Developing a "sense of initiative and entrepreneurship" is also identified as one of the four main goals of education by 2020 by the European Commission (2014) [21] and advocated as one of the eight key competencies by European Commission (2016) [22]. Volkmann et al. (2009) also viewed entrepreneurship as one of the basic 21st-century skills that all children should acquire before reaching adulthood [10]. Entrepreneurship may also be interpreted as a driving force that can develop competencies effectively to gain and enhance 21st-century skills.

Having various studies on entrepreneurship brings up many questions. What is entrepreneurship; a competence, a process, an effort, or a business initiative? Why do we focus on entrepreneurship; just because it is a trend? What are the reasons for researching entrepreneurship? We can pose many more questions. In this section, we aim to answer these questions to some extent.

What is entrepreneurship; a competence, a process, an effort, or a business initiative?

To promote the beneficial use of entrepreneurship, we need to understand the various perspectives. Different researchers viewed entrepreneurship from different perspectives; some view it as a business initiative, some view it as an effort, some view it as a process, or others view it as a competence.

At early times, entrepreneurship was viewed as related to trading and commerce. For example, Schumpeter (1934) defined entrepreneurship as "carrying out new combinations of a firm's operation including different dimensions, such as new products, new services, new source of raw materials, new methods of production, new markets and new forms of organisation" [23]. A discipline-specific concept of entrepreneurship usually adopts the financial perspective of entrepreneurship and addresses the challenge of forming a new business [24]. For example, from a traditional perspective, Jean Baptiste Say emphasizes the primary goal of entrepreneurship as economic development and defines an entrepreneur as a person who can achieve economic progress by finding ways to do new and better things. Other traditional definitions depict the topic from a similar angle and align with Say's definition in essence. For example, Mark Casson (1982) defines the entrepreneur as an individual specialized in making effective decisions using limited resources [25]. Again, the main goal here is to increase the economic efficiency of limited resources.

Entrepreneurship is also defined as a process, and various definitions of entrepreneurship agree on "a kind of behavior," which is composed of

i. "initiative taking;
ii. the organization and reorganizing of social and economic mechanisms to turn resources and situations into practical account;
iii. the acceptance of risk or failure" [26]

As suggested by Hisrich and Peters (2002), entrepreneurship is "the process of creating something different with value by devoting the necessary time and effort; assuming the accompanying financial, psychological, and social risks; and receiving the resulting rewards of monetary and personal satisfaction and independence" [27]. Allen (2003) refers to some other aspects of the process of entrepreneurship and defines it as "the process of organising," that includes "committing resources to an opportunity; establishing procedures for the use of resources; identifying, assembling and configuring resources; and interacting with people and coordinating and establishing routines" [28]. Kaya et al. (2018) combine these aspects and define entrepreneurship as "the process of establishing new economic, social, institutional, cultural and scientific environments or organizations to create future products and services by realising the opportunities and their possible failures and using required resources" [29].

Some view entrepreneurship as an effort to create new environments. For example, Rindova et al. (2009) define entrepreneurship as efforts to create new environments [30]. This definition has "creating environments" in common with the definition of entrepreneurship as a process.

Many researchers defined entrepreneurship as a competence that is needed by the public due to technological and global changes. Since the 1980s, there have been researchers defining entrepreneurship as a competence. In Timmons' words, entrepreneurship is referred to as "the ability to create and build something from practically nothing, it is initiating, doing, achieving and building an enterprise or organisation rather than watching, analysing or describing one" [31]. In 2014, the European Commission referred to entrepreneurial knowledge, skills, and attitudes [21]. A model including the competencies that refer to entrepreneurship was adapted from Heinonen and Poikkijoki (2006) [32] and presented in the document "Entrepreneurship Education at School in Europe" published by the European Commission in 2012 [33]. Based on the model, Entrepreneurship Education at School in Europe reported the aspects of attitudes, knowledge, and skills for entrepreneurship in Table 1 [33, p. 19].

Even though many researchers believe that entrepreneurship is a competence that people are born with [34, 35], others believe that entrepreneurship is a competence that can be learned [36]. Research studies reported the positive effect of entrepreneurship education on individuals' entrepreneurial competencies [16–20]. Within this context, entrepreneurship education, an objective of the European Union, should be supported at every stage from primary school to university and beyond [21].

Why do we focus on entrepreneurship; just because it is a trend? What are the reasons for researching entrepreneurship?

Researchers have different reasons to investigate entrepreneurship; some researchers investigate it simply because it is currently a worldwide trend, but others explore it because they believe in the opportunities entrepreneurship can accompany. There are various benefits of incorporating entrepreneurship into different disciplines. For example, entrepreneurship can provide self-employment as a career opportunity [24, 37] and increase public awareness of economics-related issues [38]. Entrepreneurship can enable individuals to think critically, creatively, and innovatively, make decisions, take risks, and solve complex problems [27]. Such multi-dimensional individuals are ready to be employed in industry to meet the changing needs of the global world [39]. Entrepreneurship can also provide funding for high-cost research projects. All these can contribute to the social and economic development of a country [40].

Other researchers may be against the idea of entrepreneurship; entrepreneurship might be seen as supporting capitalist ideologies that can impact public understanding and the freedom of sharing knowledge. Within this context, if

Table 1 The aspects of attitudes, knowledge, and skills for entrepreneurship

Attitude	Self-awareness, self-confidence, taking the initiative, taking risks, critical thinking, problem-solving
Knowledge	Career options, business world, economic literacy, business organization and process
Skill	Communication, representation, planning, teamwork, exploring opportunities

Source Eurydice, the information network on education in Europe [33] entrepreneurship makes people money-driven, it can negatively impact people's social values. Money-driven people can focus on making money rather than working for the benefit of the public. For example, during the current global pandemic—COVID 19 virus, if people are money-driven, they may put other people's lives at risk in different ways, such as by selling fake injections, pills, or ineffective masks. However, if people are working for public benefit, they would be working on discovering the cure of COVID 19 and increasing others' awareness by providing valid and reliable knowledge on what should be done until the cure is discovered. These researchers also see entrepreneurship as harming people's scientific ethos, such as sharing. For example, if entrepreneurship creates a competitive environment, it can result in people not sharing important information, which can hinder the development of science and society.

While we see entrepreneurship as a process, we accept an entrepreneur as a person who puts effort into operating this process. Entrepreneurs are responsible for translating new ideas and bringing them into practice to improve present products/services. For this purpose, they need to be competent in thinking critically and creatively, solving complex problems, being resilient, and having a mindset and the ability to deal with risks and uncertainties. These competencies are also integral to STEM endeavors.

Entrepreneurship has many benefits as well as drawbacks. Incorporating entrepreneurship into other subjects may provide benefits such as career development, public awareness on economics-related issues, and developing 21st-century skills. We believe that the impact of entrepreneurship depends on whether the public is educated on how society, environment, economy, and science can be developed by utilizing entrepreneurship and how it can treat public health and safety in its misuse. The public should be educated on the pros and cons of entrepreneurship and the potential threat of negative entrepreneurial actions on public health and safety. Entrepreneurship can impact economic, social, environmental, and scientific growth and lead to more job opportunities involving STEM jobs. Some countries, including Europe [22], Mexico [41], and Africa [42] already put calls on youth empowerment. Youth should be empowered through entrepreneurship at every level of education worldwide.

4 Incorporation of Entrepreneurship and STEM Education

STEM education and entrepreneurship have been widely studied during the last decade [43, 44], bringing the relationship between STEM and entrepreneurship into the light. It is undeniable that STEM and entrepreneurship are crucial to the economy, society, environment, and scientific development; however, how entrepreneurship and STEM relate to each other and why their incorporation should be explored further.

STEM and entrepreneurship relate to each other in various ways. For example, STEM provides an area of study for entrepreneurship. That is, entrepreneurs may develop STEM-related ideas, produce STEM products and services, and/or establish new STEM environments [45]. STEM also offers the knowledge that helps the development of relevant products and services. An entrepreneur can realize the market, but without the required knowledge, s/he would not be able to fill this gap. STEM develops various 21st-century skills to think critically and solve complex problems, which are highly important for entrepreneurship. STEM provides technical, theoretical, and practical knowledge and skills to meet the changing world's needs. STEM highlights the importance of scientific ethos and social values. While scientific ethos refers to "attitudes that scientists are expected to adopt and display in their interactions with their fellow scientists as well as in carrying out their scientific activities" [46, pp. 1006–1007], social values are consistent with "respecting the environment, social utility, and freedom" [47]. These aspects are important to provide ethical behaviors and develop society. Additionally, STEM comes up with discoveries and innovations that benefit the market and society.

4.1 The Ways that Entrepreneurship Contribute to STEM Education

Entrepreneurship can also contribute to STEM education in various ways, such as by helping people realize where and how STEM is used in everyday life. Realizing STEM in everyday life may increase interest and motivation in STEM disciplines [45]. When people realize STEM in everyday life, they can also start realizing STEM-related issues. With entrepreneurship, these people can think creatively and solve issues through new and innovative approaches [48]. Coming up with new ideas and bringing innovative solutions to problems can contribute to discoveries and inventions, which may help develop scientific knowledge.

Entrepreneurship helps equip students with 21st-century skills and competencies [49]. Even though STEM education has the potential to develop 21st-century skills as well as the goals of education, how these skills can be improved further should be considered. While some researchers view such skills as critical thinking, decision making, and creativity as integral to entrepreneurship, some others view entrepreneurship as one of the 21st-century skills. These common competencies between STEM and entrepreneurship are required for employment and are called entrepreneurial STEM competencies in this study. Promoting entrepreneurial STEM competencies may help people realize their full potential [10]. These people tend to realize new opportunities, create new jobs, and continue career progression. Eventually, these technical, theoretical, and practical entrepreneurial STEM competencies that are required in today's world can be used to contribute to society.

Entrepreneurship would make it easier for students to realize STEM in everyday life [50]. One of the challenges that STEM education faces is developing the ability of students to link STEM knowledge with real-world problems. Students are also struggling to find and/or pursue opportunities. We need to ponder on which competencies we require from students, how students can develop these competencies and how students can apply the competencies that they gained through STEM education to their everyday life to contribute to society. Answers to these questions can be found in entrepreneurship. For example, STEM education promises to bring solutions to everyday problems by applying STEM competencies in everyday life and presenting the interrelations between education, society, and business [49]. Usually, the solution to these everyday problems requires new and innovative solutions. Entrepreneurship can support coming up with new and innovative solutions to problems as it is one of the main aspects of entrepreneurship.

The process of entrepreneurship can provide opportunities to individuals, help them with employment and career development [29, 51]. While STEM education provides the knowledge and its practical applications, entrepreneurship helps to transform this knowledge and the available resources into products and services [52]. That is, entrepreneurship can help develop STEM-related new products and services. If the produced products and services are to bring solutions to everyday issues and benefit society, these products and services should be distributed to the public who need them. In this case, the industry mass produces such products and services. After mass production, entrepreneurship supports transferring these products and services from academia to the market [50]. By doing so, more and more people find jobs in small companies outside of the fields that they were trained in. Jobs in these small businesses require different knowledge and skills, and one person is expected to produce work in many different fields. Under these conditions, employers prefer individuals who have gained different knowledge and skills and can do different jobs. In particular, new generation engineers are expected to be versatile engineers with innovative and communicative skills in marketing and technology [53]. Thereby, entrepreneurship and STEM create opportunities, help with employment and job creation, and contribute to society by working together. Considering this trend, the importance of entrepreneurship and STEM education becomes clearer.

4.2 The Importance of the Incorporation of STEM and Entrepreneurship

Entrepreneurial companies have initiated radical STEM research and development changes worldwide by introducing radical innovations and contributions [54]. In today's global world, funding is required to conduct high-level and high-cost research, such as CERN's Large Hadron Collider (LHC) experiments. This funding can be provided through entrepreneurship. Once the funding is provided, entrepreneurship and STEM are needed in order to earn money and develop society and science. Let us explain how. Conducting LHC experiments and building a center like CERN require innovative thinking, creativity, knowledge, and many other competencies. These competencies are widely inherited in entrepreneurship, and the knowledge and the foundation devices to conduct experiments come from STEM. After opening CERN and building LHC, the findings of the experiments transform into knowledge, product, and services and are shared with the public. The transformation of the findings and distribution to the public is facilitated by entrepreneurship. If the experiment is successful or findings provide scientific, societal, or environmental development, this center may provide more funding. Such systems transforming knowledge into money via entrepreneurship and aiming to create citizens who can produce knowledge and transform it into products and services are called knowledge-based economies. However, discussions on the benefits and drawbacks of knowledge-based economies are out of the focus of this chapter.

The importance of incorporating STEM and entrepreneurship can also be observed in the health and engineering sectors. The importance of entrepreneurship has been increasing in many medical fields that involve both basic sciences and applied sciences [55]. Research outcomes of basic sciences are commonly transferred by some others rather than the researcher [56]. Usually, this occurs when the researcher is missing an entrepreneurial perspective. Researchers should be aware of the limitations and potentials of the scientific outcomes of their research, especially its contribution to clinical sciences, as well as have a scientific understanding of the subject in depth [56]. This awareness can be developed by promoting an entrepreneurial mindset in STEM education. Therefore, efforts should be made to provide entrepreneurship training in medical fields [55].

The significance of entrepreneurship can also be observed in engineering departments. Traditional engineering education programs provide theoretical background followed by practical training [57]. This means that engineering graduates become engineers first and become creative and innovative after [58]. Moreover, traditional engineering programs provide new knowledge and practical application of the knowledge simultaneously, creating non-entrepreneurial, innovative, and non-critical engineers. Incorporating entrepreneurship in engineering programs as part of STEM can support creating qualified graduates equipped with 21st-century skills and contribute to society.

4.3 The Impact of the Incorporation of Entrepreneurship and STEM on a Global Epidemic

Even though the positive impact of incorporating entrepreneurship and STEM on the economy is commonly mentioned, its impact on society, environment, and scientific development is mostly overlooked. A global epidemic may be a perfect example of the potential impact of STEM collaboration on the economy, society, environment, and scientific development. STEM education may help to deal with global issues, such as COVID 19, the current global epidemic. If we create citizens who can incorporate STEM and entrepreneurship, these citizens can work on cures to treat people affected by the epidemic. Such citizens can use:

- science to understand the nature of the epidemic and how it can be cured;
- technology to conduct experiments;
- engineering to develop devices to work on the cure;

- mathematics to calculate how fast the epidemic is spreading, which areas have a higher risk, and what pattern is expected from the epidemic; and
- entrepreneurship to work on transforming the cure into products and services and transferring the cure to the market for public use.

Using STEM and entrepreneurship in such ways can benefit the public and life in many ways. For example, the discovery of a cure for a pandemic or innovation of a device to help with the cure is the development of science. Scientific developments help us understand the world better and make life easier. Furthermore, scientific developments improve the economy. Developing new devices that no one has yet and exporting them to other countries can improve the economy. These economic and scientific developments increase the countries' wealth and provide social utility. Another benefit is for the environment. People are destroying nature and harming the environment. Increasing public awareness and educating them on STEM-entrepreneurship incorporation for environmental benefits can contribute to protecting the environment.

We believe that there is an important relationship between STEM and entrepreneurship, and their incorporation can benefit the public and life in many ways. Yet, identifying and discussing the impact of these fields on each other would not be enough. Without knowing how we can promote STEM through entrepreneurship or entrepreneurship through STEM, we might struggle to increase the impact of their incorporation on the economy, society, environment, and scientific development. Therefore, we focus on strategies and everyday life examples to create entrepreneurial citizens through STEM education in the next section.

5 Road Map to Create Entrepreneurial Citizens Through STEM Education

Even though various STEM strategies and definitions of entrepreneurship are known, how they can be incorporated remains unclear. By providing rich environments through STEM education [59, 60], entrepreneurship can be integrated into STEM programs, such as STEM teacher education. Suppose STEM education is important to achieve the targeted learning intentions. In that case, teachers should be educated on the benefits, drawbacks, and implications of entrepreneurship before they start working as they are the first implementers of STEM education.

Individuals start schooling with different background knowledge, skills, and attitudes. While some competencies (knowledge, skill, and attitude) are developed through education provided at school, some become blunt. Similarly, entrepreneurship competence can be developed through everyday experiences and the activities offered in the school environment at all education levels [61]. Yet, we have to ponder how we can incorporate entrepreneurship and STEM together and implement entrepreneurial STEM in classrooms.

To achieve this incorporation and implementation, three levels of actions that were proposed by Yorke (2005) can be considered:

i. the institution level;
ii. the academic department or program team level; and
iii. the individual or small group tutor level [62].

From this perspective, this integration should be considered at the institution level before starting the whole entrepreneurship-STEM incorporation process. Entrepreneurial STEM policy or documents can be researched and developed. These policies or documents should support the pedagogic strategy of entrepreneurship-STEM incorporation at the institutional level. The entrepreneurial STEM can be included in the curriculum that is used within the institution. Potential teaching, learning, and assessment strategies for entrepreneurship-STEM incorporation should be considered and adopted in this curriculum. The institution should refer to entrepreneurial STEM competencies to provide students with vision and leadership. At the academic department or program team level, the program team should be supported with teaching, learning, and assessment strategies of entrepreneurship-STEM incorporation. Opportunities should be provided to the program team to make the required effective changes in curricula. Additionally, periodic reviews should be organized to track the incorporation level of STEM and entrepreneurship. At the individual or small group tutor level, supporting the development of student capacity should be encouraged amongst academic staff members and tutors. Student capacity can be developed by enhancing students' behaviors in a self-regulated manner and supporting them to act autonomously.

Various teaching methods and techniques can be applied to enhance the entrepreneurial spirit in STEM. For example, collaboratives, problem-based, and project-based learning approaches, as well as learning strategies, such as drama, learning diary, twin classes, mini-businesses, trips and inviting an expert to the school, can be used to develop entrepreneurial STEM competencies [61, 63]. Another research conducted as part of the Assessment of Transversal Skills in STEM (ATS STEM) project proposed ATS STEM Conceptual Framework [64]. This framework refers to STEM Learning Design Principles as follows:

- problem-solving design and approaches;
- disciplinary and interdisciplinary knowledge;
- engineering design and practices;
- appropriate use and application of technology;
- use of real-world contexts; and
- appropriate pedagogical practices.

These design principles may be used to incorporate and implement entrepreneurship and STEM together due to their relevance to both concepts.

Another way of creating entrepreneurial spirit in STEM education might be encouraging students' active participation in entrepreneurial activities and experiences [34, 65]. Within this context, teachers' attitudes towards this incorporation gain importance [66, 67] since they are the first implementers in the classroom to develop students' entrepreneurial STEM competence. Teachers' negative attitudes towards a subject, topic, or competence greatly impact their students [68]. For example, Pihie and Bagheri (2011) researched how do teachers think of entrepreneurial STEM and self-efficacy. The result indicated that teachers' attitude towards entrepreneurial STEM was reflected in their teaching and impacted students' attitudes [69]. Therefore, we can say that non-entrepreneurial teachers cannot create entrepreneurial students. Entrepreneurial teachers should have basic characteristics such as being inspirational, open-minded, confident, flexible, responsible, collaborative, and communicative [21].

6 Conclusion

Global epidemics impact our lives from the way we work to what we need in everyday life, hindering many things such as health, economy, and social relationships. This chapter looked into global epidemics from a different perspective to bring more durable or permanent innovative solutions. The chapter proposed going to the roots of the problem that underlies education. We believe that exposing students to entrepreneurial STEM education can create future citizens who are innovative, curious about their surroundings and beyond, and who can take the initiative by gauging the risk level. Such citizens contribute to the economy, society, science, health, and environment and make us more prepared for future outbreaks.

As various STEM strategies and definitions of entrepreneurship are known, we have to focus on incorporating entrepreneurship and STEM together and implementing entrepreneurial STEM in classrooms. Three levels of implementation of formative assessment can be adapted to the incorporation and implementation of entrepreneurial STEM education. Effective and successful education is directly related to pedagogy embraced in the classroom. Entrepreneurial STEM competencies should be learned through experience; thus, it is important to choose appropriate pedagogies. To improve entrepreneurial spirit in STEM education, different teaching, learning, and assessment methods and strategies should be implemented in the classroom simultaneously. Six STEM Learning Design Principles proposed by Butler et al. (2020) can be utilized to incorporate and implement entrepreneurial STEM education [64].

We should also focus on incorporating entrepreneurship and STEM and their implementation in teacher education programs. Suppose STEM education is important to achieve the targeted learning intentions. In that case, teachers should be educated on the benefits, drawbacks, and implications of entrepreneurship before they start working as they are the first implementers of STEM education. Going back to the beginning quote, "*If opportunity doesn't knock, build a door,*" we can build our doors by creating entrepreneurial teachers who are educated in STEM or creating entrepreneurial STEM students. To create entrepreneurial teachers, teachers should be encouraged to be inspiring, open-minded, confident, flexible, responsible, collaborative, and communicative [21].

Core Messages

- Entrepreneurial STEM perspectives help students bring practical, economical, and innovative solutions.
- Implementation and inclusivity of the entrepreneurial STEM programs are very important for the next generations.
- Promoting profound entrepreneurial STEM education programs offer a more permanent solution to our problems.
- Implementation levels of entrepreneurial STEM education include the institution, department, and individual levels.
- The public should be educated on the threat of negative entrepreneurial actions on the public as well as its benefits.

Acknowledgements We would like to thank Orla McCormack for kindly reading and providing her opinion on the text.

References

1. Camesano TA, Billiar K, Gaudette G, Hoy F, Rolle M (2016) Entrepreneurial mindset in STEM education: student success. Presented paper at the annual conference on open, National Collegiate Inventors & Innovators Alliance, Portland, Oregon, 4–5 March 2016
2. McLoughlin E, Butler D, Kaya S, Costello E (2020) STEM education in schools: what can we learn from the research? Report #1 In: ATS STEM report series. Dublin City University, Dublin. https://doi.org/10.5281/zenodo.3673728
3. Bybee RW (2013) The case for STEM education: challenges and opportunities. NSTA Press, Arlington, VA
4. Sanders M (2009) Integrative STEM education: primer. Technol Teach 68(4):20–26
5. Costello E, Girme P, McKnight M, Brown M, Kaya S (2020) Government responses to the challenge of STEM education: case studies from Europe. Report #2 In: ATS STEM report series. Dublin City University, Dublin. https://doi.org/10.5281/zenodo.3673600
6. Kelley TR, Knowles JG (2016) A conceptual framework for integrated STEM education. Int J STEM Educ 3(1):11. https://doi.org/10.1186/s40594-016-0046-z
7. Corlu MS, Capraro RM, Capraro MM (2014) Introducing STEM education: implications for educating our teachers in the age of innovation. Egitim ve Bilim 39(171):74–85. Retrieved from http://hdl.handle.net/11693/13203
8. Schoolnet E (2018) Science, technology, engineering and mathematics education policies in Europe [Scientix Observatory Report]. European Schoolnet, Brussels

9. Nistor A, Gras-Velazquez A, Billon N, Mihai G (2018) Science, technology, engineering and mathematics education practices in Europe [Scientix Observatory Report]. European Schoolnet, Brussels. Retrieved from http://www.scientix.eu/observatory
10. Volkmann C, Wilson KE, Mariotti S, Rabuzzi D, Vyakarnam S, Sepulveda A (2009) Educating the next wave of entrepreneurs: unlocking entrepreneurial capabilities to meet the global challenges of the 21st century [A report of the global education initiative]. World Economic Forum, Switzerland. https://doi.org/10.2139/ssrn.1396704
11. Siekmann G, Korbe P (2016) Defining 'STEM' skills: review and synthesis of the literature. NCVER, Australia
12. Observatory (2016) The global race for STEM skills. Retrieved from www.obhe.ac.uk/newsletters/borderless_report_january_2013/global_race_for_stem_skills
13. Palotai P (2017) E-skills and jobs in the digital age. Retrieved from https://epale.ec.europa.eu/en/content/e-skills-and-jobs-digital-age
14. Fayer S, Lacey A, Watson A (2017) STEM occupations: past, present, and future. Spotlight Statist 1:1–35
15. Morrison J (2006) STEM education monograph series: attributes of STEM education. Teaching Institute for Essential Science, Baltimore, MD, USA
16. Fayolle A, Gailly B, Lassas-Clerc N (2006) Assessing the impact of entrepreneurship education programmes: a new methodology. J Eur Ind Train 30(9):701–720
17. Kuratko DF (2005) The emergence of entrepreneurship education: development, trends and challenges. Entrep Theory Pract 29(5):577–597
18. Oosterbeek H, van Praag M, Ijsselstein A (2010) The impact of entrepreneurship education on entrepreneurship skills and motivation. Eur Econ Rev 54(3):442–454
19. Peterman NE, Kennedy J (2003) Enterprise education influencing students' perceptions of entrepreneurship. Entrep Theory Pract 28(2):129–144
20. Von Graevenitz G, Harhoff D, Weber R (2010) The effects of entrepreneurship education. J Econ Behav Organ 76(1):90–112
21. European Commission/EACEA/Eurydice (2014) Entrepreneurship education: a guide for educators. Retrieved from http://ec.europa.eu/DocsRoom/documents/7465
22. European Commission/EACEA/Eurydice (2016) Entrepreneurship education at school in Europe. Eurydice report. Publications Office of the European Union, Luxembourg
23. Schumpeter J (1934) Capitalism, socialism, and democracy. Harper & Row, New York
24. Bruyat C, Julien PA (2001) Defining the field of research in entrepreneurship. J Bus Ventur 16(2):165–180. https://doi.org/10.1016/S0883-9026(99)00043-9
25. Casson M (1982) The entrepreneur: an economic theory. Barnes & Noble Books, New Jersey
26. Shapero A (1975) The displaced, uncomfortable entrepreneur. Psychol Today 9(6):83–88
27. Hisrich RD, Peters MP (2002) Entrepreneurship. McGraw-Hill, New Delhi
28. Allen KR (2003) Bringing new technology to market. Prentice Hall, Upper Saddle River, NJ
29. Kaya S, Erduran S, Birdthistle N, McCormack O (2018) Looking at the social aspects of nature of science in science education through a new lens: the role of economics and entrepreneurship. Sci Educ 27(5–6):457–478
30. Rindova V, Barry D, Ketchen DJ (2009) Entrepreneuring as emancipation. Acad Manag Rev 34(3):477–491
31. Timmons JA (1989) The entrepreneurial mind. Brick House Publishing, Andover, MA
32. Heinonen J, Poikkijoki S (2006) An entrepreneurial-directed approach to entrepreneurship education: mission impossible? J Manage Dev 25(1):80–94
33. European Commission/EACEA/Eurydice (2012) Entrepreneurship education at school in Europe: national strategies, curricula and learning outcomes. European Commission (EACEA), Brussels. https://doi.org/10.2797/80384
34. Fayolle A, Gailly B (2008) From craft to science: teaching models and learning processes in entrepreneurship education. J Eur Ind Train 32(7):569–593
35. Thompson JL (2004) The facets of the entrepreneur: identifying entrepreneurial potential. Manag Decis 42(1/2):243–258

36. Hindle K (2007) Teaching entrepreneurship at university: from the wrong building to the right philosophy. In: Fayolle A (ed) Handbook of research in entrepreneurship education, vol 1, pp 104–126
37. Birdthistle N, Hynes B, Fleming P (2007) Enterprise education programmes in secondary schools in Ireland: a multi-stakeholder perspective. Educ + Train 49(4):265–276. https://doi.org/10.1108/00400910710754426
38. Irzik G (2013) Introduction: commercialization of academic science and a new agenda for science education. Sci Educ 22(10):2375–2384
39. Hynes B, Costin Y, Birdthistle N (2010) Practice-based learning in entrepreneurship education: a means of connecting knowledge producers and users. Higher Educ Skills Work-Based Learn 1(1):16–28
40. Amos AA, Onifade CA (2013) The perception of students on the need for entrepreneurship education in teacher education programme. Global J Hum Soc Sci 13(3):75–80
41. de Lourdes C-S, del Pilar A-L, García-Lopez E (2017) Developing entrepreneurship in primary schools. The Mexican experience of "My first enterprise: entrepreneurship by playing." Teach Teach Educ 64:291–304. https://doi.org/10.1016/j.tate.2017.02.013
42. Adeola Adegun O (2013) Entrepreneurship education and youth empowerment in contemporary Nigeria. J Emerg Trends Educ Res Policy Stud 4(5):746–751. Retrieved from https://hdl.handle.net/10520/EJC145165
43. Etzkowitz H (2008) The triple helix: university-industry-government innovation in action. Routledge, New York
44. Sanders M (2007) Scientific paradigms, entrepreneurial opportunities and cycles in economic growth. Small Bus Econ 28(4):339–354
45. Ucar S (2020) Girişimcilik Eğitimi-Temel Eğitimden Öğretmen Eğitimine Genel Bakış (Overview of entrepreneurship education-general education to teacher education). Ankara, Turkey, Akademisyen Yayınevi
46. Irzik G, Nola R (2014) New directions for nature of science research. In: International handbook of research in history, philosophy and science teaching. Springer, Dordrecht, pp 999–1021
47. Erduran S, Dagher ZR (2014) Reconceptualizing the nature of science for science education: scientific knowledge, practices and other family categories. Springer, Dordrecht
48. Deveci I, Cepni S (2014) Entrepreneurship in science teacher education. J Turkish Sci Educ 11(2):161–188
49. Jang H (2016) Identifying 21st century STEM competencies using workplace data. J Sci Educ Technol 25:284–301
50. Kaya (2019) Enhancing pre-service science teachers' understanding of how science works in society: the role of economics and entrepreneurship. Published Ph.D. thesis, University of Limerick, The Republic of Ireland
51. Alvarez SA, Barney JB (2007) Discovery and creation: alternative theories of entrepreneurial action. Strateg Entrep J 1(1–2):11–26
52. Sarasvathy SD (2001) Causation and effectuation: toward a theoretical shift from economic inevitability to entrepreneurial contingency. Acad Manag Rev 26(2):243–263
53. Duval-Couetil N, Reed-Rhoads T, Haghighi S (2010) Development of an assessment instrument to examine outcomes of entrepreneurship education on engineering students. Presented paper at the IEEE Frontiers in Education Conference (FIE). Washington, DC, USA, 27–30 October 2010
54. Baumol WJ (2004) Entrepreneurial enterprises, large established firms and other components of the free-market growth machine. Small Bus Econ 23(1):9–21
55. Salminen L, Lindberg E, Gustafsson ML, Heinonen J, Leino-Kilpi H (2014) Entrepreneurship education in health care education. Educ Res Int 2014:1–8. https://doi.org/10.1155/2014/312810
56. Shaywitz DA (2005) Entrepreneurs: the missing link in the training of medical scientists. Nat Biotechnol 23(11):1447–1448

57. Makimurto-Koivumaa S, Belt P (2015) About, for, in or through entrepreneurship in engineering education. Eur J Eng Educ 41(5):512–529
58. MacLeod I (2009) The education of innovative engineers. Eng Constr Archit Manag 17 (1):21–34
59. Agommuoh PC, Akanwa UN (2014) Senior secondary school physics teachers' assessment of entrepreneurial skills needed for global competitiveness. IOSR J Res Method Educ 4(1):25–29
60. Saribas D, Ceyhan GD (2015) Learning to teach scientific practices: pedagogical decisions and reflections during a course for pre-service science teachers. Int J STEM Educ 2:article 7. https://doi.org/10.1186/s40594-015-0023-y
61. Anette C (2011) Mapping of teachers' preparation for entrepreneurship education. Final report. Jossey-Bass Publishers, San Francisco, CA
62. Yorke M (2005) Formative assessment in higher education: its significance for employability, and steps towards its enhancement. Tert Educ Manag 11(3):219–238
63. Seikkula-Leino N (2007) Evaluation of an innovative approach to teaching entrepreneurship. J Small Bus Manage 25(1):35–43
64. Butler D, McLoughlin E, O'Leary M, Kaya S, Brown M, Costello E (2020) Towards the ATS STEM conceptual framework report #5. In: ATS STEM report series. Dublin City University, Dublin. https://doi.org/10.5281/zenodo.3673559
65. Middleton KE, Mueller S, Blenker P, Neergaard H, Tunstall R (2014) Experience-based learning in entrepreneurship education—a comparative study of four programmes in Europe. Res Entrepreneurship Small Bus 18:1–15
66. Avramidis E, Norwich B (2002) Teachers' attitudes towards integration/inclusion: a review of the literature. Eur J Spec Needs Educ 17(2):129–147. https://doi.org/10.1080/08856250210129056
67. Heyder A, Südkamp A, Steinmayr R (2020) How are teachers' attitudes toward inclusion related to the social-emotional school experiences of students with and without special educational needs? Learn Individ Differ 77:1–11. https://doi.org/10.1016/j.lindif.2019.101776
68. Jones MG, Carter G (2007) Science teacher attitudes and beliefs. In: Abell SK, Appleton K, Hanuscin DL (eds) Handbook of research on science teaching. Routledge, NY. https://doi.org/10.4324/9780203824696
69. Pihie ZAL, Bagheri A (2011) Are teachers qualified to teach entrepreneurship? Analysis of entrepreneurship attitude and self-efficacy. J Appl Sci 11(18):3308–3314

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The only thing that interferes with my learning is my education.

Albert Einstein

Summary

The authors of *Integrated Education and Learning* were asked how they would see the future of their field 30 years later. This chapter presents the authors' views on cognitive semiotics as an integrated field of science in 2050, along with

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https://doi.org/10.1007/978-3-031-15963-3_26

thinking skills (computational thinking, scientific thinking, and critical thinking); early childhood education and its importance in developing a new intelligence and social and emotional learning; the role of arts in education and preparing

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learners for systems thinking and thinking sustainability; future forms of education and learning (e-learning, inquiry-based learning, self-directed learning, developmental education, evidence-based education, education of informa-

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tion age, entrepreneurial STEM education, education for super-smart society), and the role of integrated science in education (education for equality and for controlling social and ethical issues).

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Graphical Abstract/Art Performance

Integrated Education and Learning–Word cloud.

Keywords

Education · Integrated education · Learning · Thinking

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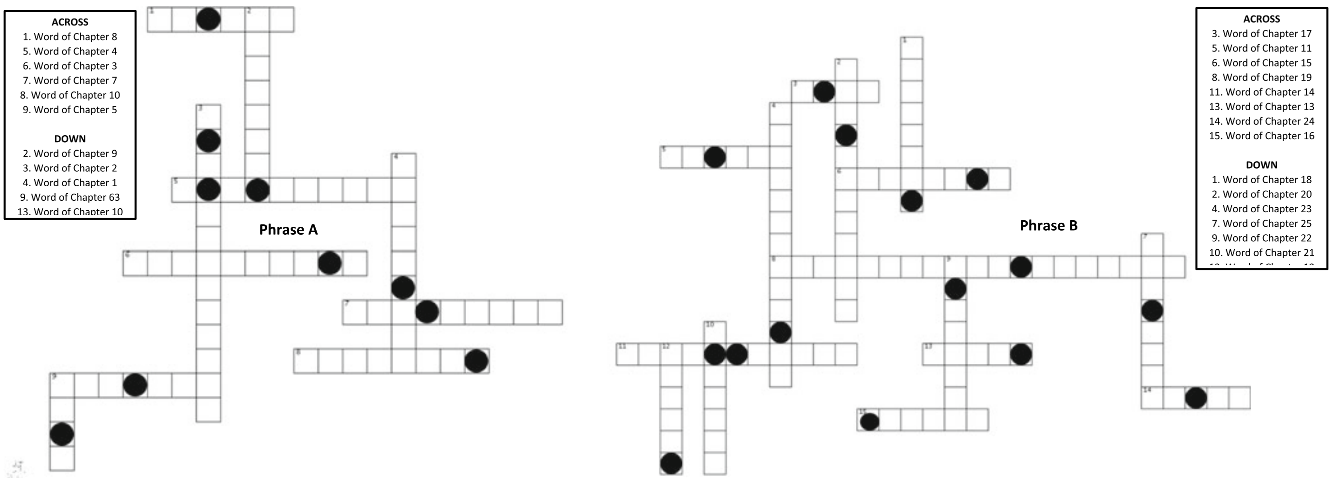

- ✓ There is a QR code for each chapter;
- ✓ Scanning the QR code directs you to the word cloud of the chapter;
- ✓ The keyword of the word cloud is intentionally not included in the word cloud;
- ✓ The word cloud is made up of words of what we discussed throughout the whole book in relation to the respective keyword; so, words of the word cloud of the chapter are not necessarily mentioned in the text of the respective chapter;
- ✓ There is a meaningful word for each chapter;
- ✓ The meaningful word of the chapter is the keyword of the word cloud of the chapter, which can be a noun (plural and singular), an adjective, or a number;
- ✓ The puzzle is filled in with the meaningful words of chapters according the clues provided;
- ✓ There is a quote for the book;
- ✓ The book quote contains two phrases A and B made out of letters in puzzle cells that contain a black circle;
- ✓ The phrase A is a four-word sentence and the phrase B is a three-word sentence;
- ✓ The book quote is the last sentence *Integrated Education and Learning* has to say on our behalf for the future and for you;
- ✓ The mystery of the book is the last quote;
- ✓ Send the quote to nimarezaei.usern@gmail.com.

1 Introduction

Integrated education and learning can be tackled in various forms, settings, and contexts. To exemplify, work-integrated learning offers to increase participation and productivity in work environments and meet the global competitiveness [1]. It is through providing opportunities for learners to be exposed to theories, develop skills, and then become responsible to facilitate a job. These opportunities have made it an intervention of interest to educational settings, e.g., university education, workplaces, international education, content and language integrated learning, etc. [2–6], with the purpose of linking theoretical education in university and practical applications in workplaces. Working in an embedded framework, however, poses several challenges and remains a to-do task.

Integrated education and learning is not limited to adults' education; instead, it is better to be implemented since early childhood. This along with other issues will be included in the following opinion-based discussion.

2 From Cognitive Semiotics to Thinking Skills

2.1 Cognitive Semiotics

In an optimistic view, cognitive semiotics will supersede semiotics, cognitive science, and all the present social and human sciences. They will then form a much more integrated domain of study, which will nevertheless always take into account what is the theme and what is the background of the specific point of inquiry. Cognitive semiotics will, when this is relevant, take into account the results of the natural sciences, but it cannot merge with them since, unlike cognitive semiotics and those sciences of which it takes on the heritage, the latter are not involved with the experience of meaning which is afforded to (some kinds of) living beings. I do not intend to sketch any pessimistic alternative here. Nonetheless, it is important to acknowledge the fact that many futuristic scenarios that have been formulated at earlier dates have come to naught because they have only taken into consideration the internal structure of the sciences and what follows from it when, in the end, it is the institutional inertia of society, which includes common prejudices and economic interests, which decides much of the destiny of the sciences. Cognitive semiotics was born, or, more exactly, labeled as such, about 30 years ago. For the sake of human advancement in knowledge, I hope it will be going strong and become stronger in 30 years (Göran Sonesson 2020).

2.2 Thinking Skills

I predict that thinking skills will gain more importance than what it is today. Such technological advancements as virtual reality will give new opportunities to students to see firsthand the result of their thinking processes and decisions. However, problem-solving will remain a human quality because we make our decisions based on logic and our emotions and ethics. Although it is true that the sharp development of artificial intelligence (AI) seems to be in the direction of decreasing the importance of human judgment, I strongly believe that the human element will always be the meat of the advancement of civilization (Yalçın Dilekli and Erdoğan Tezci 2020).

2.2.1 Computational Thinking

The computational approach to science, technology, engineering, and mathematics (STEM) education provides a unique opportunity to meet the needs of a future workforce. It prepares the learner in several fields, including mathematics, computer science, and applied sciences (physics, biology, chemistry, etc.). Computational thinking (CT) education, as it is known now at the K-12 level, has spread all over the world as a global initiative. The STEM community will greatly benefit from this as CT is the foundation for scientific thinking and engineering thinking education. Thirty years from now, the use of computational modeling and simulation technology (C-MST) will be pervasive at all levels of education, and teaching expert thinking (e.g., ST and ET) to novices (young students) will be standard practice. Once we teach everyone to think like a scientist, the general public will gain a very progressive mind that will free us all from unfounded assumptions that have haunted us for generations (Osman Yaşar 2020).

We are noticing that some recent mathematics curriculum documents are making a point of highlighting the beauty and aesthetics of mathematics. And some are integrating coding within the mathematics experience, which we believe can help transform the doing and learning of mathematics, and what mathematics is accessible to students. The following comments from grade 10 students in the integrated mathematics and coding course point to an appealing future direction: “It feels like there’s more space. You don’t have to do it like everyone else.” “I did that. It’s my work. It’s a great feeling.” “It lets you go in-depth. You see how each function affects the next. How it connects together.” “I learned that it is possible to learn pretty much anything.” “I like doing math with coding. You get to use math in different ways to understand it more. You can’t code it unless you really understand the math part.” “You think: ‘I’m never going to use this.’ Then you go into coding, and you actually use it. It’s more like math in action.” “I didn’t take this course expecting it to be more collaborative. It just happened. Naturally. I like it.” “It would be cool to create something that’s going to help someone else” (George Gadanidis, Rosa Cendros 2020) [7].

The expanding support of intellectual endeavors by technologies inspires new dreams for the future. When we think of 2050, information handling and people-to-people communication spring to our minds; no physical device is required to search for information–information can be processed by connecting our brains into a rich network integrating human minds with machines. The communication style among people will change as well–the transition to an immediate “interpretation” of our language will continue, perhaps with some limitations, depending on the topic and depth of conversation.

The actual problem is the content and training program for machines and hybrid human–machine creatures in the education sphere. One of the training topics is humanoid thinking—the descendant of efforts in the field of pedagogy of computational thinking. Humanoid robots are autonomous and do research together with humans. Scientific theories become more complex and accessible only to the collective of humanoid robots, virtual agents, and digital twins. The very notion of reality is blurred; there is a hybrid-natural-virtual reality. Modeling the phenomena of such a natural-virtual environment is based on mechanisms hidden from humans and uses hybrid description languages. Simulations are understood as a tool to directly reflect a complex of mental and neural network simulations into such a hybrid reality.

The line between scientific knowledge and insights, between scientific predictions of the evolution of nature and society, and between virtual imaginations is blurred. As a result, a particular individual is involved in a complex process of consciously-unconscious choice of actions and virtual planning. Therefore, the content of the pedagogy of computational thinking includes the analysis of natural-virtual abstractions, the practice of mental and hybrid modeling and simulations, consciously-unconscious analytics, and the logic of unconscious choice. At the same time, people will become more careful with the human intellectual culture, which will be the focus of community conservation (Vladimiras Dolgopolovas, Valentina Dagiene, Sergei Pozdniakov, Alexander Liaptsev 2020).

2.2.2 Scientific Thinking

A proper science learning process will train students to use scientific thinking principles. Students who possess scientific thinking skills are expected to be able to become people with excellent qualities and able to adapt to improvements in technology. Therefore, learning science is essential to improving the quality of human resources (Johar Maknun 2020).

2.2.3 Critical Thinking

In thirty years, critical thinking will gain a more significant role in education as it is considered one of the essential skills for the twenty-first century workforce and democratic citizenship. In the future, it will become more evident that skills that differentiate human beings from machines will be more valuable as a result of automation and digitization of work. Critical thinking will enable people to adapt to the rapidly changing and increasingly complicated conditions of work and life and to make reasonable decisions under continually changing circumstances. In addition to major shifts in employment, global crises in different forms–ecological, health-related, social, and financial–will require citizens who can think “out of the box” to develop alternative and sustainable solutions to the problems that humanity faces. These solutions will be produced by the citizens of democratic countries that prioritize critical thinking in their education systems and support teacher education programs toward this goal. The ways of integrating critical thinking into core academic subjects and curricula will continue to be an essential research area. While educational systems are revised based on the needs of this new age, research investigating new methods to teach critical thinking and the design of technologically enhanced learning environments for students and their teachers' development in critical thinking will gain greater importance. Higher education institutions that achieve to create an ecosystem in which critical thinking is an integrated aspect will make the most significant contribution to a better future (Diler Oner, Yeliz Gunal Aggul 2020).

3 Early Childhood Education

3.1 A New Intelligence

It is my vision that by 2050 early childhood will be recognized as the powerhouse of potential for human intelligence. It is during early childhood that children manifest curiosity, imagination, fantastic hypotheses, intuitive theories, critical thought, spontaneity, and creative expression. Through play, young children develop dispositions and natural tendencies to explore and enjoy novelty and risk that stimulate intrinsic motivation and creative imagination. Providing environments that promote curiosity and develop creative thinking in children will form the foundations for later creative potential. Creative thinking as a core component of human intelligence will mean that education will no longer be viewed as domain-specific; rather, creativity will provide the vital connection for cross-curricula development and the multidimensional role it plays in all learning and understanding. How we view intelligence needs to change. It has been noted that an insufficient search is a common failing of human thinking. The ability to solve world problems and ultimately continue to survive as a race will require a new form of intelligence. By 2050 we will need to learn to think in new ways. Investing in the early years is essential if we are to reap the benefits for a future society that is healthy, intelligent, and striving (Nicole Leggett 2020).

3.2 Emotional Learning

When I started studying this topic a good couple of years ago, I was disappointed by the lack of interest that educational actors and policymakers had when discussing this topic. Even though there were some initiatives around the world that were standing out and making some noise, like the Cooperative for Academic, Social and Emotional Learning, I remember the doors closing one after the other, arguing that school was not the place for developing such ideas and that the fact of teaching emotions to children was nonsense that should be considered, if maybe, at home. Fortunately, today, we can already see a growing interest in important non-governmental organizations that put their ideas into practice and that consider, finally, from a serious point of view, the teaching and learning of social and emotional competencies at school. I can see this moving forward, and for the next

30 years, I'm sure that researchers will continue on this path, with patience and dedication, following the trends of other organizations that started to present evidence of the positive effects of focusing on developing these competencies. I see an exponential number of articles, reports, and initiatives that are being carried out and a growing consciousness of the topic, which makes me see an improvement not only in research but in concrete application. In 30 years from now, I am confident that we will see massive development of the social and emotional learning perspective; we will be living in a "new normal" that would be related to the development of these competencies in children all along with their school life, walking together towards the achievement of the development of a more just and peaceful society for us all (Macarena-Paz Celume, Lisa Cognard, Zoé Chamot 2020).

4 The Role of Arts in Education

My field of research has been basic education, teacher education, and sustainability. In the past year, I have broadened my perspective, and after my article [8], I have realized the importance of thinking in systems and the fact that we need to involve the whole society and reconnect different systems within the society for a sustainable future. For this to be possible, we must start blurring the boundaries between different research areas. We must now realize the facts that the human mindset needs to change with the help of both formal and informal education and information. I really hope that in my field in 2050, we educate children to use their hearts and mind when they make choices and decisions based on systems thinking that helps everyone to see and understand how their actions affect other parts in the system and in other connected systems in the society. In 2050 we have probably realized that arts, culture, and nature are as important as core science for humans to survive. A larger proportion of the world's population will be reconnected to nature then than now, perhaps with help from nature guides and nature consults that will be an appreciated and creditable profession then (Maria Hofman-Bergholm 2020).

Solving critical scientific and humanitarian crises, such as climate change, is a way to investigate the relationship between economics and creativity in the twenty-first century. Arts education in the United States developed from this pairing of utility and aesthetics, which advances an aesthetic problem-solving perspective to scientific quandaries. Sustainable media in the visual arts is being redefined through the development of recycled and ecological materials, which are having their debut in many industries. In the automotive industry, unique, sustainable fabrics have crossed over into daily wear and use. For instance, Dinamica, a suede fabric is made from plastic bottles and clothing fibers that can cover car seats or Karuun, a compressed timber product from sustainability harvested rattan, is used on car floors and trim, or vegan leather made of grape skins, seeds, and stalks are the materials of automotive dashboards, or car carpets are now made from recycled fishing nets or cork based vinyl. All of these media and designs are used to speak to the need to eliminate the carbon footprint and rethink transportation. Landscape paintings will be dated by their skylines of cell towers and wind turbines, solar panels on buildings' roofs, and driverless cars. A sustainable future requires a meta-cognition that not only debunks the myth of learning styles but requires a continual search to engender insights into thinking processes for an aesthetic and humane world (Laura Felleman Fattal 2020).

5 Future Forms of Education

5.1 E-Learning

As a field of study, educational psychology witnessed the emergence of different perspectives that represent a shift of focus from learning as a change in behavior to learning as a subjective construal of knowledge. However, twenty-first century educational practices seem to have taken a middle-of-the-road position in the sense that they draw on traditional as well as modern approaches to teaching and learning. The so-called "eclectic" approaches are exemplar practices in which the teacher conveys the information to the learners through didactic practices and reinforces it through student-centered activities. The relatively recent emergence of e-learning platforms and the subsequent calls for embracing "blended learning" might be the first step towards abandoning traditional practices. The question, however, is whether the new, computer-assisted practice can compensate the learner for the loss of the traditional element in education, an element behind viewing quality education as an end in itself regardless of the tool. Put differently, will the focus on educational tools supersede the focus on education itself? Educators will continue to monitor the situation and argue for cohesive approaches that take into account different areas of learning (interaction, critical thinking, reflection, etc.) to utilize the tools for quality education (Ghsoon Reda 2020).

5.2 Inquiry-Based Learning

Science education, in my own experiences as an adolescent learner, middle school biology teacher, and science educator, has always held the promise of providing truly student-centered, hands-on, inquiry-based learning.

In the current environment, at least in the United States, of calls for curriculum reform and teacher accountability standards–and the all too typically associated high stakes testing–we have seen more focus on the teaching of content and far less on the more messy and chaotic providing adolescent students with opportunities to investigate authentic scientific questions and to pursue them in a manner authentic to science's history of inquiry.

My hope is that as we move through this moment, that teachers and students will find opportunities to engage in this type of authentic learning. We say as a society that we value people who can creatively solve problems. Inquiry is the apprenticeship required for this goal. Let's do it (Gerald P. Ardito 2020).

In 30 years, we will have run out of excuses for the continuation of a patronizing socio-controlling adult agenda in education by those "who always know best" and have concluded that there is a need for a more flexible, creative, problem-solving workforce. The big picture of the curriculum will be centered around 'growth' leading to reflection and inquiry—realigning knowledge acquisition onto the development of three core skills:

- first, enabling all students to become successful learners who enjoy learning, making progress, and achieving;
- second, creating confident individuals who lead safe, healthy, and fulfilling lives; and
- third, creating responsible citizens who make a positive contribution to society

This big picture will have an integrated education dimension and will advocate that pedagogy should become more active, practical, and constructive–and embrace learning in tune with the student's own development. This big picture will have moved education practice away from delivering knowledge—coupled with quantitative assessments and academic grades–and towards Nelson's [9] thinking on the pedagogic use of 'Socratic dialogue' as a 'maieutic' service—'bringing others' thoughts to birth with a questioning [9, p. 35 f/n].

And this shift in epistemology will enable learners to develop the citizenry idea of 'self-determination' [10, p. 142]—where the individual does not allow his/her behavior to be determined by outside influences but judges and acts according to his/her own insights, his/her own developing awareness. This will be education in the round, fit for the purpose of developing well-rounded people (Brian Lighthill 2020).

5.3 Self-Directed Learning

Education in the next 30 years will be non-textbook, paperless and the learning that takes place is more focused on the output carried out collaboratively between students from primary school level to tertiary level. Assessment will no longer be based on knowledge and understanding only but will extend to the level of understanding to analyze, practice, and generate new ideas that are more dynamic. Future education involves the process of research, the discovery of new knowledge, testing of hypotheses and investigations, and students working collaboratively. The education system in the future is able to offer wider learning experience opportunities. For example, teachers emphasize the diversity of students when applying thinking skills. Future challenges require a generation capable of thinking and making decisions. As such, case-based learning is a learning method that can provide opportunities for students to think by applying theory to practice in the real world. Even thinking tools such as thinking maps in the form of advance organizers can be applied to students as thinking tools that benefit students throughout their lives. This is because thinking skills are skills that differentiate between innovators and followers. The next 30 years of education give students space to build themselves with certain skills such as thinking skills, problem-solving, and decision making. Through these skills, the next 30 years of education culture will change to self-directed learning, self-regulated learning, mastery learning, and independent learning using the latest technology and free learning wherever they are. In this regard, sophisticated infrastructure with the changing role of educators as capable facilitators through the teacher-scholar approach should already be planned. The culture of teacher-scholar should be lifelong learning where the government provides opportunities for all teachers to improve educational qualifications and cultivate research in teaching and learning and share every discovery through the publication of high-impact journals (Nurulwahida Azid, Tee Tze Kiong 2020).

5.4 Developmental Education

Education is a discipline in development. A discipline that is continuously renewed, like the phoenix, the fantastic animal of mythology that is periodically reborn from its ashes, while retaining at the same time its dynamic nature of identity. The myth of the phoenix brings together the dialectic of opposites in education, as the plurality of research objects, the multiplicity of methodologies, the relationship with other sciences, the synergy between theory and practice, and so on. Education rebuilds itself in always different ways, planning new solutions and paths for learning environments design. In the next thirty years, education will go towards developmental education, a science that studies the possibilities of education itself. The concept of educability will substitute the basic idea of education since the teaching and learning processes will be more and more adaptive, and any study in this area will have to cope with the multiple variables which contribute to the educational development of the mind in epigenesis to individuate the guiding criteria for regulating educational actions. Even if there will be unpredictable issues in the interplay between teaching and learning, the basic keys to the future of education will probably focus on empowering personal cognitive potential through the individuation of core preferences in organizing learning. The interplay between education and technology will be enhanced, and mobile learning will be increased. In the future scenario, a grounded scope of the frontier of education will be to co-create tailored approaches to enhance adaptation processes to any situated learning environment (Flavia Santoianni, Alessandro Ciasullo 2020).

5.5 Evidence-Based Education

Thirty years from now, education will draw more from research evidence in decisions that are made about teaching and learning methods and practices. For example, research findings on the mechanisms of the brain will increasingly impact how instruction is provided (e.g., much like how we can now monitor heart rate and other physiological activity, brain activity can be monitored so that instruction can be adjusted to fluctuations in levels of concentration, interest, tiredness, etc.).

The artificial compartmentalization of subject disciplines will largely disappear, and many education systems will adopt a more holistic approach to learning (i.e., future iterations of project-based learning and phenomenal education). There will be more emphasis on ensuring learners' understanding of their own health and psychological well-being and of global and environmental issues–including the responsibilities these entail. The cultivation of competencies in communicating and relating with others, cooperation and collaboration, self-regulation, graphicacy, and critical thinking will become integral components of instruction provided in the formal education. By then, teacher education will also have had a major overhaul so that the knowledge and skills teachers develop will have greater relevance to the learning needs of students they will teach (i.e., it will move on from the models and systems developed as far back as the 1950s that are still being used at the time of writing this opinion) (Emmanuel Manalo 2020).

5.6 Education in the Information Age

As a result of the rapid advances in science and technology in our life, I foresee radical changes and reforms, especially in science education, in the next 30 years. At the beginning of these changes may be the change of the components of science education, which has an integrated structure by its nature. In a clearer sense, computer science and data science may be added to physics, chemistry, and biology sciences, which are covered by science education. The needs of the era shape the education programs, and the age we are in is called the "information age." So, the need for individuals who can produce and analyze information will increase, and science education will have to integrate computer science and data science disciplines into its body to meet this need. Or science education may need to cover computational physics, computational chemistry, and computational biology, which are newly developing disciplines. Schools and universities that teach teachers should be prepared for these rapid and sharp changes (Kaan Bati 2020).

5.7 Entrepreneurial STEM Education

The world has been changing due to scientific and technological advancements. When the first computer was invented, we would not imagine being able to control many things through small mobile phones that had touch screens and wireless rechargeable batteries. Nowadays, we all are becoming digital and focusing on distant education due to the current global pandemic–COVID-19. These changes have majorly emerged due to entrepreneurship and STEM competencies. Similarly, it is very difficult to dream of what we can achieve 30 years from now. Everyday life might change according to the type of citizens that we create. Citizens who are equipped with entrepreneurial STEM competencies can be aware of potential risks, learn from their possible failures, realize the opportunities and use sustainable resources. Their innovative perspective, curiosity about their surroundings and beyond, and initiative-taking skills by gauging the risk level can help develop the economy, society, science, health, and environment as well as make us more prepared for future global epidemics. Imagine a future where students have an entrepreneurial STEM perspective. They can create their own STEM products and services that ease daily life, increase the wealth, health, and education in society and help protect the environment and the world that we live in. Entrepreneurial STEM education has the potential to make this dream come true as long as we provide an objective and ethically correct entrepreneurial perspective. It is our hope that in the next 30 years, the importance of entrepreneurial STEM will be understood, and entrepreneurial STEM will become a part of education at all levels (Sila Kaya-Capocci, Sedat Ucar 2020).

5.8 Education for a Super-Smart Society

The Integrated Education and Learning 2050 is to prepare people to face the super-smart society 5.0. To become members of society, we must have good collaborative skills and communication skills and must also be able to manage group activities and social interactions. In the world of education, individual learning approaches, such as creative thinking skills, critical thinking, and metacognition, can increase individual autonomy. That includes adaptability, independence, and flexibility. The individual must have digital literacy skills and information and communication technology, including the use of technology as a tool for learning, communication, and collaboration. Local culture is one of the determining factors for an individual to be able to enter the super-smart society 5.0. “Local culture is the strength of people's character in entering the super-smart society 5.0.” From 2026 to 2050, we will realize Super Smart People 5.0 through local culture as a whole in society (Wahyu Widada, Dewi Herawaty 2020).

6 Conclusion–The Role of Integrated Science in Education

6.1 Education for the Equality

The promotion of education for democratic, inclusive, and plural citizenship will necessarily involve the curricular and didactic treatment of relevant social problems or socially alive questions. Unequal gender relations, as a social problem and, specifically, as a socially alive question (Objective 5 of the SDG), require the educational incorporation of the concept of gender as a social and historical construct and a category of analysis in the history and other social sciences education. The approach of students to the complexity of their local and global reality will continue to require resources of critical literacy to achieve a true education in and for equality, the visibility of all the constructive voices of social knowledge, and the critical analysis of the underlying intentionality of social narratives, particularly those developed in the consolidated digital spaces of social relation (Delfín Ortega-Sánchez 2020).

6.2 Controlling Scientific Ethics and Social Issues

Over the years, integrated science education has contributed positively to solving many challenges with varying degrees of complexity. Across a multidisciplinary approach, integrated science has succeeded in occupying the development of advanced digital-based science and technology that makes it easier for humans to carry out activities and solve daily problems. However, we understand that the universe's behavior is always a mystery and requires a continuous struggle so that humans can ever live safely and prosperously. Furthermore, over the next 30 years, many tremendous challenges will be difficult to predict. We face the fact that limited natural resources and the balance of the universe due to climate change and instinctive behavior that threatens both naturally occurring and human-induced are still verifying the existence of integrated science. Besides, integrated science must be able to provide solutions to the fact that the world population will explode with an abundant number of elderly citizens, so treatment and care technology must be more sophisticated. DNA engineering technology will be one of the solutions for curing degenerative diseases more accurately. This technology is also very likely to give birth to magical babies with extraordinary intelligence. Furthermore, the impact of the development of AI in the future will be an idea that sounds like science fiction with the prediction that AI will be more reliable than human intelligence. Therefore, integrated science has two roles at once, not only guarding the development of science and technology sustainably but also strictly controlling scientific ethics by promoting the more civilized aspects of humanity (Abdurrahman Abdurrahman 2020).

The future of scientific-educational pedagogy must draw heavily from the intersections of the disciplines of cognitive psychology, neuroscience, philosophy of mind, and social and political philosophy. The function of neuroception in the learning responses to hostile social environments will help reform educational practices, policies, and institutional cultures (Horace Crogman, Maury Jackson 2020).

Core Messages

- Integrated education and learning need to develop thinking skills, particularly computational, scientific, and critical thinking.
- Early childhood education is important in developing a new intelligence and social and emotional learning.
- Arts in education can help prepare learners for systems thinking and thinking sustainability.
- Future forms of education and learning include e-learning, inquiry-based learning, self-directed learning, and developmental education.
- Integrated science can help develop education for equality and for controlling social and ethical issues (Fig. 1).

Fig. 1 Integrated Education and Learning–quote

References

1. McLennan B, Keating S (2008) Work-integrated learning (WIL) in Australian universities: the challenges of mainstreaming WIL. Citeseer, pp 2–14
2. Charalampidi M, Hammond M, Hadjipavlou N, Lophitis N (2017) A content and language integrated learning (CLIL) project: opportunities and challenges in the context of heritage language education
3. Choy S, Delahaye B (2011) Partnerships between universities and workplaces: some challenges for work-integrated learning. Stud Contin Educ 33(2):157–172
4. Gribble C, Blackmore J, Rahimi M (2015) Challenges to providing work integrated learning to international business students at Australian universities. Higher education, skills and work-based learning
5. Doolan M, Piggott B, Chapman S, Rycroft P (2019) The benefits and challenges of embedding work integrated learning: a case study in a university education degree program. Australian J Teacher Educ 44(6):91–108

6. Rice M, Shannon L-JY (2016) Developing project based learning, integrated courses from two different colleges at an institution of higher education: an overview of the processes, challenges, and lessons learned. Info Syst Educ J 14(3):55
7. Gadanidis G, Cummings J, Integrated Mathematics+ Computer Studies–Gr. 10
8. Hofman-Bergholm M (2018) Could education for sustainable development benefit from a systems thinking approach? Systems 6(4):43
9. Nelson L (1965) Socratic method and critical philosophy: selected essays. Translated by TK Brown III. Dover Publications, Inc., New York
10. Saran R, Neisser B (2004) Enquiring minds: socratic dialogue in education. Trentham Books, Stoke-on-Trent

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N. Rezaei (ed.), *Integrated Education and Learning*, Integrated Science 13,
https://doi.org/10.1007/978-3-031-15963-3