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Sila Kaya-Capocci
Erin Peters-Burton *Editors*

Enhancing Entrepreneurial Mindsets Through STEM Education

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Sila Kaya-Capocci • Erin Peters-Burton
Editors

Enhancing Entrepreneurial Mindsets Through STEM Education

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Preface

Imagine yourself sitting on a couch, thinking that you want to make a difference but you don't really know how. This is how we started.

The world has been changing in many ways; it is digitalizing, it is globalizing, and it is environmentalizing… We can keep up with these changes and protect the only world that we have by creating a new generation who is skillful, who innovates, who does the best for the environment, and considers the social benefit. Yes, this is all possible with enhancing a true entrepreneurial mindset through STEM education.

Entrepreneurship is defined in different ways in different fields. Some researchers define it from a specific perspective as starting a business, while some others define it from a broader perspective as a process of establishing new social, economic, environmental, institutional, cultural, and/or scientific environments. However, there seems to be a borderline between business schools and education departments. Believing that the educators in the Business School and the Department of Education can teach each other many things, in this book, we aimed to bring entrepreneurs, teachers, educators in Business Schools, and the Department of Education and researchers in STEM education centers. We are proud of bringing 52 entrepreneurship and STEM experts from ten different countries to remove the borders between the Business Schools and the Department of Education. By doing so, we hope to help Business Schools to develop their educational practices further and help the Department of Education to develop their knowledge of entrepreneurship from its formal discipline. Throughout the writing process, we have gone through an expert feedback exchange, where the experts from the field of education, STEM departments, and Business School provided feedback to the content of each other's work. Therefore, this book is a real hybridization of two fields and provides enriched theory and practice.

In this book, we look at entrepreneurship from a broader perspective in the STEM education context and synthesize entrepreneurship and STEM education by providing authentic examples grounded in everyday scenarios so that STEM education is accessible to all students, inclusive of those typically underrepresented. The book involves four parts: (1) Entrepreneurial Mind of STEM Education in Theory, (2) Example Practices for Fostering an Entrepreneurial STEM Mindset, (3) Empirical Results of Enhancing an Entrepreneurial STEM Mindset, and (4) The Ways of Conducting an Assessment of Entrepreneurial STEM Education.

In Part I, İsa Deveci and Jaana Seikkula-Leino set the stage in Chap. 1 by exploring the connections between STEM education and an entrepreneurial mindset and propose benefits to the integration. In Chap. 2 Tiago Ribeiro, Joana Silva, Marta Paz, Alexandra Cardoso, Nuno Teles, Cláudia Nogueira, and Telmo Ribeiro examine the links between STEM education and entrepreneurship with a lens on societal and environmental impact. Leander Penaso Marquez, Victor Manuel R. Aricheta, and Sharehann T. Lucman discuss how STEM education can develop leadership skills in students and the implications for entrepreneurial education in Chap. 3. In Chap. 4, Marwa Eltanahy extends the conceptual and theoretical underpinnings of entrepreneurial STEM learning to explain pedagogical strategies via a model for high school teachers. In Chap. 5, Gillian Kidman, Roland Gesthuizen, Hazel Tan, and Holger Dielenberg provide a teaching framework that integrates business and STEM education by breaking down a case study from an Australian business to illustrate different entrepreneurial STEM practices.

In Part II, authors describe practices they have used to develop entrepreneurial STEM mindsets. In Chap. 6, Andrzej Kozyra, Anna Gnida, Dariusz Halabowski, Robert Kippen, and Iga Lewin use an interdisciplinary STEM approach to improve the entrepreneurial attitude of undergraduate students. Lynne M. Pachnowski, Karen B. Plaster, Brad M. Maguth, and Nidaa Makki explain the practices of an entrepreneurial STEM summer program for students aged eleven to fifteen that evolved into a formalized curriculum that allows students to share their innovation with a larger community in Chap. 7. In Chap. 8, Briga Hynes, Yvonne Costin, and Ita Richardson propose a unifying framework to guide program design, implementation, and evaluation that takes into account a variety of STEM stakeholders, including educators, policy makers, and funding agencies. In Chap. 9, Isha DeCoito and Lisa K. Briona explain a variety of project-based learning and digital video game contexts that promote STEM and entrepreneurial competencies and mindsets in the capacity of teacher education. In Chap. 10, Naomi Birdthistle, Therese Keane, Tanya Linden, and Bronwyn Eager report on the results of a project examining the perceived capabilities, knowledge, and understanding of entrepreneurship education of a sample of Australian high school teachers and propose recommendations for STEM teacher education and school-wide adoption of entrepreneurial STEM education. In Chap. 11, Helen Douglass explains the development of a STEM education minor at the university level that uses design thinking to enact entrepreneurial mindsets.

In Part III, authors explain empirical results of studies they have done to enhance entrepreneurial STEM mindsets in various stakeholders. In Chap. 12, Aaron J. Sickel reports on a study done to examine how design thinking can serve as an instructional driver to foster preservice teachers' integrated STEM learning outcomes and entrepreneurial mindsets. In Chap. 13, Maeve Liston, Gillian Barry, and Patricia O'Sullivan describe an interdisciplinary educational outreach program for students between the ages of 14 and 17 years old that combined scientific and entrepreneurial thinking, resulting in the translation of ideas into action. In Chap. 14, Alandeom W. Oliveira and Adam O. Brown examine and analyze a group of undergraduate science students' oral performances and perceptions of a STEM pitching activity designed to enhance their entrepreneurial mindset.

In Part IV, authors describe approaches for assessment of entrepreneurial STEM education. In Chap. 15, Lisa Bosman and Katey Shirey use bioengineering and bio-inspired design to assess the entrepreneurial mindset of high school and college engineering students through integrated science, technology, engineering, art, and mathematics. In Chap. 16, Joshua Saboorizadeh, Hao He, Suzanne Burgoyne, Ferris Pfeiffer, Heather Hunt, and Johannes Strobel use theater-based creativity activities to assess entrepreneurial STEM education outcomes. In Chap. 17, Sila Kaya-Capocci and Erin Peters-Burton describe assessment approaches for entrepreneurial STEM education using digital formative assessment.

We would like to wholeheartedly thank the chapter authors for their contributions. We appreciate that these leaders in the field were willing to share their time, efforts, and expertise. We hope that this book will be the first step for us to achieve our vision of a more inclusive future in entrepreneurial STEM education.

Agri, Turkey — Sila Kaya-Capocci
Fairfax, USA — Erin Peters-Burton

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Contents

About the Editors

Sila Kaya-Capocci is currently an Assistant Professor of Science Education at Agri Ibrahim Cecen University in Turkey. She holds international degrees in science education (undergraduate education in Turkey; M.Sc. in the UK; Ph.D. in the Republic of Ireland). She worked as a research assistant at University of Limerick and postdoctoral researcher at Dublin City University in the Republic of Ireland. Dr. Kaya-Capocci also has international teaching experience at primary, post-primary, and university levels. Her expertise involves the areas of formative assessment, entrepreneurship, and STEM education, where she has international publications. Dr. Kaya-Capocci has been involved in, and coordinated, national and international projects. She was involved in the management of an EU funded project, entitled Assessment of Transversal Skills in STEM (ATS-STEM), aimed to enhance digital assessment of second-level students' transversal skills in STEM by developing a framework and teaching, learning, and assessment materials for this aim. Another project she managed was entitled Women as Catalyst for Change in STEM Education (STEMChAT, SFI funded project) aimed to encourage female post-primary students to pursue STEM subjects and careers. The project brought post-primary students together with the company managers, academics, and STEM undergraduates. She has also worked as an Editor of an education supplement for students as part of a national newspaper series in Ireland. Dr. Kaya-Capocci holds editorial and reviewer positions at international journals.

Dr. Erin Peters-Burton is the Donna R. and David E. Sterling Endowed Professor in Science Education and Director of the Center for Social Equity through Science Education at George Mason University in Fairfax, Virginia, USA. Dr. Peters-Burton's research agenda is based in social justice and she pursues projects that help students who feel excluded in science classes become more aware of the scientific enterprise and how scientific knowledge is generated. She is interested in the nexus of the nature of science, science teacher pedagogical content knowledge, computational thinking, and educational psychology. She is PI for an NSF-funded research project entitled, *Fostering Student Computational Thinking with Self-Regulated Learning*, which has developed an electronic notebook that prompts students to think computationally with self-regulated learning strategies while collecting analytics on student learning (SPIN; Science Practices Innovation Notebook). She has been co-PI for two NSF-funded grants, Opportunity Structures for Preparation and Inspiration in STEM (OSPrI) and Developing a Model of STEM-Focused Elementary Schools (eSTEM) that have empirically identified criteria for the design of successful inclusive STEM high schools and elementary schools. In addition, Dr. Peters-Burton is an editor of the STEM Road Map curriculum series published by NSTA Press, which is a K-12 curriculum based on 5-week problem-based learning modules that integrate STEM, English language arts, and social studies concepts and practices. Dr. Peters-Burton is an Associate Editor of the Journal *School Science and Mathematics* and the *Journal of Science Teacher Education*.

Part I
Entrepreneurial Mindset of STEM Education in Theory

The Link Between Entrepreneurship and STEM Education

1

İsa Deveci and Jaana Seikkula-Leino

I have not failed. I've just found 10,000 ways that won't work.

Thomas Edison

Abstract

Entrepreneurship education is a relevant field of study at all educational levels. The concept of entrepreneurship education has been integrated into a variety of content areas in recent years, such as physics, chemistry, biology, and art. Recent global pedagogical strategies promote the integration of both STEM and entrepreneurship education. Researchers are working to understand how the world works, solve everyday problems, and develop technology, science, society and economy. In this sense, when STEM is not enough to explain a phenomenon or solve a problem, another field can be integrated into STEM, extending the STEM approach to, for example, E-STEM, STEM+A, or STEAM. Researchers are trying to integrate STEM education with other subjects such as art, environmental studies, entrepreneurship and design when an everyday problem could not only be solved by using STEM education. The concept of entrepreneurship is especially useful because entrepreneurship also has the

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capacity to contribute to STEM education in addition to adding an additional step to STEM and contributing to STEM education by helping to create innovative and entrepreneurial citizens. This chapter is a non-systematic literature review which aims to inform readers about the links between STEM and entrepreneurship education. This non-systematic literature review indicated that STEM and entrepreneurship are two important interdisciplinary approaches that complement each other. The emphasis in the literature on the need for STEM students, teachers and leaders to adopt an entrepreneurial mindset is increasing day by day. In addition, it can be said that the ideas, products or designs revealed via STEM education may have more value creation potential from an entrepreneurial perspective.

Keywords

Entrepreneurial mindset · Entrepreneurship education · E-STEM · STEM education

1 Introduction

The economic effect of innovation and entrepreneurship is extensively accepted [1]. Entrepreneurship has always been regarded as a tool for innovation and value creation and is seen as a key to economic growth [2]. As the STEM disciplines are also viewed as drivers of economic and social growth in the areas of innovation and technological development [3], STEM contributes significantly to entrepreneurship and innovation [2]. Companies in STEM industries also need employees with backgrounds in other disciplines, especially business and entrepreneurship [4]. As a consequence, institutes of STEM education have begun to benefit from entrepreneurship to create a more entrepreneurial-minded technological labor force infrastructure [1]. STEM careers are seen as successful and viable life projects that generate economic benefits [5]. They draw attention to the need to develop, for example, engineering projects that focus on solving daily life (real) problems and making a positive result on society, which requires promoting technology-based entrepreneurship and innovation in students [6]. One of the ways to reinforce and develop students' skills through integrated disciplines such as STEM and entrepreneurship education is to encourage real-life practices that increase their productivity [7].

There is also an increasing motivation in creating new ventures involving scholars, recent university graduates, and students enrolled in undergraduate programs at universities, particularly in STEM related programs [8]. Due to the need for STEM graduates in new ventures and different areas, the interest in STEM disciplines has been growing worldwide [9]. Therefore, a need for a higher number of students specializing in STEM and entrepreneurship is emerging at all education levels [10]. More young people should be made aware of the opportunities emerging from entrepreneurship and STEM fields [11].

Entrepreneurship and the application of STEM knowledge are regarded as key twenty-first century skills [12]. The strategies that guide education across the board also emphasize the need for developing such competencies and/or knowledge in societies. For example, according to the United Nations, technology, science, and innovation have been recognized for a long as one of the key drivers behind productivity gains and a crucial long-term lever for economic development and prosperity [13]. The United Nations' Sustainable Development Goals, for example, advocate entrepreneurial competencies as a way to support young people to start businesses, innovate and create jobs [14]. Furthermore, the European Union (EU) is also taking action in the field of education. The European Skills Agenda [15] establishes a framework for reform and policy at both the EU and national level. This framework emphasizes the importance of developing an entrepreneurial mindset and provides all learners with at least one entrepreneurial practical learning experience during mandatory schooling, resulting in STEM education that is strengthened through entrepreneurial work-based learning. The importance of entrepreneurial and STEM based competencies were also highlighted by the European Council's recommendation in 2018 [16].

Despite how strategies, needs-based analysis of labor market development, and positive experiences with pedagogical experiments in STEM and entrepreneurship education have aligned with the re-profiling of teaching and research, much remains to be done. For instance, the links between STEM and entrepreneurship education have not been analyzed even though there are empirical studies of, for example, integrating STEM and entrepreneurship education. Therefore, this chapter focuses on a non-systematic literature review [17] which/that points to connections between entrepreneurship and STEM education.

In this chapter, firstly, we present entrepreneurship education and entrepreneurial mindset. Secondly, we provide an overview of how these educational areas could be linked to STEM education. Thirdly, we show how these ideas have their origins in reform pedagogy and the added value of integrating STEM and entrepreneurship education. Fourthly, we present outcomes and experiences from different education levels and contexts. Finally, we summarize some opportunities and challenges of linking STEM and entrepreneurship education, thus providing some future directions.

2 Entrepreneurship Education and Entrepreneurial Mindset

Entrepreneurship education aims to develop the necessary information, knowledge, ability, skills, and competencies for individuals to establish or run a business. Entrepreneurship education also aims to provide individuals with an entrepreneurial mindset. Creativity, social skills, and the ability to solve realistic and significant everyday problems are viewed as the essential competencies to develop an entrepreneurial mindset [14]. Entrepreneurship or entrepreneurial education offers a way to foster such competencies [18, 19].

In overall, entrepreneurship education gives students the opportunity to take more responsibility for their own learning and success, to become creative, to set and achieve goals, innovative, critical, and active citizens. Students will be also capable of realizing existing opportunities and creating new ones. Moreover, they will cope with and thrive in complex societies [19]. Besides that, an important goal is for students to participate actively in the job markets, in which entrepreneurship is seen as a natural career choice [20, 21]. Entrepreneurial education enables the development of both individuals and communities in different organizations and communities [22]. Academics have emphasized that entrepreneurship education should not be overly simplistic or overly focused on market or business creation if it is to provide viable solutions to complex cultural, environmental, social, and economic issues, such as promoting sustainability in societies [14, 23, 24].

The entrepreneurial mindset is defined as the set of behaviors, attitudes, and skills students need in order to succeed, professionally, academically, and personally [25]. For example, the entrepreneurial mindset can be viewed as an ability to see opportunities that are in high demand both for non-profit organizations and profit, to organize resources and to create value [25]. An entrepreneurial mindset enables people to think and then act in a certain way in order to discover, evaluate and exploit opportunities by understanding the value proposition of a new idea and identifying a potential market [26]. Thus, the development of an entrepreneurial mindset is critical for a person to perceive and benefit from entrepreneurial opportunities [27].

3 STEM and Entrepreneurship Education as the Areas of Interaction

STEM education is an interdisciplinary approach focusing on teaching different disciplines or subject knowledge from STEM disciplines to solve real life problems in a student-centered environment [28]. STEM education offers learning opportunities that challenge students to create innovative designs [29, 30]. Considering the production of innovative solutions to real-life problems in entrepreneurship education from a pedagogical point of view, it can be said that STEM and entrepreneurship education are approaches that complement each other. In this sense, individuals can gain an entrepreneurial mindset by making use of the complementary aspects of STEM and entrepreneurship education, since both disciplines stress creation and innovation.

The fact that there are many similarities in terms of pedagogical approaches provides important clues for the integration of these two educational approaches. For example, both entrepreneurship education and STEM education can be based on producing solutions to real problems [31–33]. STEM activities are commonly focused on challenges or daily life problems [34]. Through this feature of STEM education, integrated STEM education offers a suitable infrastructure for the inclusion of entrepreneurial thinking in STEM education [31]. The STEM work-force provides skills and competencies not found in traditional education partly because traditional teaching generally focuses on passive learning, while non-traditional subjects such as entrepreneurship need more active learning approaches [35]. In this sense, the use of student-centered and active learning approaches in STEM education creates another suitable application area for entrepreneurship education. In addition, using experiential learning approaches in both STEM and entrepreneurship education can be seen as another advantage. It has been determined that experiential learning via competency-based practices is the good approach for high school students to adopt the interdisciplinary E-STEM model [30].

Studies have shown that education using generative approaches such as "design thinking" generally develop an entrepreneurial mindset [36]. Through an effective integrated STEM education, teachers can help students develop a range of twenty-first century skills, including an entrepreneurial mindset, in a student-centered, self-regulated learning that allows students to find potential solutions to problems [37]. Eltanahy et al. concluded that understanding STEM learning opportunities is critical for instilling an entrepreneurial mindset in STEM students [30]. If the goal is to develop such a mindset in students, it is essential to understand the main dimensions of the entrepreneurial mindset [25]. Lau et al. examined 23 studies investigating the competencies of entrepreneurs and found that among these competencies the most dominant characteristics were innovativeness, integration, pro-activeness, and results orientation [38]. As such characteristics are involved in STEM education, it can be said that the competencies that will enable students to have an entrepreneurial mindset can be gained through STEM education.

Both STEM and entrepreneurship education have an inherent consistency in their purpose and strong synergies in their applications [39]. Several studies point to the increasing importance of an entrepreneurial mindset in STEM subjects [40, 41]. Similarly, career paths in STEM disciplines are becoming more and more entrepreneurial [42]. Moreover, both entrepreneurship education and STEM education have good systematization in practice and can be deeply integrated [39]. This may be why supporting entrepreneurship seems to be a dominant trend, especially in STEM education [43]. STEM education can be seen as a useful support platform for innovation and entrepreneurship, which provide the impetus to STEM education [39]. Entrepreneurship (perspective) should be linked with STEM education [44] in order to achieve sustainable economic development [45]. In short, there are many studies claiming that STEM education and entrepreneurship education should be integrated or implemented together.

Students can use their entrepreneurial mindset to bring STEM products to the market. Therefore, the purpose of integrating entrepreneurship pedagogy into STEM education is to enable a new generation of STEM students to proactively create products and businesses that meet society's needs [46]. Local needs in urban environments create opportunities for STEM students and professionals to develop innovative and unique solutions [47]. In general, as seen in the aims of STEM education and entrepreneurship education presented in Table 1, STEM education and entrepreneurship education complement each other.

An example of the complementary aspects of entrepreneurship and STEM approaches shown in Table 1 is the search for solutions to daily life problems that are frequently emphasized in the aims of STEM education. In order to develop an idea or product (commercial or social project) that has the potential to create value in daily life, it is necessary to look at the problems with an entrepreneurial mindset. So, when looking for everyday life problems in STEM education, the entrepreneurial mindset can be a trigger. As another example, while STEM education aims to prepare individuals for the labor market, entrepreneurship education aims to improve the employment skills of individuals or to create new employment areas. STEM and entrepreneurship education complement each other in terms of recognizing professions and gaining professional skills.

Table 1 Some of the aims of entrepreneurship education and STEM education

Approaches	Aims
Entrepreneurship education	• To help students acquire skills and knowledge that are crucial for the development of an entrepreneurial mindset [48; p. 195]
	• To equip students with skills to make them entrepreneurial (whilst working within an organization) or entrepreneurial (go ahead to start a business) [49; p. 1098]
	• To impart entrepreneurship knowledge, skills, and experience to students through entrepreneurship courses, entrepreneurship competitions, and other training, to cultivate innovative thinking and entrepreneurial ability [50; p. 2]
	• To strength undergraduates' awareness and ability of self-employment [51; p. 185]
	• To refer to the teaching of the domain of entrepreneurship and the training of entrepreneurs [52; p. 3]
	• To develop in an individual the innovative spirit of an entrepreneur; namely, a creative attitude that calculates risk, is adept with their environment, sees the values of business propositions for themselves and for society at large, while seeking and making good use of opportunities [53; p. 3]
STEM education	• To cultivate innovative talents by improving students' ability to comprehensively apply interdisciplinary knowledge in solving practical problems [54; p. 60]
	• To learn to apply the basic content and practices of the STEM disciplines to situations they encounter in life [55; p. 5]
	• To prepare students for a diverse STEM workforce [56; p. 77]
	• To teach learners to solve real-world problems, collaborate, integrate these four disciplines, and not to learn them separately, just as they are not separate disciplines in the real world [57; p. 1]

3.1 The Origins of Integrating Entrepreneurship and STEM Education

The similarities between entrepreneurship education and STEM education are particularly evident in how education reformists in the past have promoted learner-centered learning based on both action and experience which form the bases of both education paradigms. For instance, the similarities between entrepreneurship education and STEM education are particularly evident in how education reformists in the past have promoted learner-centered learning based on both action and experience which form the bases of both education paradigms. For example, according to Dewey, human is a living thing that lives in interaction with the world [58, 59]. In this interaction process, people create knowledge and are tested or confronted with the results of the knowledge created [60]. Pragmatists like Dewey seek to understand, learn, and assimilate reality through action. For pragmatists, truth emerges through action and results are given meaning [58, 61]. Furthermore, as Mises' praxeology already assumes, economic science cannot be confirmed or refuted through the analysis of observable emporia, but by deriving all explanations from the basic proposition that human beings act [62]. While this action takes place as an interaction with others, it is deeply related to the context in which it takes place [21, 63].

As authors, we are also aware of the nuances of the concepts and the complexities of the phenomenon. Nevertheless, both educational paradigms and their integration have much to contribute to the development and understanding of education [63]. As a reform pedagogue and as a representative of pragmatism and symbolic interactionism, Dewey's work serves well to simultaneously demonstrate ontological commitments and also the interplay between the individual and society in the understanding of entrepreneurship and STEM education since we know that in today's world, it may not be enough to develop a product, find an idea, or offer a social service project. Instead, we need to consider the following questions. What real-life problem will this product, idea or service solve? Who can use the product or service developed with the STEM process? How many STEM experts emphasize that the target audience of the product is important in the development process today? We think there are very few of them. On the other hand, how much does the developed product cost? Have the developers considered how much to sell it for? Developers of STEM products should consider the market for which this product has been developed. Only in this way can they gain an entrepreneurial perspective. Of course, to develop an entrepreneurial mindset, students must be trained by entrepreneurial STEM teachers. It is, therefore, recommended for teachers to acquire an entrepreneurial mindset before commencing STEM education or concurrently with STEM education.

In sum, considering how education reformists throughout decades have emphasized the learner's active learning process in various, e.g., in real-life contexts, we could get more ideas for developing the integration of entrepreneurship and STEM education in the future by re-exploring, e.g., Dewey's and other reform pedagogues´ ideas, research, and experiments.

3.2 Combining STEM and Entrepreneurship Education

There is an increasing emphasis in the literature on the need to integrate entrepreneurship and STEM education [64, 65]. Olawale et al. state that combining basic STEM activities and engineering activities such as design and manufacturing with entrepreneurial learning is important in student engagement and learning success [25]. However, there is also research that points out that STEM curricula in colleges and universities do not regularly contain an entrepreneurial component [42]. Neglecting the integration of entrepreneurial components and STEM and focusing solely on entrepreneurship may lead to (1) a decline in interest and propensity to learn in most STEM students who do not have the desire to start a business [25] and (2) lack of ability in students to think critically or solve problems when faced with new situations [33]. Additionally, the understanding of STEM education that results in a discovery, invention or product can easily lose its importance unless it contains a basic understanding of the market. The integration of STEM and entrepreneurship education can help overcome these issues.

There have been a number of researchers who have worked to bring together the concept of STEM education and entrepreneurship education using different expressions and terminology, as seen in Table 2.

To clarify, the "E" used here for E-STEM has also been commonly used in the literature for environmental studies, but for this chapter the letter "E" added to STEM denotes integrating entrepreneurial learning into STEM education, to bring the results of STEM efforts to the market [10, 29, 30, 32]. Therefore, it is recommended that STEM education can be seen from a new perspective that includes entrepreneurship practices in markets and the business world [72].

Learning through E-STEM means that integrated discipline-based practices can encourage STEM students' entrepreneurial learning while performing a STEM task [30]. For example, the inclusion of the maker-movement, which aims to create and develop new products using technology and tools such as 3D printers in school curriculums, combines the concepts of entrepreneurship and STEM in an educational environment [11]. In another example, it is possible to see an example of a unified STEM education to bridge the gap between STEM practice in private and public schools [73]. Thus, Eltanahy et al. have developed an interdisciplinary E-STEM learning task that combines mathematical thinking, technical literacy,

Table 2 Concepts and terminologies combining entrepreneurship and STEM

Concepts and terminologies	Authors
E-STEM	[10, 29, 32]
STEMpreneurs	[66]
STEM entrepreneurship	[3, 67, 68]
Entrepreneurial STEM	[69]
STEM entrepreneurship Academy	[33]
STEAMS-based entrepreneur	[70]
STEM-based entrepreneurship	[71]

scientific inquiry, entrepreneurship, and engineering design applications from five key disciplines [30]. Further research into ways that STEM and entrepreneurship education can be integrated, will further clarify what form this integration should take. This is likely to happen soon because the integration of STEM education and entrepreneurship is a research topic that has come to the fore in recent years.

4 E-STEM Practices at Different Education Levels

The importance of integrating entrepreneurial learning with existing STEM lessons implemented in schools is the subject of much recent discussion [72]. In particular, STEM-integrated entrepreneurship courses are used to equip students with the innovation and technical skills needed to compete in a global economy [68]. Most post-secondary entrepreneurship courses are offered in business schools integrated with STEM programs [68]. In the literature, it is possible to see educational practices that integrate STEM education and entrepreneurship in primary and lower secondary schools [41, 71]. At younger educational levels, the primary focus of entrepreneurship education has shifted from content to pedagogy to develop students' entrepreneurial skills [74].

Students may not have entrepreneurial competencies yet, or even if they do, they may not have encountered opportunities to reveal these competencies. Of course, it may not make sense to expect a business idea proposal from primary and middle school students. These opportunities could be given by teachers, or, more specifically, by STEM teachers. For example, as part of the training, teachers can provide students with exemplary stories of entrepreneurs who won awards or started their own company at a similar age (maybe in the middle school age group). Teachers can easily find these examples with a little research on the internet. In addition, teachers can introduce students to entrepreneurial individuals. Moreover, by scheduling visits to various institutions, teachers can help students gain an entrepreneurial mindset about how institutions solve problems in society. Another example is for teachers to ask students questions that elicit entrepreneurial thinking: Could there be an innovative way to sell lemons to students? Of course, questions like these may also be related to local, regional, or national problems. An entrepreneurial pedagogy-focused perspective is mainly concerned with developing students' core entrepreneurial competencies [75].

What is important at this point is which entrepreneurial competencies of students at the basic education or lower secondary school level are being targeted. Huang et al. exposed seventh and eighth grade students to a STEM-Inc project design integrated with entrepreneurship [4]. As a dimension of entrepreneurship, they added ways to help students determine the business value of the product they designed to their STEM-Inc project design process and to promote that product through creating new ventures. The entrepreneurship dimension in this training included common terminology used in business and entrepreneurship, business planning, team building, business negotiations, effective communication and design-oriented thinking. The results showed that students showed more interest and confidence in engineering than in entrepreneurship, which may mean that STEM-Inc was essentially a project for STEM learning and entrepreneurship was used as a tool to involve students in STEM learning. The following paragraphs introduce some learning cycles, programs and strategies that integrate STEM education and entrepreneurship at different levels of education. Shahin et al. implemented a STEM-based entrepreneurship program for female students aged 14–16 [71]. The program consists of four key components: icebreaker, role model, ideation and solution, pitching. They concluded that the STEM-based entrepreneurship education significantly increased the entrepreneurial intention (tendency to start a new business) of secondary school female students [71]. Moreover, Amri et al. carried out a STEM learning design (project) on the increased value added to banana chips in order to improve the motivation and entrepreneurial attitude of high school seniors in rural areas [76]. The authors also stated that the learning design they developed should be applied in different subjects and in other schools. The connections between STEM education and entrepreneurial thinking in naturalistic contexts in teacher education need further exploration [31].

The World Bank points out that high school students should be educated with tangible and realistic practices that integrate STEM in order to increase entrepreneurship opportunities and encourage innovation for students [77]. At high school level, it seems difficult for students to direct their entrepreneurial skills towards the market [30]. In order to overcome this difficulty, exemplary practices need to be realized, disseminated and promoted. For example, they developed an E-STEM strategy plan for high school students comprising ability determination, brainstorming, SWOT analysis, prototyping, E-STEM design, and a business plan [29]. Eltanahy et al. aim to develop projects for STEM high school students to create value in society with this E-STEM strategic plan [29]. Eltanahy et al. also state that more clarity can be achieved in the definition of E-STEM's meaning, purpose and process by taking into account the best pedagogical framework of E-STEM [29]. These studies try to integrate entrepreneurship-specific dimensions into STEM education including icebreakers [71], finding innovative ideas, contribution of innovative idea to national economy, target group, product cost and selling price, advertising and marketing strategies [32], E-STEM design, business plan [29], pitching/presenting the product or service [32, 71].

Deveci developed a design cycle in science teacher education and called it the entrepreneurial (E-STEM) project process [32]. This entrepreneurial (E-STEM) project process comprises the following elements: (a) finding innovative ideas, (b) deciding on one of the innovative ideas, (c) identifying the difference between this idea and existing ones, d) contributing an innovative idea to the national economy, (e) identifying the target group, (f) sourcing the tools and materials needed, g) creating drafts and drawings, (h) testing product prototypes, (i) calculating the product cost and selling price, setting daily, (j) monthly and annual sales targets, (k) designing advertising and marketing strategies, and (l) presenting the product or service [32]. However, entrepreneurial project cycles may be different in different departments and at different age levels. The author also conducted this entrepreneurial project cycle in undergraduate science teacher education over a period of 14 weeks (two hours per week). As a result, it is possible to see educational research on integrating entrepreneurship and STEM education at other education levels except pre-school.

4.1 Outcomes and Experiences from Different Education Levels and Contexts

The teaching practices in which STEM education and entrepreneurship are integrated contribute to the entrepreneurial spirit and/or mindset of students at different levels of education. Today, we can say that STEM education and entrepreneurship education are pedagogical approaches that are included at almost all levels of education from primary school to adult education. For example, the primary purpose of the STEM Entrepreneurship Academy is to expose high school students to integrated science, technology, engineering, mathematics and entrepreneurship [33]. Through this exposure, high school students can explore options in STEM and entrepreneurship [33].

Olawale et al. found that junior year engineering students stated that STEM education aimed at increasing the entrepreneurial mindset contributed to their entrepreneurial learning [25]. Rokhmaniyah et al. addressed in their applied research that Science, Technology, Engineering, Arts, Mathematics, and Society (STEAMS) based entrepreneurship education can improve the elementary school students' entrepreneurial spirit [70]. Rokhmaniyah et al. also suggest that stakeholders, practitioners and researchers strengthen entrepreneurship with STEAMS in primary school. Fasoro et al. concluded that STEMpreneur Pitch (E-STEM education) gives middle school students (grades 6–8) the opportunity to apply their technical and entrepreneurial skills in order to develop innovative solutions [78]. Jäggle et al. held a workshop focusing on collaboration to increase the interest of primary (8 to 9 years) and middle (12–14 years) school students in entrepreneurship and STEM [11]. Thus, Jäggle et al. found that this workshop reflects positively on teamwork skills and encountered no difficulties as it represents the entrepreneurial skill of students. Also, Belcher has shown how entrepreneurship and an entrepreneurial-based STEM challenge (for 6–8 grades) can support engagement and STEM learning, especially in mathematics [79]. Huang et al. found that STEM-Inc project design practices integrated with entrepreneurship greatly improved 7th and 8th grade students' overall STEM learning experiences and recommended incorporating business entrepreneurship practices into STEM learning in middle school (7th and 8th grades) [4].

Deveci noted that pre-service science teachers gave positive feedback about the entrepreneurial project (E-STEM) development process which they say improved their decision making, entrepreneurship skills, analytical thinking, communication, and creative thinking [32]. However, Deveci found that some pre-service science teachers stated that the E-STEM process had a positive impact on their teamwork skills, others felt that it had a negative influence [32]. STEM awareness of pre-service science teachers significantly predicted entrepreneurial competencies (emotional intelligence, being innovative, taking risks, seeing opportunities and self-confidence) [64]. The variable that this STEM awareness predicted most among entrepreneurial competencies was emotional intelligence with a 29% variance rate [64]. Aydın-Günbatar tried to support pre-service chemistry teachers' participation in STEM + applications by using art and entrepreneurship in addition to STEM disciplines [34]. Aydın-Günbatar concluded that pre-service chemistry teachers understand that science, art and entrepreneurship skills are necessary to market a product through the use of creative ideas and artistic ability. Some studies contain pedagogical tips on how to integrate STEM and entrepreneurship education. For instance, Eltanahy et al. found that the STEM leader teachers who participated in their study stated that the characteristics of the learning environment needed for both entrepreneurship education and STEM education were relatively similar [30]. In addition, STEM lead teachers explained that opportunities to integrate STEM education and entrepreneurship education will increase through experiential learning strategies.

4.2 Overcoming the Challenges Faced in E-STEM Practices

Entrepreneurship education has been generally accepted as an independent subject in business-related studies, offered to students as an elective course [30]. Entrepreneurship education outside the field of business can be designed according to basic entrepreneurship content and entrepreneurship competencies. Thus, entrepreneurship education offered in other educational contexts can be competence-oriented rather than purely theoretical knowledge. Students who are exposed to competency-oriented entrepreneurship training at an early age can find opportunities to use the competencies they have gained in their future lives. Efforts to offer entrepreneurship education to young students in educational environments are increasing day by day. Due to these efforts, integrating entrepreneurship education with different subject areas or courses in educational contexts may lead to more positive outcomes. On the other hand, debates continue in the entrepreneurship education literature on how to include entrepreneurship practices in current course content [30]. One challenge is how entrepreneurship and STEM education should be integrated. In the previous section, we mentioned a few sample applications. Based on those studies, it is clear that students, teachers, and researchers face a number of difficulties in applied research where STEM education and entrepreneurship are integrated. Additionally, some pedagogical challenges can be expected as there is no standard for how to integrate STEM education and entrepreneurship.

Entrepreneurship education is challenged not about inspiring the small number of STEM students who have already make decision to become entrepreneurs, but about raising the entrepreneurial intentions of the vast majority of them who are not initially interested in entrepreneurship and helping them use their creative potential and knowledge to open up ideas and put them into action [46]. Entrepreneurial intention can be increased by placing the necessary components such as value creation, innovation, advertising, marketing in STEM education to develop an entrepreneurial mindset in STEM students or students exposed to STEM education. For example, value creation may be achieved by directing towards realistic problems in the STEM education process. So, the problem that needs a solution should be perceived as a serious problem by a certain segment of society. The problems implied here refer to the realistic problems that students observe in the school environment or out-of-school environment that they try to solve. When the problem is solved, the probability of it becoming a solution that will create value in that society may increase. For innovation, students in the STEM education process should consider innovative thinking in solving their problems. Students should pay attention to the originality of the idea in their solution proposals. Is the solution found by the students really original or does it bring a new perspective to an existing idea? In terms of innovation, one of these two elements needs to be present in the solution. Generally, in the STEM education process, the marketing and advertising aspects of the idea that students are considering may be neglected or the instructor may not guide them in this regard. As a result, neglecting dimensions such as value creation, innovation, advertising and marketing in STEM education can make it difficult for students to develop entrepreneurial skills in STEM education. Although STEM education contributes positively to developing some entrepreneurial skills, STEM courses which do not include entrepreneurship practices, fall short in fostering entrepreneurial individuals [30]. Understanding the role of entrepreneurship education, especially for STEM, is crucial as it has a lasting impact on student learning outcomes [80].

Another challenge of developing the entrepreneurial mindset of all STEM students is about what to teach, how to teach, and when to teach students in the STEM field [81]. Which components of entrepreneurship should be included in STEM education? From the entrepreneurial perspective, these components could include finding an innovative idea, creating value, identifying a target audience and promoting the product. In addition, it is important that STEM students or students receiving STEM education have an innovative perspective in terms of entrepreneurship. Students with an innovative perspective will be more likely to find products, services, or ideas that create value in society as a result of STEM education. Then, there is the question of when to introduce a new approach, method, or learning cycle that integrates STEM and entrepreneur education. What is the appropriate grade level and how should it be implemented? They point out that entrepreneurship education should be tailored to meet the needs of a specific group, namely business and STEM students [81]. In the literature, researchers try to integrate STEM education and entrepreneurship in different courses or at different levels of education. According to Belcher, little is known about how entrepreneurial STEM challenges or supports student engagement or STEM learning, especially regarding mathematics (6–8 graders) [79]. Moreover, Masunda et al. conclude that the majority of STEM undergraduate freshmen have some knowledge of the entrepreneurship concepts but have difficulties in applying those [81]. Furthermore, it is necessary to provide infrastructure and resources in senior secondary schools for the effective acquisition of entrepreneurship skills in STEM education [82]. The reason for this may be to meet the financial needs for workshops, technological equipment, tools and equipment needed to integrate stem and entrepreneurship.

Finding a qualified person to deliver instruction that integrates STEM education and entrepreneurship may be another challenge. The competencies of teachers or educators on how to include these two approaches in their lessons are very important to consider. Keyhani and Kim examined the process of an entrepreneurial teacher designing and running an informal STEM environment [83]. Keyhani and Kim determined that in this process, the entrepreneurial teacher's competencies such as vision, risk-tolerance, and self-improvement orientation appear insufficient or absent. STEM educators with the professional development program increased science teachers' awareness of E STEM, which includes self-confidence, risk-taking, motivation, perseverance, communication, determination, presentation, and marketing dimensions [10].

In tertiary institutions of learning, entrepreneurship education skills and entrepreneurial perspective need to be included in the STEM education curriculum [84]. Universities are beginning to examine the impact of entrepreneurship programs on STEM [85]. Olowookere et al. examined the entrepreneurial capacity and entrepreneurial intentions of non-STEM undergraduates and STEM, they concluded that non-STEM undergraduates revealed more entrepreneurial capacity and entrepreneurial intentions than STEM students [86]. This result can be evidence that STEM education, which lacks the entrepreneurial dimension, only directs students to create products or designs. Of course, it can be said that more evidence is needed for this. On the other hand, Mars examined how contemporary innovation and entrepreneurial demands affect the professional perspectives and academic development of STEM graduate students enrolled in agricultural colleges [87]. Mars found that the students expressed little direct insight into the concept of entrepreneurship and its intersection with technological and scientific research. Jones examined the dimensions of STEM education that affect STEM-educated graduates to pursue high-tech entrepreneurship [88]. Jones attributes the lack of relationship between high-tech entrepreneurship and STEM-support program elements in part to the general program objectives and insufficient emphasis on completing education and seeking employment. In another study, Ferreira et al. examined entrepreneurship education at higher education institutions in several European countries (Cyprus, Germany, Italy, Lithuania, Portugal, Spain, and UK) and found that different kinds of activities and practices are carried out in different European countries to promote an entrepreneurial spirit in STEM graduates and students [80]. Ferreira et al. concluded that among the obstacles preventing STEM graduates from starting a company are the difficulty of obtaining financial support and the high costs of patents. Moreover, Jäggle et al. point out that there are many opportunities for young people interested in various areas of STEM and/or entrepreneurship. However, interest in pursuing a career in areas of the STEM or taking the risk of becoming an entrepreneur is fairly limited [11].

5 Conclusions

This chapter highlights the links between STEM and entrepreneurship education. The non-systematic literature review pointed to strong connections between entrepreneurship education and STEM education. Whether approached from the perspective of entrepreneurship education or from the perspective of STEM education, the result is that these two educational approaches have a complementary structure and can add value to education. It is very important to organize approaches that integrate STEM education and entrepreneurship in a way that attracts students' attention. Otherwise, STEM education, which contains a lot of technical and content information specific to entrepreneurship, may not engage students. Entrepreneurship education directs students or individuals to a problem that will create value in society when it is resolved and this is the starting point of STEM education. On the other hand, the interdisciplinary dimension of STEM education and its engineering design process can be used as a necessary infrastructure for entrepreneurship education. In addition, the economic dimension and marketing dimension, which are barely taken into account in STEM education, add a different dimension to STEM education thanks to entrepreneurship training.

Although some difficulties were encountered in previous studies in which STEM education and entrepreneurship were integrated, there were also positive results. These positive results provide some evidence that STEM and entrepreneurship should be integrated. On the other hand, the challenges faced point to the need for more research on the integration of STEM and entrepreneurship at different educational levels. More research is needed to better understand the nature of higher education institutions and their relationship with entrepreneurship, especially in the STEM field [80]. There is still very little consensus strategy or models for how to teach entrepreneurship education at the primary and lower secondary levels. Today, there are many problems in the implementation of innovation and entrepreneurship education in colleges and universities [39]. Long draws attention to the fact that the concept of innovation and entrepreneurship education is not being sufficiently applied [39]. Meanwhile, more explicit education is needed about the role of entrepreneurial thinking in STEM professions [31].

Since key global organisations such as the United Nations and the European Union promote entrepreneurship and STEM education as a means of supporting young people to innovate, start businesses and create jobs, create solutions, we focused our study on this area. Our literature review supports the conclusion that educational initiatives integrating STEM and entrepreneurship education. However, more research and practical implementation is needed to promote meaningful change. The effort to integrate STEM and entrepreneurship education is not only a current issue, it will be the subject of further research in the years to come.

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2 Strengthening Bridges Between STEM Education and Entrepreneurship: Pathways to Societal Empowerment Towards Sustainability

Tiago Ribeiro, Joana Silva, Marta Paz, Alexandra Cardoso, Nuno Teles, Cláudia Nogueira, and Telmo Ribeiro

(...) the ones who are crazy enough to think that they can change the world, are the ones who do.

Steve Jobs (1997)

Abstract

In the twenty-first century, there are severe social and economic disparities worldwide. Due to this century's unprecedented pandemic situation, these disparities were exacerbated, reinforcing the need for a more cohesive society

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where the different socio-economic sectors work together towards a better and prosperous future. Many of these inequalities result from the non-existence or difficult access to proper education. By providing citizens with the knowledge and competencies to live fully, we are empowering society. However, to build a capable society, more democratic and participatory, it is essential to boost entrepreneurship. By assigning meaning and social-economic value to intrinsic competencies and knowledge, entrepreneurship may bring up the requirement for enterprising citizens. Such citizens should be able to implement the necessary changes and create new opportunities for all, which requires creativity and the ability to generate new ideas and solutions. Enterprising citizens also need to be equipped with competencies such as identifying opportunities and measuring possible risks to implement the new ideas and solutions and contribute to the development of a society, which is also important in Science, Technology, Engineering, and Mathematics (STEM) education and social innovation. This chapter addresses possible relations between different social topics—such as sustainable development, social innovation, and environmental education—with STEM education and entrepreneurship to respond to contemporary society's uncertainties and increasingly complex challenges.

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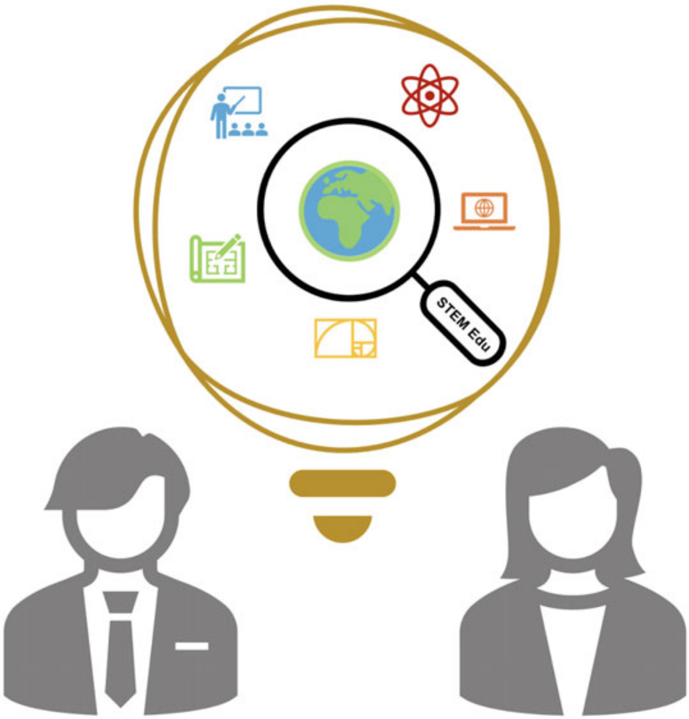
Graphical Abstract



Keywords

Entrepreneurship · Environmental education · Social innovation · STEM education · Sustainable development

1 Introduction

In the twenty-first century, the global panorama poses a myriad of challenges to societies from an uncontrolled and unprecedented pandemic in an extremely globalized world—such as the SARS-CoV-2 virus—, to the most severe and unpredictable effects of climate change—such as intense and catastrophic climate events. Humankind must deal with the dynamic feedbacks of the Earth system to the anthropogenic actions that trigger it [1]. This feedback response has impacts on environmental, social, and economic dimensions, and humankind must understand the complexity of the world [2, 3]. The Earth system complexity makes finding solutions difficult, needing a great capacity for problem-solving and critical thinking from citizens [3–6]. In this sense, society must become more resilient while facing these socio-scientific issues.

Contemporary problems, such as the (in)suitability of the Earth system and human species, are increasingly complex and interdisciplinary and are explained in diverse documents such as the 2030 Agenda for Sustainable Development of the United Nations [7]. Aware of these problems, the United Nations developed this agenda in 2015 [1, 7], reuniting the main global challenges faced by society and aiming to achieve 17 SDGs by 2030 to ensure the future of humankind. These goals comprise 169 targets that imply an interdisciplinary approach to answer critical challenges [1, 7]. The fourth goal of the 2030 Agenda advocates quality education accessible to all, regardless of gender, age, or sociocultural background [7]. Through the development of society's literacy, it becomes possible to have a more critical, contextualized, and real intervention concerning the global challenges. A more efficient and cohesive response is essential to achieve the remaining objectives of the mentioned document. There is a growing need to educate participatory and active citizens that can act as change agents [2]. In this path of change, the promotion of citizens' entrepreneurial and innovative competencies are necessary steps for the social, economic, cultural, political, and environmental development of today's society. A society more scientifically literate, innovative, and active is, consequently, a society that is more capable and better prepared to respond to the panoply of issues that may arise. Thus, the empowerment of entrepreneur citizens is in itself a preponderant element for the solution of known problems.

Leveraging contributions from different disciplines allows citizens to respond to contemporary problems in a more complete and realistic way [8]. The limits of discrete knowledge no longer make sense considering the complexity of today's challenges (such as social, economic, and environmental sustainability). There is a need to articulate and use interdisciplinary approaches to find solutions to these issues [2]. Science, Technology, Engineering, and Mathematics (STEM) education, one type of interdisciplinary approach, is increasingly required and essential in interpreting real-world phenomena and finding solutions to everyday issues. An interdisciplinary approach and the interplay of the various areas of STEM are required to find solutions to everyday problems and develop sound and meaningful outputs [9].

STEM education has been used as a generic label for any program, policy, or practice that involves one or several of the STEM disciplines [10] since it originated in the 1990s in the United States of America [11, 12]. STEM education refers to an integrated approach to teaching and learning in the STEM fields [13–16]. It typically includes educational activities across all grade levels, from pre-school to post-doctorate, in both formal and non-formal settings [14, 15], including science communication. Bybee [11] argues that to advance STEM education in today's educational systems, it is fundamental to actively integrate all four of STEM's components in the elementary years. The integration of engineering is especially significant since this component is poorly represented in pre-higher education. If future citizens are exposed to technology and engineering early in their school career, knowledge and competencies required in current job markets will be reinforced throughout their education rather than starting from scratch when they enter the workforce. Thus, education in STEM areas in early years emerges as a preponderant element for society and its development [2].

Combining interdisciplinary approaches, such as STEM education, with entrepreneurship can be even more effective in finding solutions to global problems. Entrepreneurship can generally be defined as the process of recognising opportunities and implementing new ideas, or old ideas in new settings [17]. By redirecting knowledge and competencies towards the development of an enterprise, whether individually or within a team, we might generate positive financial and, subsequently, social impacts [17, 18]. Entrepreneurial thinking and spirit require a series of competencies, such as creativity or adaptability, that one either is naturally inclined to have or actively works to develop. Developing such thinking and spirit may allow us to spot opportunities as well as the right conditions to successfully implement new ideas [19]. The education of entrepreneurial and active citizens requires more contextualized and bolder approaches to curriculum content and other non-scholar activities, like science communication. That is, more than the curriculum content, citizens must be endowed with knowledge and competencies that allow them to establish direct relationships between scientific knowledge and the real-world problems, demonstrating its applicability and importance for citizens' individual and social conduct, following moral and ethical standards [2, 20–22].

Embracing current and future challenges towards sustainability demands finding synergies between entrepreneurship, social innovation, and the interdisciplinarity of STEM and environmental education (EE). From this confluence, more complete, contextualized, and innovative solutions to the problems we face may emerge. The challenges identified in the 2030 Agenda demand innovative, effective, and interdisciplinary solutions to achieve sustainability. It will only be a reality if all citizens join forces to instigate social change, articulated with science and technology. In this dialogue, it is essential that citizens believe in science, which may be a result of proper scientific education and communication. Given the growing misinformation that undermines the credibility of science, which may cause citizens to distance themselves from science, it is critical to acknowledge the importance of science.

This chapter aims to create a holistic understanding of how an interdisciplinary articulation with scientific communication, STEM and EE, and entrepreneurship can contribute to social innovation towards sustainability. To achieve this aim, a convergence between STEM education and entrepreneurship is built, supported by scientific communication, social innovation, and EE, as a pathway to reach sustainability. The synergy between entrepreneurship, STEM, and EE and their contributions to sustainable development are discussed. Integration of STEM into the curriculum is suggested for supporting entrepreneurship and societal empowerment.

2 STEM Education and Entrepreneurship: Possible Convergences

The relationship between science and society exists in a delicate balance of influence. Scientific advancements are known to push societal development further while social, economic, cultural, and political contexts contribute to the prosperity of science. Throughout history, science has equipped society with the necessary tools to progress and thrive. Science has been inherently connected to social issues and values. This means that science should not be seen only from a technical standpoint. Instead, it should be observed carefully from a socio-technical perspective, ensuring that the desirability, sustainability, uncertainty, and ethical aspects of innovations are addressed [23–25].

To meet the Sustainable Development Goals (SDGs) by 2030, all over the world, countries of different development levels are focusing on their transition to digital and green economies. Most countries are convinced that their future economic competitiveness will depend upon how quickly they manage the transition to digital societies [26]. This transition can be managed through education as it plays a crucial role in preparing citizens for a future of complex challenges and uncertainty, such as globalization, digitalization, or climate change [27]. High-quality science and technology education are essential to provide citizens with the relevant knowledge and competencies to understand scientific and technical interrelations. The required competencies, such as problem-solving, creativity, innovation, critical thinking, collaboration, entrepreneurship skills, communication, and predictive thinking, are highly important for openly embracing the change and conscientiously shaping the future, in a responsible and participatory way [27].

Entrepreneurship can be seen as the ability to create new and innovative businesses that will provide better opportunities for the future of the citizens. Entrepreneurship is significant for citizens to apply their knowledge to real-life situations and increasingly valued for future professionals. Entrepreneurship and innovation are considered, by the specialized literature, as the main engine of economic growth and an important contributor for creating new jobs and innovations as well as strengthening local and global economic dynamics [28–31]. Certainly, the earlier and more widespread exposure of citizens to what entrepreneurship and innovation are, the greater the probability that they will become entrepreneurs, in one form or another, at some stage in their lives [28].

To instil entrepreneurial competencies to deal with real-world problems, STEM educational approaches can be followed, and efforts must be made to include entrepreneurial competencies in the curricula [20, 32, 33]. STEM education goes beyond the mere acquisition of knowledge as it also contributes to the creation of the next generation of innovators that is sorely needed for a dynamic, globalized, and competitive work environment. [34]. This requirement is anchored on empirical evidence that shows STEM education as enabling citizens' development of competencies. These include systems thinking and the ability to adapt [11], critical thinking, and complex problem solving, all of which are needed to advance science and technology knowledge in the workplace, community, and the global arena [34, 35].

Another important feature of STEM education is that it starts from an authentic, real-life problem or project, preferably one that learners can relate to [15, 35, 36]. To effectively implement this feature, it is necessary to develop a conceptual framework for STEM education inholding a deep understanding of the complexities of the teaching and learning processes. To do so, educators should stay loyal to the nature of the STEM content applied to real-world situations and, therefore, utilize a STEM education integrated approach to enhance learning [37]. The increasing complexity of the world's challenges can generate an opportunity for creative entrepreneurs to explore, think and solve these problems. While the stressful conditions of an ever-changing world can create chaos and uncertainty, these circumstances provide entrepreneurs with new perspectives and resources for innovation and change. As entrepreneurs create new ventures, they face difficult situations and resort to emerging practices [38]. The creation of entrepreneurs contributes to the greater involvement of citizens in the global challenges through innovation and social change to react to socio-scientific issues—that can be contextualized and integrated into society through science communication and education.

3 Science Communication, Social Innovation, and Entrepreneurship: Citizen Engagement for Social Change

The increasing number of science communication channels, such as social media, has allowed the crossing of different fields of science, spreading science among society and conducting greater information. Increased science communication could generate scientific literacy and raise the public participation interest, but, on the other hand, could also create misunderstandings and alternative conceptions about socio-scientific issues among citizens [39]. Bucchi and Trench [39] defend that:

> The relationship between science and society is often represented in terms of misunderstandings, gaps to be filled, and bridges to be built. This traditional stereotype posits science as distinct and separate from society in terms of content, organizational practices, institutional aims and communication processes. (p. 2)

Considering current events, such as the SARS-CoV-2 pandemic, the disconnect between science and society is nonsensical. Science, socio-scientific issues, and scientific and technical concepts have entered our daily lives quite explicitly. However, science is not always understood by citizens, especially scientific phenomena requiring adequate scientific communication to avoid misinformation, misunderstandings, and disbelief. Also, given the new way of living at a distance during the pandemic, digital media has great importance enhancing digital communication.

Given the pandemic, the number of digital communication and collaborative work platforms increased. Engineering and information technology were indispensable, building a foundation for increasing scientific literacy, providing diverse opportunities for new ways of communicating science and reaching a wider audience [39]. However, science communication media can lead to changes in the perception of real scientific knowledge, leading to misunderstandings replicated in social media. This can result in questioning the authority and credibility of science. For example, misinformation and conspiracies about the COVID-19 disease and vaccinations have spread rapidly, especially through social media platforms. This misinformation resulted in weaponizing the characteristic uncertainty of science and any possible lack of consensus within the scientific community to foment distrust and hostility towards science and scientists, increasing the existing polarization of public opinion on science [23, 40]. Despite this, the scientific enterprise continues to be one of the key driving forces of contemporary society. This highlights the dependence on scientific progress in terms of innovation and the maintenance of already existing services and products, such as antibiotics, means of transportation, and the internet. The scientific enterprise has shaped habits and relationships in the modern world.

Science education and communication play an important role in both the sharing of scientific information and the contextualizing of socio-scientific issues. Such issues, relating to scientific matters, have implications in citizens' everyday lives and science communication approaches can present more participatory models of citizens in scientific initiatives. This fosters a close collaborative relationship between science and society to address social needs and anxieties surrounding new technologies, as well as the creation of knowledge [41].

Today's society is increasingly demanding and globalized, requiring new strategies to respond to the consumption of information and resources. However, even though science greatly impacts our world and the modern society that heavily relies on it, science alone does not hold all the solutions to contemporary problems [42]. Even when science offers solutions to urgent issues, scientific efforts are often being directed towards superfluous and possibly harmful innovations, such as trendy gadgets and weaponry, which in turn highlights the necessity of channelling scientific knowledge towards specific societal problems [43]. This brings us to the concept of social innovation and social entrepreneurship, which relies on new ideas or existing ideas that are applied in new contexts to solve social problems and meet social needs, resulting in changes in social relationships and the empowerment of society [43, 44]. In the case of social entrepreneurship, these goals are met through a business model. Much like the case of scientific advancements, though, social innovations are bound by their contexts, requiring environments that not only do not punish those who wish to implement change, but encourages it [45].

Concepts such as responsible research and innovation and the sustainable development goals demonstrate how science and social innovation must coexist and collaborate to provide the necessary solutions to contemporary societal problems, while also being conscious that science cannot be regarded as simply a means to an end [46, 47]. Social innovators and social entrepreneurs are those individuals, movements, or organizations that work to bring awareness to social issues and solve social problems that both governments and other institutions have not yet addressed [48]. Environmentalism is only one example of how a wide social movement can prompt many social innovations, from community gardens to the recycling of urban waste [43]. These innovators and entrepreneurs, nevertheless, rely on their capacity of gathering the commitment and passion from the rest of civil society to implement their ideas [43].

There are several initiatives designed to encourage citizens to become social innovators and entrepreneurs, from university programmes and training courses by non-profit organizations to The School for Social Entrepreneurs [43, 49]. All the aforementioned initiatives have a common goal: equipping future generations with the necessary competencies and connections to implement positive social change [43]. Science is a very powerful driver of change. Therefore, STEM is at the vanguard of the technological and scientific advancements that can simultaneously work towards ensuring economic success, societal progress, and an overall improvement of quality of life on Earth. Given the role that science and scientists play in promoting and generating change in the form of technological and scientific innovation, as well as in the form of social innovation and entrepreneurship, initiatives that foster entrepreneurial competencies in citizens are an important addition to science education programmes and curricula, as this is not a very frequent component in most of them [50, 51].

Contemporary problems such as climate change, rising infectious diseases, and scarcity of resources only exacerbate the already existing social inequalities in the world. Therefore, scientists equipped with entrepreneurial competencies have a unique role in social innovation and entrepreneurship, being able to address these issues from both the perspective of a scientist and an entrepreneur, generating innovative solutions to urgent societal problems. This is possible when merging STEM education with entrepreneurship education to ensure that the future is filled with scientists who are capable of being successful leaders of change, mobilizing competencies, people, and resources, and of improving the world. Scientific communication can also play a very important role as it can complement STEM education as a vehicle of information, enriching learning environments and reaching other audiences than school-age citizens.

4 Entrepreneurship and STEM Education: Contributions for Sustainable Development

Despite sustainable development being a distant reality, as recognized in the 2030 Agenda for Sustainable Development, efforts are needed if society wants to prosper and desires to leave the planet in a better state so future generations can thrive [52]. As one of these efforts, the implementation of the 2030 Agenda aspires to guide society so that global challenges can be recognized as targets of reflection and needs to be solved [7, 21]. Therefore, the agenda, including SDGs, is a plan of action for people, the planet, prosperity, peace, and partnership that intends to boost actions in environmental, social, and economic dimensions [7]. SDGs should be implemented in an integrated way as they are addressed as a whole, and this requires an interdisciplinary approach [1]. Citizens need to be conscious of the role they play in the progress for sustainable development and the need to develop key competencies to act in a way that contributes to the achievement of the SDGs [2, 3, 21, 53]. These competencies can be divided into domains, namely: (i) cognitive domain—system thinking, anticipatory, and normative competencies; (ii) socio-emotional domain—strategic, collaboration, critical thinking competencies; (iii) and behavioural domain—self-awareness, and integrated problem-solving competencies [4–6, 54–56].

The 17 goals of the agenda are diverse and require knowledge and competencies from different disciplines and efforts from every citizen to achieve these goals. In this context, education is crucial to reach truly sustainable development because it necessitates changes in our daily basis, highlighting the active role of society for that change. Education is recognized by the United Nations as an important element for sustainable development and this is reflected in the fourth SDG—ensure inclusive and equitable quality education and promote lifelong learning opportunities for all [2].

The development of knowledge, behaviours, attitudes, and values towards sustainability is of paramount importance to instil a better relationship between humans and the planet [2, 3]. STEM education and entrepreneurship may turn out to be effective, innovative approaches to help citizens contribute actively to the resolution of current world challenges and the achievement of the SDGs [2, 40, 57]. Education is internationally recognized as the best way to prepare future citizens for the requisites of sustainable development and to build a society ready for the challenges that global changes pose in the present and future. Innovative approaches are needed for an education that shapes human actions for sustainable development [2].

STEM education can provide opportunities to citizens to develop creative ways to enhance knowledge, behaviours, attitudes, and values towards sustainability and help them in acquiring most of the competencies referred to above to make future decisions [55, 58]. Moreover, to resolve the main problems faced today, all subjects of STEM are needed for future actions as well as the competencies developed within STEM education [21, 53, 55, 56]. Therefore, with STEM education, citizens develop competencies that can increase the chance of generating sustainable lifestyles [2]. Citizens will begin to have the tools needed for the development of a new perspective of the planet and then act towards sustainability [21]. Sustainability can act as a unifying theme between the disciplines involved in STEM helping citizens to work in an interdisciplinary way and become empowered professionals by developing competencies in different areas [56]. There can be a synergy between STEM and sustainable development education to give citizens better opportunities to participate in democratic important decisions for the future of the planet and humankind.

STEM education allows for the addressing of real contextualized problems, such as the issues underlying SDGs. Through STEM education, citizens can improve on how to make decisions concerning environmental, social, and economic real-life problems and it can help them to behave in a way that promotes sustainability [21]. Addressing sustainability requires the use of integrated STEM content, contextualized problems about the real world, and cooperative work to develop competencies and literacy [2]. The interdisciplinary characteristic of STEM can help future citizens gain insight into global challenges, which could enable them to help society pursue solutions for current sustainability issues. STEM education that incorporates sustainability can bring together STEM in a merging way [56]. Preparing citizens to face sustainability problems is essential for their future [54].

To find solutions that meet the SDGs of Agenda 2030, entrepreneurial competencies are necessary. Empowering citizens with entrepreneurial competencies can help them to find solutions for the needs of society as well as for the challenges it faces. In this way, SDGs and the United Nations adopted a resolution that considers entrepreneurial competencies as essentials for the advancement of society [20, 33, 59]. Also, the United Nations recognizes that businesses will be key factors in the pathway for achieving SDGs and enhancing the very important concept of circular economy—it is a model of production and consumption in which the life cycle of products is extended, as the reuse, repair and recycling of materials and products are promoted [33]. Entrepreneurship education can help students to become employers and work to achieve economic sustainable development [20]. The fourth SDG presupposes citizens should have entrepreneurship education for the development of several competencies that have the potential to enhance society and consequently contribute to sustainable development [40]. It is relevant to disclaim that the United Nations encourages the inclusion of entrepreneurship education for all students and:

> (…) recognizes that entrepreneurs can address sustainable development challenges by developing effective and simple solutions in the areas of utility services, education, health care, hunger eradication and the environment, and that social entrepreneurship, including cooperatives and social enterprises, can help to alleviate poverty and catalyse social transformation by strengthening the productive capacities of vulnerable groups, including persons with disabilities, and producing goods and services that are accessible to them. [40, p. 11]

Boosting sustainable development education based on STEM and entrepreneurship can bring value and enhance the relationship between human beings and the planet. Therefore, solutions for environmental, social, and economic issues can be addressed using the STEM educational approaches to develop effective ways to deal with global challenges and enhance society's behaviours [2, 20, 21, 33, 57].

Implementing STEM and entrepreneurship in the classroom can result in future citizens who are better prepared to face their future careers [20, 33, 58]. Citizens empowered with STEM and entrepreneurship knowledge and competencies can contribute to the achievement of sustainable development. They can develop, for example, creative and innovative businesses that promote sustainability in several ways, considering the SDGs, taking actions for people, the planet, prosperity, peace, and partnership.

4.1 Entrepreneurship, STEM, and Environmental Education: Synergies for Sustainable Development

Recently, the scientific community has progressively recognized that the Earth's unique conditions for human survival may soon disappear, making it imperative to adopt more sustainable ways of acting [60, 61]. EE for all can be viewed as one way of supporting sustainability. This is not a new concept and emerged in the early 1960s out of a need to respond to growing environmental crises [62]. The development of ecological and environmental literacy was supported, requiring citizens to understand the socio-political, value-laden, place-based, and emotional contexts that environmental issues prompt and which need to be analysed and resolved [62]. Despite its growing awareness and importance in the late decades, EE faces some controversy in society, as there are several competing ideas and perspectives about how to respond to environmental issues and concerns. These competing and contentious ideas make it difficult to identify the research, innovations, and programs that can be used to change our course of actions, create a more sustainable environment, and prevent further damage to it [59]. Thereby, achieving consensus is imperative, to construct a universal language towards EE, recognized by all actors of society.

Presently, much EE research focuses on investigating the learning processes that enable citizens of all ages to develop (1) the competencies that allow them to respond critically, creatively and ethically in relation to environmental issues they face, (2) the conscious, informed and responsible decision-making on these issues, and (3) the commitment to act either individually or collectively to sustain and improve the environment [59, 60, 62].

According to Vasconcelos and Orion [60], one of the major goals in EE is the development of an environmental insight. This is a powerful competency that can guide citizens to become aware of the efforts needed to overcome the current trend of imbalance in the Earth system, providing real transformation of habits and behaviours. The development of this environmental insight depends on the ability to perceive the Earth system [60, 63] and the positive impact of the environment on socio-economic changes from a holistic point of view [64]. This concept may also be related to what Levrini et al. [65] refer to as the ability to predict the future. Thinking about the future implies that citizens think and face their values, desires, and fears. In this sense, the perception of the future comprises commitment and personal involvement [65] and may contribute to change and transformative action towards an environmentally sustainable future.

The goal of improving twenty-first century competencies is also fundamental to environmental educators' efforts to create an environmentally literate citizenry [63, 66]. Nevertheless, current initiatives in EE in schools only seem to promote awareness on environmental issues [63], rather than developing a true environmental literacy. This kind of literacy includes: (1) an awareness of and concern about the environment and its associated problems, embracing the social, economic, and political dimensions of our interaction with natural systems; (2) knowledge, competencies, and motivations to work toward solutions of current problems and the prevention of new ones [67, 68].

In the face of the world's current complex environmental issues, EE does not advocate a particular solution or action but instead facilitates citizens' ability to draw on, integrate and synthesize knowledge and competencies from a variety of discipline areas, to conduct inquiries, solve problems in an innovative and proactive way, and make decisions that lead to informed and responsible actions [66]. At the same time, dealing with those environmental issues requires being able to think and work within the scope of uncertainty. As such, a major opportunity for STEM education is related to integrating one of the greatest challenges of our societiesenvironmental concerns—into its curriculum. Socio-scientific issues like climate change, energy efficiency, food security, or natural resources exploitation, among others, can be addressed using the four components of STEM in an integrated way, to emphasize and understand those problems [10, 11, 69, 70], as well as trying to find the better answers to respond to them. Additionally, addressing these environmental questions must be a reality not only in formal educational contexts but also in other different learning contexts, like non-formal or informal contexts [71].

The importance of connecting STEM with EE was recognized by the North American Association for Environmental Education [NAAEE] [70], using for the purpose Environmental—Science, Technology, Engineering, and Mathematics (E-STEM). We must acknowledge that STEM education seeks to help citizens understand environmental issues in the context of their lives and also their lives in the context of environmental issues [72]. According to Russell and Dillon [73], without adequate STEM and EE education, tomorrow's citizens will be unable to appreciate their relationship with the environment and, as a result, might not make the conscious and responsible choices that will lead to a more sustainable future. Therefore, education must use strategies that can develop those entrepreneurial competencies [28, 31], such as the learning of EE through a STEM approach and preparing future citizens for solving even more challenging and complex, interlinked, and fast-changing problems.

Nevertheless, it is important to recognize that EE deals with contentious socio-scientific issues. Beyond their scientific character, EE issues entail multiple and complex social and cultural facets [62, 74–76]. These everyday environmental socio-scientific issues have enormous educational potential, as they can be analysed from different perspectives, involving more complex dimensions such as ethical and moral issues [74, 75, 77], helping to build bridges between the scientific content learned and citizens' social and political context [77]. Additionally, they allow the development of more accurate conceptions of the nature of science [74, 78] and higher-level cognitive competencies, such as critical thinking, decision-making, or problem-solving, fundamental to enable the transition to responsible action in the future [78]. Therefore, their resolution can be impeded if people attempt to do so using only scientific knowledge [76]. Stephan [79] argues that "(…) the most important aspects of scientific literacy involve knowing the content and practices of science well enough to make informed decisions about the natural world around us" (p. 16).

In many cases, learners' scientific academic experiences tend to strictly focus on disconnected proficiencies within the fields of STEM, which usually lacks social, moral, and cultural lenses [74, 76, 80]. As argued by Gough [80], Herman et al. [74], Yanez et al. [81], and Zeidler [76], this is problematic, especially when the interests of economic advancement, production, and consumerism of material goods are overvalued and anchored in a knowledge that is virtually devoid of sociocultural and ethical values. Similarly, Rauf et al. [64] also address the importance of values and social attitudes in environmental entrepreneurship education.

The present pandemic situation might be one powerful example showing the importance of integrating EE through the lens of ethics with a STEM approach. Several authors acknowledge that the disruptive way in which humankind acts towards the environment (increased habitat degradation, deforestation, wild animal trade) can increase the risk of species spill over, resulting in new human diseases [60, 82, 83]. STEM education has been revealed to be crucial in answering this outbreak [84, 85]. It would not have been possible to respond to the pandemic without an integrated approach that allowed the development of a number of vaccines, in the shortest time possible, effective medical treatments, tracing the origin of the virus, discovering ways of transmission, or developing epidemiological studies, which require enormous statistical support [84, 85]. Within this context, it is fundamental that the marriage between entrepreneurship, STEM education, and EE reaches beyond the development of knowledge and some of the referred essential twenty-first century competencies in the citizens, such as problem-solving or creativity. The joining of entrepreneurship, STEM, and EE will give citizens the possibility to enhance their reflective judgment and social and moral considerations. Placing citizens in active roles and using real-world tools in authentic socio-technical contexts may contribute to the effective transformation to confront their abilities and limitations to engage in personally relevant ways, as innovative, entrepreneurial, and conscious producers, with technical and scientific knowledge, embodied in ethical values.

Society must learn how to deal with the challenges of environmental issues, and education has a crucial role to achieve that purpose. STEM approaches are considered essential in promoting innovation, productivity, entrepreneurship, and economic growth. Developing a synergic link between STEM education and EE, without leaving behind social, cultural, and ethical values, offers an opportunity for that learning to happen, and can result in a meaningful environmental and societal outcome. As such, an investment in STEM education with those assumptions in the present will surely be profitable to future generations [11, 34, 38, 85].

5 Entrepreneurship and Societal Empowerment: STEM into Curriculum

STEM education is, at least in most western countries, considered a priority. This is due to the agreed importance of equipping society with a STEM literate and skilled workforce, which, in turn, is seen as a vital step to ensure economic growth [50]. In fact, STEM professionals are responsible for much of the innovation and entrepreneurial ventures seen in contemporary society [50, 86]. Currently, it is urgent to consider the inclusion of entrepreneurship modules into STEM curricula or provide aspiring scientists with the resources and connections to develop entrepreneurial competencies and networks outside their assigned programmes, which can allow interesting partnerships. There are anecdotal examples of successful technology entrepreneurs that forfeit traditional higher education, which might discourage young and impatient people from long and challenging STEM courses and inspire them to try their "luck". However, it is important to note that most founders of highly successful technology ventures are highly educated individuals with academic degrees in STEM fields [87].

STEM education programmes should, then, provide students with not only the scientific and technological knowledge and competencies, but also the entrepreneurial skills to successfully develop and implement business models as well as innovative ideas, whether those are focused on creating economic or social value, in today's ever-changing world [51]. Furthermore, although both scientists and entrepreneurs already share one key trait in innovation, which requires creativity, entrepreneurs must also be resourceful, persuasive, risk-taking, and, more importantly, must be able to identify and seize opportunities [50]. Curiosity and creativity must be promoted in STEM education, shifting the focus from memory to understanding, avoiding the passive transmission of information and mindless compliance, and instead encourage a sense of wonder and capability, allow and foster interdisciplinarity, as well as the connection of science to everyday experiences [88]. By enterprising citizens with knowledge and competencies in STEM, we are creating citizens who are more aware of the need to adapt to the world in progress and can become pioneers of a new digital revolution, for which they must be prepared.

The search for solutions to contemporary challenges is one of the most ambitious and complex missions that society faces. The hunt for solutions to these problems is a matter of concern for science. This challenge might be overcome in a coordinated response of science and entrepreneurship, with the impetus for social innovation. For this to happen, we must educate critical citizens with the tools to actively participate in society. Educational approaches within the scope of STEM, subordinated to inquiry-based teaching, can contribute to this domain. The latter presupposes learners mirror the work of scientists, as active agents of their learning. Then, it becomes essential that learners develop a sense of what scientific practice is. Experiencing it can increase the level of citizen involvement with science, in what is called citizen science. Citizen science, articulated with STEM education, can raise the bar, and enhance the development of scientific competencies and knowledge, which are crucial for finding solutions to socio-scientific issues.

We are currently witnessing the integration of citizens in scientific practice, as crucial elements to scientific research, in what is defined in the literature as citizen science. Citizen science appears as an approach that can be used in STEM and entrepreneurship education to foster the development of scientific competencies by experiencing how science is conducted. Irwin defends a notion of participatory and inclusive citizen science [89]. In this view, citizens contribute to and in the development of science through their inclusion in scientific practice and stages, such as collecting data or establishing research objectives [89]. In this sense, citizens' participation in the scientific practice itself allows the development of knowledge and various competencies that actively involve them in the advancement of science and society. Educational approaches based on a perspective of citizen science may provide citizens with essential knowledge, competencies, behaviours, and values so that they can actively and responsibly participate in society and debate socio-scientific issues with greater ownership of what scientific practice is. Participation in citizen science initiatives, integrated into a STEM curriculum with an entrepreneurial mindset, can allow citizens to develop knowledge and competencies that lead to the empowerment of society, creating scientifically literate and active citizenries.

6 Conclusion

Without realizing it, STEM is always present in our daily lives. Education in these areas makes the knowledge and competencies acquired by citizens interdisciplinary, empowering them in their decision-making and opinion-forming on contemporary socio-scientific issues. Entrepreneurship and social innovation are complimentary key elements for the search toward better solutions that promote sustainable development in its three domains—social, economic, and environmental. However, curricula and lifelong learning activities do not always reflect the presence and relevance of either a STEM educational approach or entrepreneurship as elements of change and social innovation. Thus, the need to bring together STEM, entrepreneurship, and social innovation becomes clear. Citizens' engagement, from the smallest daily problems to the biggest global challenges, is essential to achieve a better quality of life, respect the Earth system balance, and ensure prosperity. For this, it is necessary to promote an interdisciplinary and humanist culture amongst citizens, ranging from the school curriculum to their attitudes and values. In this way, it will be possible to build a more capable and resilient society in the face of the great present challenges and the ones that will come.

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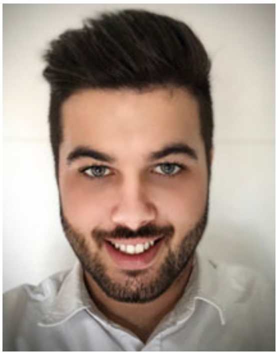

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3 Cultivating Entrepreneurial Leadership Skills Through STEM Education

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Sic itur ad astra (*Thus one journeys to the stars*).

Virgil, Aeneid

Abstract

STEM education is often associated with training in research, experimentation, computation, innovation, analysis, verification, and the like. It is rarely linked with the concepts of business and entrepreneurship. However, various prominent figures that make their living out of scientific and technological innovations seem to have cultivated entrepreneurial leadership skills that allowed them to transform their "garage experiments" into multimillion-dollar companies. This makes one curious about how these STEM practitioners become successful entrepreneurs. Is a business degree or taking courses in business and entrepreneurship necessary to build a successful business out of STEM fields? Or is STEM education a sufficient training ground to cultivate future entrepreneurs? In this light, this chapter seeks to explore the notion of

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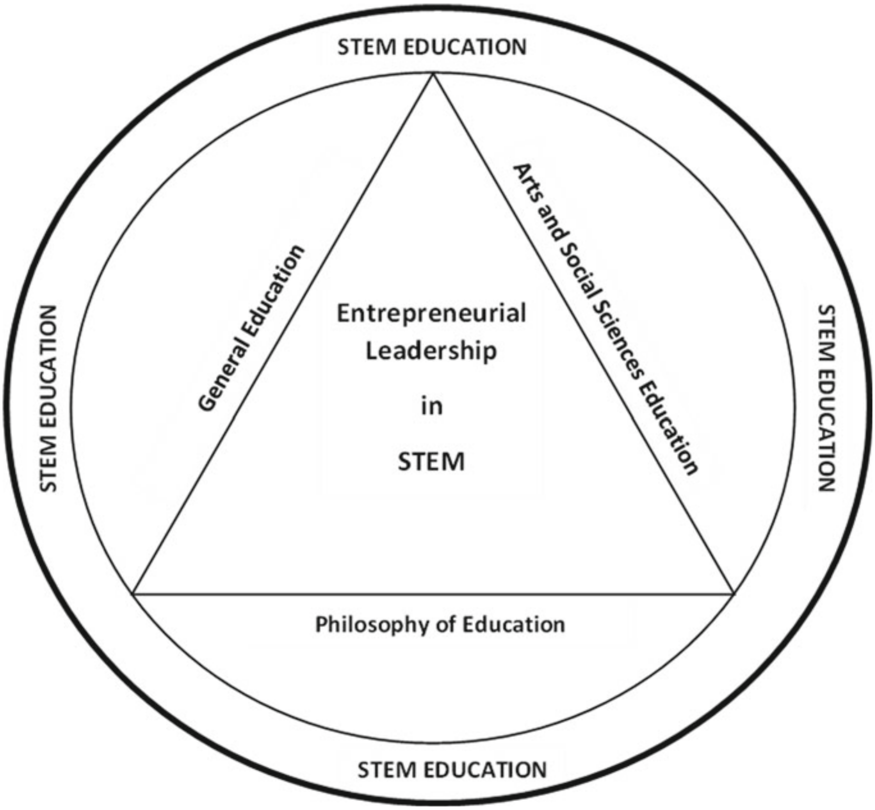
entrepreneurial leadership in relation to STEM education. In particular, the chapter discusses how STEM education can develop entrepreneurial leadership skills among students, and what this implies to the STEM and business communities and the society, in general.

Graphical Abstract



Keywords

Entrepreneurial leadership · STEM education · General education · Arts and social sciences education · Philosophy of education

1 Introduction

It is a commonly known fact that global progress today is driven by businesses that have strong links with science, technology, engineering, or mathematics. Cryptocurrencies, online banking, smartphones, food supplements, ride-hailing apps, IMAX theaters, social networking sites, online stores, and automatic cars, among others, are some of the commodities that not only make life more comfortable, but more so, normal. The value of such commodities contributing to the improvement of people's life quality across the world during the early twenty-first century became more apparent during the onslaught of the COVID-19 pandemic. These STEM-powered commodities have connected many people who were observing government-imposed quarantines and responsible self-isolation. It is not an exaggeration to say that availing oneself of these commodities have become more of a matter of necessity today than a matter of desire or fancy.

Behind the success of these STEM-powered commodities are individuals who can be considered as the leaders who are mainly responsible in making "entrepreneurial STEM" a part of everyday life. Owing to their respective visions and the extent of their personal desire to help improve the quality of life in the world, these leaders have successfully built entrepreneurial ventures that many depend on today.

Jeff Bezos, Carlos Slim Helú, Bernard Arnault, Othman Benjelloun, Isabel Dos Santos, Mukesh Ambani, Luis Carlos Sarmiento, and Alejandro Bulgheroni. These individuals have two features in common—they are some of the richest businesspeople in the world, and they have an educational degree in STEM [1]. It is common to hear about wealthy entrepreneurs who have educational backgrounds in business-related fields. Thus, what makes this list interesting is the fact that the educational background of these personalities is in the fields of science, technology, engineering, or mathematics. This raises the question whether STEM education can help someone become an entrepreneurial leader.

STEM education is not commonly associated with the concepts of business and entrepreneurship. STEM education is normally linked with training in research, experimentation, computation, innovation, analysis, verification, and the like [2]. However, some wealthy and prominent individuals, such as Mark Zuckerberg and Bill Gates, have cultivated entrepreneurial leadership skills that allowed them to transform their "dorm room or garage experiments" into multimillion dollar companies. This phenomenon leads to several questions that are worth exploring. How can STEM practitioners become successful entrepreneurs? Is a business degree or taking courses in business and entrepreneurship necessary to build a successful business out of STEM fields? Can STEM education cultivate future entrepreneurs? What educational philosophy should be employed to develop entrepreneurial leaders in STEM? This paper touches on these questions by exploring the notion of entrepreneurial leadership in relation to STEM education. By examining the goals and benefits of STEM education, entrepreneurial leadership in STEM education, and the societal impacts of entrepreneurial leadership in STEM, the succeeding discussions will consider how STEM education can develop entrepreneurial leadership skills among students and what this implies to the STEM and business communities, in particular, as well as its implications to society, in general.

2 The Goals and Benefits of STEM Education

Originally called SMET (Science, Mathematics, Engineering and Technology), the term STEM was introduced by the US National Science Foundation in the 1990s [3]. While the use of the acronym STEM is fairly recent, STEM concepts were already being applied in the business and engineering sectors as early as the Industrial Revolution in the production of revolutionary technologies (e.g., light bulbs, automobiles, etc.). Thomas Edison, who used an incubator program, is viewed as one of the early entrepreneurial scientists [4, 5]. In the U.S., the increasing federal attention to STEM education after World War II was the result of militaristic concerns—for instance, the original Sputnik moment [6]—and economic concerns. Historical aspects of STEM are discussed in detail in published literature [7, 8].

The economic benefits of a STEM education are substantiated. At an individual level, those with STEM degrees, on average, earn more than their non-STEM counterparts. For example, in the U.S., the 2020 median annual salary for STEM jobs (e.g., computer and mathematical occupations, architecture and engineering, life and physical science occupations, STEM-related sales and management) was more than twice the median annual salary for non-STEM jobs—$89,780 versus $40,020 [9]—and, in 2015, ninety-three out of 100 STEM jobs have wages above the U.S. national average [10]. At a national level, countries that invest heavily in science and technology, such as South Korea, Taiwan, and China, experience rapid economic growth. Indeed, a 2017 report for Science|Business suggests a 20% return from public investment on research and development, R&D [11]. Moreover, STEM jobs are expected to grow in the next decade [12], which is not surprising since a cursory glance at the top 10 largest companies by market capitalization (i.e., Apple, Microsoft, Saudi Aramco, Amazon, Alphabet, Facebook, Tencent Holdings, Tesla, Alibaba Group, and Berkshire Hathaway [13]) shows that the majority are in the technology sector. Thus, partly in recognition of these economic benefits, governments around the world have implemented national policies regarding STEM education, which are reflective of their respective social, economic, cultural, and educational priorities.

Salient differences between these national policies are described by Freeman, Marginson, and Tytler as follows:

> High performing Anglosphere countries such as the United Kingdom, Canada, Australia and New Zealand, and a number of Western European countries have national STEM policies aimed at addressing unmet labour market demand for STEM skills, and securing international competitiveness within an increasingly globalized economy … In contrast, East and South East Asian countries with very high performing education systems,

> including Japan, South Korea, China and Taiwan, typically have national science and technology policies and plans … These policies emphasize university science and technology, industry-driven R&D and innovation … Finally, emerging economies and education systems, including Brazil, Argentina, and arguably South Africa, have established national policies focused on quality education and emerging industry development. [14, p. 355]

According to a review of the current STEM educational policies of eight EU countries (Austria, Belgium, Cyprus, Finland, Ireland, Slovenia, Spain and Sweden):

> Common themes such as the significance of introducing STEM at the primary and post-primary level of education are prevalent in most policy initiatives. Some unique aspects were varying levels of emphasis on under-represented groups and/or social, environmental, and economic outcomes of implementing STEM policies in their respective countries/regions. There are also notable variances in stakeholder input and the consultation process followed for the development of the particular policies. [15, p. 24]

In the U.S., specific goals of their STEM education system described by the U.S. National Academies of Sciences, Engineering and Medicine [16] include:

1. to increase the number of professionals with advanced degrees and careers in STEM fields,
2. to increase the number of STEM-capable workers,
3. to broaden the participation of women and minorities in STEM fields,
4. to increase scientific literacy among the general public.

Other goals for an integrated STEM curriculum were set by the Committee on Integrated STEM Education [17] and this include increasing twenty-first century competences and expanding the students' interest and engagement in STEM.

The third and fourth goals enumerated above are of particular importance because they address certain global problems. The third goal recognizes that women and racial minorities are currently underrepresented in STEM fields relative to the overall workforce. For example, in the U.S., 58% of bachelor's degrees were awarded to women in 2015–2016, but only 36% of STEM bachelor's degrees were awarded to women [18]. With a few notable exceptions (e.g., Myanmar, Venezuela, Azerbaijan, Mongolia, Tunisia, etc.), the underrepresentation of women in STEM is a global phenomenon and occurs in every region of the world [19].

It is important to note that not all students are inclined, nor should be forced, to pursue STEM-related careers. Even so, there is significance in teaching STEM in primary and secondary levels of education. The fourth goal above acknowledges this. In a world that is increasingly driven by science and technology, a certain level of scientific knowledge is necessary to make informed decisions and understanding and coming up with solutions to the most pressing world problems (e.g., climate change, environmental degradation, food security, pandemics, nuclear weapons, mental health problems, etc.) require scientific literacy. Moreover, a STEM education not only teaches scientific facts and technical skills to students, but it also equips them with twenty-first century skills—skills that enable flexibility and adaptability which are important in the rapidly changing digital society of the twenty-first century. Problem-solving skills, creativity, critical thinking, resilience, innovation, and collaboration are imparted by a STEM education [20]. These are transversal skills and are valuable to the individual regardless of their talent, mental disposition, or chosen career.

2.1 STEM Education Approaches and Curriculum Implementations

STEM teaching practices vary from country to country. These practices are invariably shaped by several factors which include, among others, the current national priorities (e.g., economic development and scientific literacy) and the prevailing philosophy of education (e.g., student-centered learning, didactic teaching, pragmatism, essentialism, etc.). These factors, in turn, depend on the existing social, economic, and environmental conditions of a country. This is a reflection and affirmation of the earlier point made about how STEM education-related policies are instituted according to the respective priorities of each nation.

To illustrate some differences in the different countries' approach to STEM education: Italy and Singapore adopted an inquiry-based and student-centered approach for STEM education, while India focuses on a student-centered approach with emphasis on procedures and drill practice [21]. The former is indicative of pragmatist philosophy of education while the latter points towards a progressivist one.

Aside from the different teaching and learning approaches to STEM, countries also implement different STEM curricula. Some countries tend to elevate particular subjects in their STEM curriculum. For instance, Singapore emphasizes mathematics and technology in primary and secondary education, while India focuses on science and technology [22]. STEM education in China is described as "technologically intense and innovative" [23], implying a focus on technology. Meanwhile in the Philippines, the senior high school science curriculum was designed to enable student-centered and inquiry-based learning, as well as to increase the number of students in college STEM programs. However, local educators have expressed concerns that the curriculum focuses on the acquisition of scientific knowledge and facts to the detriment of scientific literacy, and that the curriculum is overcrowded with content for a genuine inquiry-based learning to happen [24].

2.2 Teacher Education

Lately, there have been growing efforts to encourage STEM educators to take on a more holistic teaching approach in teaching STEM subjects [24]. They are encouraged to develop socio-culturally relevant pedagogy in their classrooms where they infuse socio-scientific issues in the curriculum. In other words, teachers are asked to be inclusive and relate their lessons with realities of the social and cultural contexts of their students. There are plenty of training courses as well as literature today that aim to equip pre-service and in-service STEM teachers with practical and engaging methods in teaching scientific literacy, creative thinking, and problem-solving skills in more authentic social contexts [25, 26]. To this end, these teachers are exposed to a broad range of knowledge (also perhaps skills and attitudes) not limited to science and technology, but including the humanities, philosophy, and the social sciences [27]. They are taught to employ teaching approaches that are "multi-, inter-, and/or transdisciplinary" premised on the idea that "such approaches are necessary to understanding the historical development of science and technology within society, the problems and risks that have resulted, and the possibilities with these problems and risks now and in the future" [27, p. 1416]. These approaches would also help them learn how to develop their students' reasoning and communication competencies as applied to solving not only technical STEM problems, but ethical and socio-political issues as well.

3 Entrepreneurial Leadership in STEM Education

3.1 The Notion of Entrepreneurial Leadership

Given the status of STEM education in terms of teaching and teacher education, it is a wonder how entrepreneurial leaders are born from STEM academic backgrounds. As pointed out earlier, it is fairly common to see entrepreneurial leaders, more so, managers who have educational qualifications in business administration or management. Hence, successful entrepreneurs who were STEM-trained seem to be fairly out of the ordinary. To delve deeper into this curious phenomenon, it will be helpful to explore what entrepreneurial leadership is by first considering what leadership is and juxtaposing it with management. Doing so will provide clarity to these related, yet distinct concepts. For this purpose, Kotter [28] provides an informative comparison, presented in Table 1. Kotter believes that while

Table 1 Management versus leadership comparison

	Management	Leadership
Structuring	Planning and budgeting • Establish agendas • Set timetables • Allocate resources	Establishing direction • Create a vision • Clarify the big picture • Set strategies
Workforce	Organizing and staffing • Provide structure • Make job placements • Establish rules and procedures	Aligning people • Communicate goals • Seek commitment • Build teams and coalitions
Attribute	Controlling and Problem Solving • Develop incentives • Generate creative solutions • Take corrective action	Motivating and inspiring • Inspire and energize • Empower subordinates • Satisfy unmet needs

Source [28]

management is contributing to produce order and consistency, leadership helps produce change and movement [28].

Table 1 shows that the function of a manager is to ensure sustainability whereas the function of a leader is to promote forward movement. “Leadership is a process whereby an individual influences a group of individuals to achieve a common goal” [28, p. 5]. To be fair, this definition as well as Table 1 imply that an individual does not need to have formal education in administration, social sciences, STEM, and so forth to become a leader. Leadership, it appears, is a matter of behavior. A person only needs to behave in such a way to gain influence over others and direct them to a desired end. This seems to work for leadership, in general. However, what about entrepreneurial leadership? Does it simply involve acting as a leader in entrepreneurial contexts?

The term “entrepreneurship” is commonly used to refer to taking risks by starting a small business. However, “not every small business is entrepreneurial or represents entrepreneurship” [29, p. 21]. To be considered as “entrepreneurial”, they must “create something new, something different; they change or transmute values” [29, p. 22]. Being entrepreneurial means being able to initiate “the process of establishing new economic, social, institutional, cultural and scientific environments or organisations to create future products and services by realising the opportunities and their possible failures and using required resources” [30, p. 67]. This implies that entrepreneurship is not only found in business or economic ventures [29]. Rather, it is “a distinct feature whether of an individual or an institution” [29, p. 25, 30]. Thus, being entrepreneurial is a “behavior rather than a personality trait” [29, p. 26, 30].

From the foregoing analyses, entrepreneurship and leadership are both seen as behavioral. They are aimed at bringing a group of individuals, an institution, or an organization onto something new and pioneering. Entrepreneurs and leaders are those who have developed the behavior necessary to inspire others to take risks and innovate. Thus, entrepreneurial leadership entails that a person must practice being forward-looking, willing to venture into novel things, open to taking calculated risks, and adept in bringing others to work together in order to move towards greater heights. Esmer and Dayi [31] provides an informative and comprehensive list of behaviors that entrepreneurial leaders exhibit. These are: supporting entrepreneurial skills; interpretation of the opportunities; protecting the innovations threatening the current business model; questioning the current business logic; reviewing the simple questions; associating entrepreneurship with strategic management; flexibility; humility; focus; decisiveness; stick-to-it-ness; vision; paranoid confidence; ownership; positivity; salesmanship; self-awareness; and ability to listen [31]. Developing these behaviors in STEM students is the point and aim of integrating entrepreneurial leadership in STEM education.

3.2 Integrating Entrepreneurial Leadership in STEM Education

Given the nature of entrepreneurial leadership, it is essential for the purposes of this paper to ask whether STEM education can train students to become entrepreneurial leaders. In particular, can studying physics, biology, algebra, calculus, electronics, information technology, and the like cultivate a student's entrepreneurial leadership behavior? Research by Siekmann and Korbel [2] suggests a negative answer.

Review of STEM skills literature and media debates revealed that STEM skills or those skills that "have been identified to be 'technical and scientific and research skills'" are distinct from "non-technical skills such as marketing, finance, and business management" and "'soft' skills, e.g., cognitive and behavioural" [2, p. 28]. The paper concluded that current understanding of STEM skills is inconsistent but managed to come up with a definition of STEM skill as "primarily as technical skills and distinct from higher-order thinking skills and social-emotional skills" [2, p. 44]. Further, the paper points out that:

> "[d]escriptions of STEM skills usually include a combination of technical job-specific skills and advanced cognitive skills. They overlap broadly with other skills groups such as generic and cognitive skills, as well as employability skills and the twenty-first century skills. To ensure clear analysis, debate and policy work, the term 'STEM skills' should not be adopted; the original definition or their category, for example, cognitive skills, foundational literacies, job-related technical skills etc., should be used" [2, p. 45]

In other words, there appears to be a tendency for those involved in STEM to confuse or adopt skills in other fields to be inherently or even implicitly found or developed in STEM practice.

STEM education fosters STEM literacy [32]. This means that STEM education allows students to apply STEM in addressing STEM-related real-world problems. A STEM literate person has [32, p. 101]:

- Knowledge, attitudes, and skills to identify questions and problems in life situations, explain the natural and designed world, and draw evidence-based conclusions about STEM-related issues.
- Understanding of the characteristic features of STEM disciplines as forms of human knowledge, inquiry, and design.
- Awareness of how STEM disciplines shape our material, intellectual, and cultural environments.
- Willingness to engage in STEM-related issues and with the ideas of science, technology, engineering, and mathematics as a constructive, concerned, and reflective citizen [32, p. 101].

However, these do not indicate that STEM students would develop entrepreneurial leadership behaviors. Furthermore, neither the "cognitive nor the non-cognitive competencies associated with STEM" [33, p. 10] include entrepreneurial leadership behaviors. For this reason, there are numerous corporations where scientists and engineers are assigned to R&D, while managers and administrators are left to take care of the business side of things. Entrepreneurial leaders from STEM backgrounds are, simply put, a rare species. If this is the case, then how can entrepreneurial leadership be integrated in STEM education?

There are at least two ways to proceed. First is by adding general education (GE) courses in the STEM curriculum. Second is through augmenting STEM with arts (including humanities and philosophy) and social sciences courses, thereby transforming STEM education to STEAMS education. A possible third option is by incorporating Business and Management courses in STEM education, but unlike the first two options, this is only feasible if students are keen on engaging in STEM-related entrepreneurial ventures once they graduate. Further, the first two suggestions can contribute to a more holistic and liberal education of students.

It is worth noting that there is a dearth of research on GE as well as education on the arts and social sciences leading to the development of entrepreneurial leadership behaviors among students. However, numerous philosophers of education as well as educational theorists have, in various degrees and respects, stated and understood that these disciplines greatly contribute to producing truly educated individuals (see [34–38]). Further, a greater number of wealthy entrepreneurs had formal education than those who did not [1]. Thus, there is a greater likelihood for educated individuals to develop entrepreneurial leadership behaviors than those who are uneducated.

3.3 Entrepreneurial Leadership in STEM Through General Education

Integrating entrepreneurial leadership in STEM education requires a philosophy of education that reaches beyond the traditional limits of STEM education. The definition of STEM education can be understood in at least four levels, namely, discipline, instruction, field, and career [39]:

> STEM discipline and instruction are included in the school scope [K–12], which mostly talks about how to provide an active learning process through STEM learning. The next is a STEM field that exists in the university scope. The students are supported to choose the STEM field at the university level after learning STEM discipline in the [s]chool. Lastly, a STEM career is included in a STEM job or profession as the highest scope as well as become the last goals in STEM education. [39, p. 5]

From this, one can see that STEM education permeates a considerable part of a person's life as soon as the individual's formal education starts. Meanwhile, STEM education is a lifetime endeavor for those who decided to pursue a career in any STEM-related discipline. More importantly, since contemporary society relies heavily on scientific and technological innovations, it goes without saying that STEM education is vital for a person to effectively function and integrate in the current society due to the principles that it upholds, which are of everlasting value. It appears that the underlying philosophy of education here is perennialism. Interestingly, this appears to be very similar to the purposes of GE.

The aim of GE is to develop the self and the society through personal development, a mature understanding of the purpose of life, and living an ethical personal and communal life [40]. GE courses are given to "students to provide them with general and basic skills that will help them succeed. The purpose of these courses is to provide students with a breadth of knowledge, study skills, thinking skills, and writing skills" [41, p. 8]. In contrast, STEM education is focused more on specialized, technical, or vocational knowledge and skills. "For most, it means only science and mathematics, even though the products of technology and engineering have so greatly influenced everyday life. A true STEM education should increase students' understanding of how things work and improve their use of technologies" [32, p. 996]. Nonetheless, the goals of STEM education and GE are clearly similar in the sense that they aim to equip individuals with the necessary knowledge and skills for them to become productive members of contemporary society.

Perhaps, the most important thing that GE can contribute to STEM education in developing entrepreneurial leadership behaviors among students is that it balances out the specialized and technical way of thinking that STEM drills into students with a more liberal way of thinking and the disposition to taking a wider and deeper (more general and more diverse) worldview. This, of course, implies that students learn what teachers emphasize that they learn.

> … when faculty members require more writing, students report writing more and gaining more in their ability to write clearly and persuasively. When faculty members emphasize higher-order mental activities such as synthesis and analysis, students say that they enlarge their capacity to think critically and analytically and are better able to solve complex problems. When faculty members present diverse perspectives in their courses, students report having more experiences with diversity and appreciating human diversity to a greater degree. [42, p. 82]

With this being the case, having GE as one of the foci of STEM education will pave the way for students to pick up certain skills such as thinking beyond ordinary (or specialized) thinking, asking socially relevant questions, questioning the status quo, reflective and reflexive thinking, and ability to consider diverse perspectives, to name a few, which are all important for entrepreneurial leaders to develop and manifest in their actions and behavior. It may be argued that these skills are already involved in STEM disciplines, but the focus of STEM disciplines on cultivating these skills are not as intensive as the focus that is given by GE towards them. Simply, STEM disciplines have priorities other than the development of these skills while GE focuses more on their development.

3.4 Entrepreneurial Leadership in STEM Through Arts and Social Sciences

Infusing STEM education with arts (including humanities and philosophy) and social sciences is similar to adding GE subjects or courses to the STEM curricula. The only difference is that the former can focus more on praxis whereas the latter can heavily rely on theory. Although topics in the arts and the social sciences can be covered in GE, the breadth of the GE curriculum as well as the limitations due to time constraints and the structure of formal education can make it difficult for GEs to go beyond concepts and theories. Focusing on Arts and Social Sciences will open more opportunities to delve into the practical aspects of these disciplines and spend time on their application. This seems to draw from an essentialist philosophy of education.

One of the central behaviors that an entrepreneurial leader must exhibit is innovativeness, which draws a great deal from creativity. “Creativity is an active process necessarily involved in innovation … The creative process is at the heart of innovation and often the words are used interchangeably” [43, p. 53]. Meanwhile, the kind of thinking that is involved in creativity, that is, creative thinking, “is exemplified by the thinking that goes into the making of art” [44, p. 248]. Lipman claims that a person’s creative thinking manifests one’s unique judgment; “Like all judgment, it is expressive of the person making the judgment and appraisive of that person’s world” [44, p. 249]. The reality that creativity does not only drive innovation, but also allows one to become flexible, question prevailing logic, and think outside of the box, among others underscores the importance of art (along with humanities and philosophy) education in developing entrepreneurial leadership behaviors.

In relation to this, social science education allows students to have a better appreciation of how individuals behave in society and institutions; how individual and group behaviors affect society and institutions; and how societal and institutional behaviors affect individuals and groups. For STEM students, this implies being able to see how science and technology affect society. It has been found on a number of occasions that STEM students have superficial awareness of, if not lack of interest for, societal issues since they do not necessarily affect the subject matter of their lessons [45, 46]. However, “[w]hile students should be expected to learn mathematics and science, [teachers] noted the importance of these discreet disciplines being grounded in a social, political, economic, and environmental fabric” [47, p. 84]. Being socially aware can lead to students developing a certain degree of care or empathy for other members of society because they (environment, indigenous peoples, underprivileged individuals, the government, the state, etc.) begin to matter. “[W]e care about things that matter, even though how much they matter is a matter of degree, depending upon how much we care” [44, p. 263], and people tend to think about things that they care about (i.e., caring thinking). In one sense, caring thinking “means to think solicitously about that which is the subject matter of our thought” [44, p. 263]. For entrepreneurial leaders, this results in demonstrating their sense of vision, humility, positivity, and ability to listen, among others, thereby highlighting the relevance of social studies education in cultivating these behaviors.

4 Societal Impacts of Entrepreneurial Leadership in STEM

Accelerating innovation is widely perceived as vital to the ability of a nation-state and the international community to respond to, manage, and recover from social challenges. Innovation in this context is defined as "the improvement of existing or the creation of entirely new products, processes, services, and business or organizational models" [48, p. 20].

Students with adequate training in entrepreneurial leadership in STEM have the most potential to spur innovation. Their education provides them with the opportunity to develop complex problem-solving skills, creativity, and adaptability—competencies that are essential to spark innovation [49]. Such innovation, in turn, drives long-term economic growth, global competitiveness, and quality-of-life improvements [48]. What follows are examples of areas wherein entrepreneurial leaders in STEM can have a positive impact.

4.1 Long-Term Economic Growth

Information and Communications Technology (ICT) innovations contribute significantly to a country's productivity levels not only significantly and positively, but also increase over time [50]. This increase in productivity levels effectively contributes to a country's economic growth, which improves its citizens' standard of living [48]. For instance, in the U.S., innovations accounted for at least 55% of the country's productivity growth from 1959 to 2005 and as much as 75% of the growth in the American economy since the Second World War is attributable to technological innovations [48, p. 21].

These findings support the argument of economist Joseph Schumpeter. According to Schumpeter, contrary to the traditional view that economic growth stems from the accumulation of capital, labor productivity, or effective macroeconomic management of business cycles, the development of technological innovations coupled with entrepreneurial initiatives is the major force that drives long-term economic growth [51]. This is evident in the "exceptional economic growth" across the globe of the past two hundred years, which was brought about by the rise in entrepreneurial activities and innovations. In other words, technological innovations have fostered the creation of new growth businesses that are central to economic growth [51]. Moreover, the societal return on investment of publicly funded R&D is remarkable: ranging from 20 to 67%, while in terms of academic research, economist Edwin Mansfield approximates the societal rate of return on investment from 28 to 40% [48, p. 21].

Technological innovations are also perceived to generate employment. By analyzing cross-country firm-level data, the Organization for Economic Cooperation and Development (OECD) has found that:

> Technology both eliminates jobs and creates jobs. Generally, it destroys lower-wage, lower-productivity jobs, while it creates jobs that are more productive, higher-skilled, and

> better-paid. Historically, the income-generating effects of new technologies have proved more powerful than the labor-displacing effects: technological progress has been accompanied not only by higher output and productivity but also by higher overall employment. [48, p. 21]

Interestingly, a 2011 report by the US Department of Commerce has also found that STEM degree holders have an economic edge over their non-STEM counterparts noting that [52]:

- STEM workers command higher wages, earning 26% more than their non-STEM counterparts;
- More than two-thirds of STEM workers have at least a college degree, compared to less than one-third of non-STEM workers; and
- STEM degree holders enjoy higher earnings, regardless of whether they work in STEM or non-STEM occupations.

This highlights the centrality and importance of STEM in influencing economic growth as well as provides justification to the priority given by governments into instituting policies that affect and direct their respective nation's STEM education.

4.2 Global Competitiveness

As more countries continue to be more connected to the global economy, the competition among countries to develop advanced technological industries has increasingly heightened. This is based on the premise that if these countries seek to maintain or improve their place in the global market, they need to gain and sustain a competitive advantage over other countries by acquiring valuable and non-substitutable goods and services—products that rely on complex production processes such as mobile platforms, cloud services, and data analytics. Take, for example, the efforts of the Chinese government to dominate new technological spaces by providing subsidies to emerging companies such as Huawei. Huawei, a Chinese multinational technology company headquartered in Shenzhen, Guangdong, has been leading in providing 5G technologies and solutions much to the ire of the U.S. and the European Union (E.U.) [53, 54]. As several foreign policy commentators have noted, China may prove itself to be stiff competition in the STEM-related commercial arena if the U.S. and the E.U. fail to keep up and enhance their own digital innovations [53, 54].

4.3 Improvements in Quality of Life

As a society, so many aspects of our daily lives are increasingly dependent on science and technology. Cutting-edge and novel technological innovations in various fields such as medicine, engineering, communications, education, and finance have significantly improved our quality of life. Most of the world's population is currently far better off in terms of living standards than the generation of their parents and grandparents [51]. Such progress has come despite different social crises throughout history such as wars, recessions, and natural disasters. It is precisely because of emerging developments in the STEM industry that pharmaceutical and biotechnology corporations such as Pfizer and Moderna were able to develop vaccines for COVID-19 at a historically rapid pace without compromising safety during this pandemic [55].

However, while innovations in STEM have significantly advanced the quality of human life, some of these developments have also caused many of the problems that our society faces today. As Zandvoort et al. [27, p. 1414] notes:

> [i]n addition to the possibility of deliberate misuse, there is always the potential for (or reality of) unforeseen risks and unintended negative consequences such as pollution and the depletion of natural resources, which may, in turn, lead to social conflicts of various sorts.

4.4 Social Problems Related to STEM

Driven by the relentless pursuit of production and profit, certain technological innovations have led to the exploitation of the environment, human beings, and animals.

Society's growing culture of consumerism has led to enormous environmental and societal crises. For instance, mankind's heavy reliance on fossil fuels as an energy source has led to irreversible ecological damage such as the depletion of natural resources, destruction of natural habitats, extinction of certain species, and climate change. Several ICT innovations such as social media platforms and internet sites also appear to take advantage of the naiveté of their consumers by insidiously collecting and using their data evident in the multiple privacy and security issues that we have today.

In addition, STEM innovations seem to have achieved little in bridging class divides. In some cases, they seem to have widened and exacerbated the gap. This is apparent in the existing unequal distribution of wealth and resources among individuals, households, and countries across the world. For instance, Jeff Bezos, a billionaire who has amassed his wealth from establishing Amazon, a multinational e-commerce company, is being criticized for perpetuating exploitative and oppressive labor practices [56]. Similar criticisms have been directed toward Elon Musk, founder and CEO of Tesla, an American electric vehicle and energy company. Musk and Tesla have been criticized for relying on child labor in cobalt and lithium mines in the Democratic Republic of the Congo. Cobalt and lithium are used to dramatically extend the battery lifespan of Tesla products [57].

Entrepreneurial leadership in STEM that is fueled by GE and arts education may help in curbing these social problems by infusing social awareness, ethics, and responsibility in STEM.

4.5 Importance of Embedding Social Responsibility in Entrepreneurial Leadership in STEM

The severity of social problems, such as animal, human, and environment exploitation, underscores the importance of embedding the value of social responsibility in teaching entrepreneurial leadership in STEM. While the main goal of entrepreneurial leadership may be to develop new and innovative products to bring about profit and growth, giving equal emphasis to social responsibility makes students aware of their equally important role in safeguarding and promoting a peaceful, just, and sustainable world [27]. This would provide the students not only the opportunity to become STEM entrepreneurial leaders but also empowered citizens equipped to respond to the political and ethical consequences that science has in the world and to initiate transformations that promote social justice [26]. By embedding social responsibility in entrepreneurial leadership in STEM, students balance market considerations with questions of ethics and social responsibility.

To this end, teaching students about the different conceptualizations of "social responsibility" in STEM may be beneficial. In a meta-analysis of 263 journal articles, Glerup and Horst [58] were able to articulate four ways on how STEM has a responsibility toward society.

The first type of social responsibility is *demarcation*. This conceptualization is based on the idea that STEM is an honorable profession that ought to have a high level of autonomy from external actors i.e., non-scientists. Individuals and institutions outside of the realm of STEM should not interfere with discussions about the responsibilities of STEM actors and how these could be achieved. However, this begs the question: who will hold STEM actors accountable for their actions and potential misconduct? According to this view, STEM as an institution and profession, ought to install and adhere to a set of basic ethical principles or a moral code that most STEM actors could embrace.

> But the profession itself ought to employ a number of techniques to install a specific kind of responsibility, to be honest and objective in every single individual scientist. So, the profession's freedom from interference from external actors is articulated as dependent on the internal establishment of a strong professional culture. This internal control system should constantly monitor the members of the scientific profession by scrutinizing methods and results and by socializing aspiring scientists into the system. Only by assuring that each individual scientist is rigorous, honest, transparent, and not influenced by society's interest in her work, is it possible to maintain proper responsibility within science [58, p. 37]

The second type of social responsibility is *reflexivity*. In a nutshell, this articulation is anchored on the belief that STEM should learn from societal problems and provide solutions. While *demarcation* views STEM as a self-regulating institution that continuously questions its own motives and method, *reflexivity* is more skeptical of the "honest" nature of the institution. Reflexivity acknowledges that STEM is not without faults. It calls our attention to the reality that there have been and will be misapplications and misuses of STEM. Technological innovations also cause "bad side effects" and unfortunately, while STEM actors are often celebrated for their "glorious achievements", rarely are they held accountable for the negative impact these "achievements" have [58, p. 37]. Therefore, *reflexivity* encourages STEM actors to not only perform according to the highest standards of the discipline, but they should also be able to reflect on the consequences of their own practice. Put differently,

> So not only do scientists have a responsibility of finding truths about the world, but they also have a responsibility for assessing if their science is good or does good in society… The Reflexivity rationality sees part of scientists' task to be attentive to society and its problems—not the least of which are problems that science may itself have caused. [58, p. 39]

The third type of social responsibility is *contribution.* According to this view, society has a decisive role in shaping the visions and goals of STEM innovations. STEM as a profession is regulated by society to ensure that all its outputs are useful. They should be innovative and contribute with knowledge and technologies to improve national and global living conditions. STEM should also function in accordance with democratic principles such that the interests and actions of STEM actors are aligned with expressed public needs and preferences. In addition, STEM should be transparent where all STEM endeavors and outputs are subject to close and careful public scrutiny. STEM actors are much more than experts who seek knowledge for the sake of curiosity at the comfort of their ivory towers. Rather, they are regarded as public servants who would maximize public trust and put the interests of society above all else in their ventures.

The last type of social responsibility is *integration* [58]. Like *contribution*, society plays a critical role in STEM, however, to a much higher degree for *integration*. STEM actors and the rest of society are viewed as equal partners who need to collaborate toward achieving socially beneficial goals. Based on this conceptualization, it is imperative that STEM and non-STEM actors engage in continuous dialogue and share equal duty and influence in the process of knowledge production. Therefore, STEM actors should be competent not only in technical terms but also in terms of being able to communicate and cooperate with laypersons as well as being able to accept and respond to public feedback.

Demarcation, reflexivity, contribution, and integration are four of the identified responsibilities of STEM to society and embedding awareness and recognition of these responsibilities in the education of entrepreneurial leaders in STEM are instrumental in transforming STEM into an enterprise that is socially aware, ethical, and responsible. By developing entrepreneurial leaders into socially responsible individuals through GE, arts, and social sciences education, these leaders will be able to direct their efforts in starting ventures that are not only money-generating but are responsive to societal problems. This, however, requires a philosophy of education that is more flexible and adaptive (perhaps pragmatism?). If successfully implemented, in theory, this can change the landscape of putting up STEM-related businesses from one that is self-serving to something that is altruistic. Ultimately, this is a good reason as any that highlights the importance of having socially responsible STEM entrepreneurial leaders.

5 Conclusion

Virgil's words in the *Aeneid* were borrowed at the start of this paper. "*Sic itur ad astra*" translated as "Thus one journeys to the stars" signifies how STEM education as a discipline, as a form of instruction, as a field, and as career pursuit has allowed humankind to journey to the stars both literally and figuratively. As the precursors of the scientists, technologists, engineers, and mathematicians of today, the natural philosophers of antiquity, looked up to the stars wondering where everything came from, STEM education has allowed humans to explore the subjects of their curiosity allowing them to better understand the world and what lies in the stars. Meanwhile, entrepreneurial leaders in STEM-related fields have enabled these "explorers" to journey to greater heights.

STEM-trained individuals who present their vision for others to share with and take part in; take calculated and educated risks; respond to the needs of the times; invest their money, time, effort, and expertise; inspire others to work together to achieve the goal that they have set; and influence the direction of progress of civilization, among others encapsulates the pioneering and social dimensions of STEM education infused with entrepreneurial leadership. Entrepreneurial leaders in STEM empower humankind to journey to the stars today, yet their visions and endeavors go beyond the here and now, but well into the future—"*Non nobis solum sed omnibus in futurum*"—"Not for us alone, but for all in the future".

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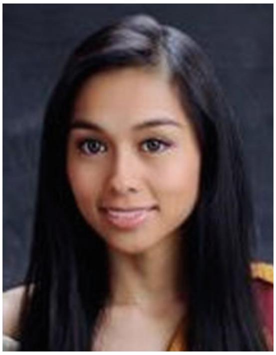

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Innovative Pedagogy and Practice for E-STEM Learning

4

Marwa Eltanahy

You are the best one to turn your invention into a valuable product.

Marwa Eltanahy

Abstract

It has become a reality that the development of any country relies on generating innovative solutions by its human capital through integrating knowledge and practices of different disciplines. This chapter is based on a Ph.D. thesis (Eltanahy in Development of entrepreneurial core competencies: E-STEM model implementation for high school students in the UAE. The British University in Dubai, 2019 [1]) and a series of research studies concerning incorporating entrepreneurial learning into STEM education through Entrepreneurial STEM Learning (E-STEM). The purpose of this chapter is four-fold: First, to highlight the rationale of E-STEM incorporation. Second, to introduce a strong conceptual and theoretical underpinning of E-STEM learning. Third, to discuss the pedagogical strategies of E-STEM learning, and finally, to develop activities for the interdisciplinary E-STEM model that guide high school teachers to implement meaningful practices of E-STEM learning.

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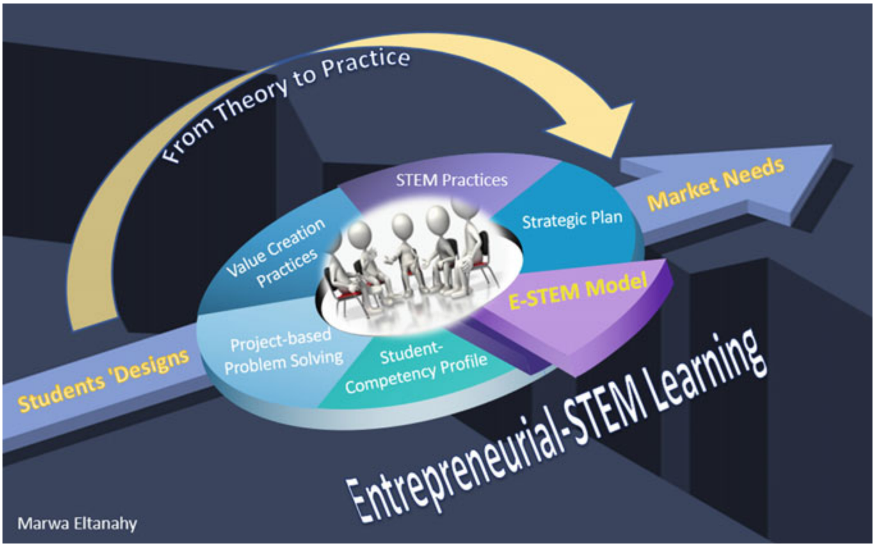
Graphical Abstract



Keywords

Entrepreneurial-STEM learning · Entrepreneurship · STEM education · E-STEM pedagogical strategies · STEM reform · Student-competency profile · High school · Education through entrepreneurship

1 Introduction

Students' orientation to a specific context requires an acquisition of a new set of competencies with consideration to their work function and aptitude. Their repertoire of skills should be consistently developed to help them adjust to the requirements and challenges of future life. In today's world, it is imperative to prepare a new generation of STEM-literate workforce who are not only equipped with the required skills of employability but also capable of engaging their interdisciplinary skills and thinking in the context of self-employment as an indicator of sustainable career [2]. Therefore, STEM education should be re-structured to include entrepreneurial practices to reshape the environment of the STEM context to be business-like. This new structure will allow the enhancement of education for not only employment but also self-reliance. In this sense, integrating entrepreneurial practices with STEM education seems beneficial to enhance the overall ability of STEM students to practice and perform entrepreneurial activities more effectively.

With the aim of broadening the structure of STEM education to include entrepreneurial practices, this chapter provides a deep understanding of the nature of this incorporation through highlighting both pedagogy and practices of E-STEM learning. This chapter, first, introduces STEM and entrepreneurial learning and argues the rationale for their incorporation. Next, a conceptual framework and a theoretical framework are provided, and the potential pedagogical strategies to use for these frameworks are introduced. This is followed by proposing an interdisciplinary E-STEM learning Model and introducing practices to use when implementing the model. The chapter is finalised by summarising the main principles of Integrated E-STEM Learning.

2 STEM Learning

STEM education adopts the interdisciplinary approach to integrate the content from STEM disciplines (science, technology, engineering, and mathematics) to produce more meaningful learning experiences for students and to enhance their motivation for STEM careers. It was argued that STEM professions are not desirable for all students as many of them have different interests and the right to pursue a related career [3]. However, STEM learning is still useful for everyone because its practices benefit students in the careers that they pursue [4]. Regardless of students' future career choices, learning the basic knowledge of science and technology applications and developing twenty-first century skills can help students overcome many career challenges. For example, consistent implementation of the logical process of thinking enhances problem-solving skills which is considered as the core of STEM practices [5]. Being equipped with problem-solving skills can support students in their future career by enhancing their abilities to retain information and utilize diverse types of instructions to address real life scenarios. However, to the extent that STEM practices help students to overcome career challenges depends on the focus of students during learning and the way they adopt such practices. Lin-Stephens, Manuguerra and Uesi conducted a non-experimental study in an Australian University with 617 students and 62 employers [6]. The researchers found a gap between perceptions of STEM graduates and employers regarding career development; while students were focusing on gaining knowledge of a topic, employers focused on competencies that allow students to apply their knowledge into different contexts. Learning that promotes meaningful STEM-related curriculum opportunities, required for better STEM outcomes [7]. Despite the consensus in the literature regarding the prominence of STEM education, standards of integrated education and its implementation are not clearly identified in schools [4]. Although STEM students are commonly encouraged to think creatively and challenge themselves to come up with new ideas and STEM designs that can benefit the community, further practices should be considered. One way to consider is to broaden the focus of STEM education and expand it to situate STEM practices and curriculum elements within a business context [8].

3 Entrepreneurial Learning

Entrepreneurial learning is an ongoing process that focuses on turning entrepreneurial practices into relevant information and outcomes to adding values to the society. This process seeks to enhance students' entrepreneurial competencies to develop their business performance. The literature concerning entrepreneurial learning argues that if the noble educational objective is to transfer learning experience into real-life applications, students' entrepreneurial identity should be developed to achieve this goal [9–12]. Constructing entrepreneurial identity refers to developing a set of attributes and beliefs to play an entrepreneurial role that can prepare students for unstable employment [13] as well as enhance their competencies in a learning-by-doing entrepreneurial environment [14].

It is very difficult to identify the required competencies of the careers that may exist in the future [15]. In this context, developing and mastering entrepreneurial competencies at different education levels can provide meaningful learning and work opportunities to prepare students for unknown future careers. To do so, competency-based approach (CBA) was emphasized as a successful approach to integrate entrepreneurial learning into different courses because it offers practical learning experiences that enrich students' entrepreneurial knowledge and skills [16].

4 E-STEM Learning

4.1 Rationale for E-STEM Incorporation

The instability of the employment process is a growing concern across the world because it affects the economic development of countries [3, 17]. Due to this issue, STEM students should leave the education system equipped with skills required to cope with future career challenges and employment. This aligns with the European Commission's report suggesting the integration of entrepreneurial practices into all school activities across different disciplines to foster students' entrepreneurial spirit [18].

Engaging STEM students in entrepreneurial practices could produce a new generation of entrepreneurs who are scientifically, mathematically, and technologically literate, and upgrade their abilities from being not only inventors but also entrepreneurs. Not all scientists are entrepreneurs, and STEM courses taught in schools are not enough to generate future scientist-entrepreneurs. This is because current STEM learning focuses mainly on inventing but not marketing or identifying opportunities. This fact reflects the need to provide STEM students with new opportunities to enhance the acquisition of different entrepreneurial competencies required for their future careers. Forawi suggested providing students with more meaningful learning experiences that focus on aspiring their future career choices [19]. In other words, learning practices in high schools should be connected to real job tasks even if the student is distant from employment or work responsibilities [20]. Learning practices could be linked to job opportunities through incorporating entrepreneurial practices into STEM education. To achieve this, STEM education can provide students with the practices that require entrepreneurial knowledge and skills. This could motivate students to learn more about entrepreneurship and help create more skilful and ready students.

In this regard, a body of research supports incorporating entrepreneurial practices into STEM programs to help create students equipped with required skills for employment. For example, Hershman suggested restructuring STEM education to incorporate entrepreneurial practices into its curriculum to make use of STEM efforts by delivering its learning outcomes to the market [21]. Moreover, Winkler, Troudt, Schweikert and Schulman suggested that entrepreneurial practices could be effectively infused into existing STEM programs to develop entrepreneurial learning of STEM students [22]. Bruyat and Julien agreed that the notion of entrepreneurial value creation could result in development of entrepreneurial competencies because it enhances students to learning knowledge, acquiring skills, motivating attitudes that all can be used to facilitate business start-up [23].

Ideally, integrating entrepreneurial practices into STEM programs and curricula requires exploring STEM teachers' views about the possibility of adding one more E to STEM to become E-STEM because their pedagogical understanding and competence shape the learning in the classroom. Eltanahy, Forawi and Nasser found that STEM lead teachers believe in infusing entrepreneurial pedagogies into the STEM curriculum to produce more valuable STEM outcomes. Accordingly, they suggested involving business teachers to contribute to the success of E-STEM practices as they are more aware of the entrepreneurial practices than others [24].

4.2 Conceptual and Theoretical Framework of E-STEM Learning

This section provides a conceptual and theoretical framework (Fig. 1) in a graphical structure illustrating the natural progression of E-STEM learning and the link between its main concepts. This framework may help incorporate entrepreneurial practices into STEM curriculum and programs.

Figure 1 illustrates that E-STEM learning acts as a bridge to close the gap between students' STEM designs and the market needs by integrating value creation with STEM practices through competency-based approach. Three important elements are taken into consideration in the framework: pedagogy, practice, and outcome.

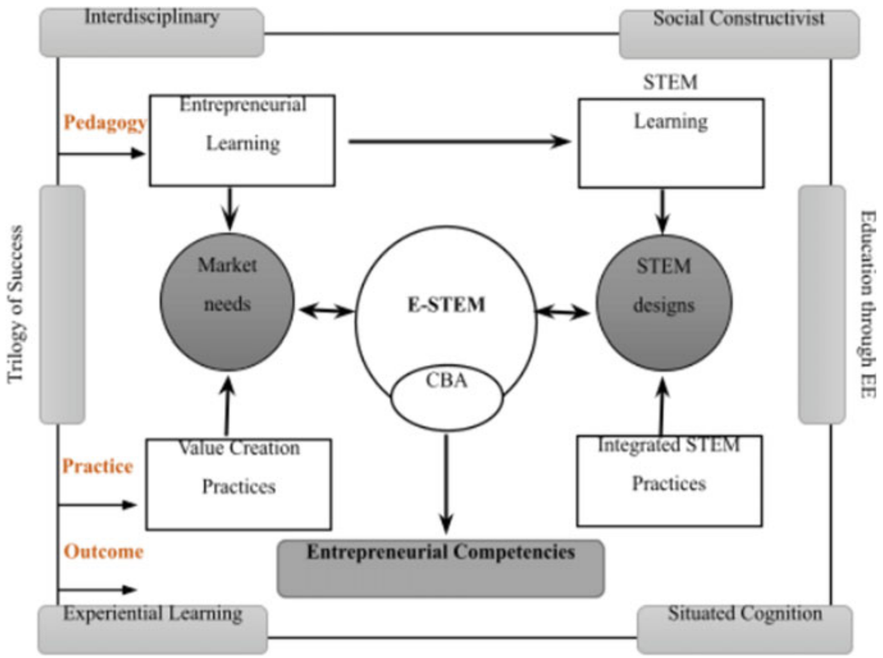


Fig. 1 Conceptual and theoretical framework of E-STEM

- ‘**Pedagogy**’ refers to the relevant theories and practices which help deliver the academic content to students and indicates the possibility of incorporating entrepreneurial practices into STEM education.
- ‘**Practice**’ refers to how entrepreneurial practices could be integrated into STEM education.
- ‘**Outcome**’ refers to the impact of incorporating entrepreneurial practices into STEM education on enhancing students’ entrepreneurial competencies.

Implementing E-STEM practices in the context of high school is supported by a shield of strong theoretical underpinnings including (a) integrated knowledge-based constructivist learning, (b) situated cognition theory, (c) interdisciplinary theory, (d) experiential learning (e) trilogy of success, and (f) education through entrepreneurship.

Mayer explained that integrated knowledge-based constructivist learning has its potential for enhancing the academic learning environment [25]. This learning provides students with opportunities to build on their own knowledge through investigating problem-based scenarios. In general, learning models that derived from the paradigm of social constructivism reflect a significant feature of situated cognition where the acquisition of knowledge and skills go hand-in-hand with understanding how they can be applied to real-world situations. Most of the content in STEM integration is also grounded in the situated cognition theory where knowledge is situated and embedded in the learning activities bound to cultural, physical, and social contexts in which knowledge was constructed and learned [26]. The credit is often given to Jean Lave regarding the situated cognition [27], which is highly influenced by the philosophy of John Dewey and Lev Vygotsky who adopted similar features of the effective learning approach.

Any academic course that considers an effective situated approach to learning will take students out of the classroom and place them in apprentice-like situations where they can learn by working with experts. Thus, assignments should be situated in the students' zone of proximal development (ZPD) just beyond their levels where collaboration and engagement can help them to learn how to solve it [28].

Based on situated cognition theory, STEM activities that adopt a design-based approach are authentic because they are grounded within a practical learning environment. This context capitalizes on the situated STEM learning where engineering design is the situated platform [29]. Similarly, integrating value creation practices from entrepreneurial learning with STEM learning will form a new situated platform (Suited E-STEM learning platform). This new learning platform will allow students to practice, actively construct entrepreneurial knowledge in a social learning environment, and develop as many entrepreneurial competencies as they can.

Interdisciplinary approach recommended integrating knowledge from different fields of learning to make more meaningful learning experiences rather than teaching disciplines concurrently [30]. Accordingly, Jacob designed models of integrated knowledge based on the level of integration between disciplines where interdisciplinary approach is highly recognized as a medium level of integration [31]. In the light of this approach, the E-STEM learning creates new elements of an interdisciplinary curriculum that consciously applies integrated practices from different disciplines (entrepreneurship and STEM) to examine new learning experiences.

Kolb and Fry explained experiential learning that is adopted as the best pedagogical strategy to implement E-STEM learning where STEM practices are applied through design-based learning strategies [32], while entrepreneurial practices focus on value creation or business-start up strategies. Furthermore, Campbell, Jolly and Perlman explained that educational practices should emphasize three main factors that shape a trilogy of students' success: the engagement (awareness, interest, and motivation), the capacity (knowledge and competencies) and the continuity (learning opportunities, resources, and desired outcomes) [33]. E-STEM is supported by the trilogy of success in learning support students to show progress in the learning path of STEM. Hence, integrated curriculum involving STEM practices and entrepreneurial learning can promote the development of students' entrepreneurial identity through synthesizing learning across real experiences and mutually reinforcing the content knowledge.

In essence, CBA is relevant because of the current educational necessity to apply successful pedagogical conditions that enhance students' acquisition of the core competencies to cope with ever-changing life situations [34]. This approach becomes a strategic priority in educational development because it emphasizes the students' way of thinking. Hence, the goal of many educational researchers is to find a connection between learning and real-life application using students' learning outcomes outside the school setting. CBA prepares students during their learning journey to understand the value of education and classroom practices and how meaningful learning is beneficial to grow competencies that are highly demanded in the workplace. The most significant result of CBA can be viewed as the development of the desired core competencies. Simply, students should be able to synthesize knowledge, understand connections, and use relationships to think and solve real problems. According to the literature, competency-based applications have become increasingly popular methods that are currently utilized for studying many fields such as entrepreneurship education [16] and STEM education [34]. A successful implementation of CBA can be achieved in education via five main principles [34]:

- Connecting learning phenomena to real life applications.
- Interacting with people like students, teachers, or experts who are experienced and acknowledged to enrich the learning path.
- Performing the main social roles in everyday life.
- Learning to use new technology programs or modern equipment to facilitate the learning endeavours.
- Evaluating personal readiness when selecting the educational track to develop a sense of direction to the most appropriate job in the workplace for each student.

Pepin explained the differences between two main approaches of integrating entrepreneurial practices into any existing curriculum that are 'Education for entrepreneurship' and 'Education through Entrepreneurship' [11]. The extent to which students are close to the workplace should be considered to select the most appropriate approach for integrating entrepreneurial learning.

- Education for entrepreneurship focuses on the profession and knowledge of venture creation where entrepreneurship is offered to higher education students as a separate course.
- Education through entrepreneurship focuses on creating authentic learning experiences through embedding entrepreneurial methods in other disciplines relying on interdisciplinary perspectives. This makes the STEM classroom in high school one of the best contexts to implement E-STEM.

Incorporating entrepreneurial practices into STEM [35] should be conducted in light of education through entrepreneurship [36], to enhance students' business mindset and awareness to be more responsive to the four economic questions; what to produce, to whom to produce, how to produce, and when.

4.3 Pedagogical Strategies of E-STEM Learning

Interdisciplinary E-STEM requires integrating knowledge and methods of learning to incorporate practices of one discipline into another one to provide students with authentic learning experiences. This draws attention to the need for integrating pedagogical methods from both disciplines (STEM and entrepreneurial learning) to incorporate entrepreneurial practices into STEM education. Essentially, it requires a relevant combination of teaching and learning practices from STEM and entrepreneurship courses [37]. Conceptions of interdisciplinary interactions are often shaped within a Venn diagram to highlight the intersections between them. Figure 2 shows that the intersection between STEM teaching methods and entrepreneurial teaching methods creates an integrated curriculum platform that involves teaching and learning methods of both STEM and entrepreneurship.

Integrating pedagogical methods from STEM and entrepreneurial learning constructs a new learning concept in education called 'Integrated E-STEM learning'. Under the umbrella of CBA, there are different social constructivist learning strategies that can be implemented successfully in integrated E-STEM lessons to promote students' competencies and support the formation of their learning motives. For example, learning by doing, Inquiry-based learning (IBL), Project-based learning (PjBL) [38], experiential learning process [39], interdisciplinary integrated practices and problem-based learning (PBL) [40] are common pedagogical learning strategies that are recommended for both STEM education and entrepreneurial practices [41].

The characteristics of the learning environment for STEM and entrepreneurship education are relatively similar. This may be because experiential learning through hands-on activities is the best approach for both when authentic learning opportunities are provided to students to be engaged in real-life practices [42]. Anderson explained that solving problems requires conducting a sequence of cognitive operations to make reasonable decisions [43]. Hence, the applications of both PjBL

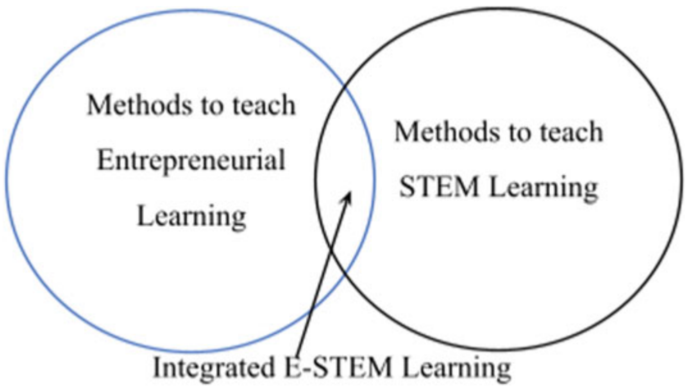


Fig. 2 Interaction between STEM and entrepreneurial teaching method

and PBL focus on STEM classes because they are recommended as effective strategies of integrative pedagogy to support STEM reform. At the same time, using project and problem-based entrepreneurial learning approaches help students gain the basics skills to act entrepreneurially [44].

A substantial amount of literature confirms that PBL and PjBL are the most successful strategies used in the classroom to enhance meaningful outcomes of integrated curriculum because they enhance students' acquisition of cognitive skills [38, 45–47]. PBL and PjBL strategies allow students not only to take responsibility for their learning, but also to enhance their cognitive abilities such as integrating knowledge from different disciplines to create innovative designs. Furthermore, the consistent implementation of these learning strategies provides students with many meaningful learning opportunities to be able to:

- Identify a problem and post their own questions to guide the inquiry process,
- Plan to collect the required data,
- Cooperate and collaborate in STEM teams,
- Engage in a logical reasoning process to enhance their thinking skills,
- Use design rubrics to evaluate their STEM projects,
- Keep reflecting on their learning to be able to modify their plans, use teachers' feedbacks to improve their products,
- Discuss, argue, and present their projects to the classmates.

On the other hand, Chandler and Hanks explained that the development of students' entrepreneurial competencies requires scanning the surrounding environment to select and take advantage of potential business opportunities by setting strategies of implementation [48]. To do so, students should experience entrepreneurial practices to enhance their abilities and willingness to perform entrepreneurially when creating new value for other people [49]. Students' engagement in real entrepreneurial practices can help them understand the value of their STEM designs and motivate them to introduce new innovative ideas to satisfy the markets' needs.

This section suggested some relevant and applicable ways to incorporate entrepreneurial practices into STEM education in high school. One way to achieve this incorporation is to establish a new department in the school to be responsible for planning and applying E-STEM practices that can be conducted both during the school year or as summer programs and for the engagement of STEM students in business tasks. E-STEM can also be supplemented with extracurricular activities, such as a hands-on group experience related to business start-up activities and company visits through regular trips to communicate with the real market, such practices can facilitate the incorporation of entrepreneurial practices into STEM education as well as enhancing the limited communication opportunities of students with the workplace. Overall, an E-STEM model should be implemented and investigated in high school classrooms [35].

5 Interdisciplinary E-STEM Model

The key insight behind incorporating entrepreneurial practices into STEM education is that students' school experiences, their future decisions, and intentions do not rely on collecting knowledge and applying abstract principles to judge theoretical dilemmas [50]. Rather, it requires consistent and authentic engagement with real problems in which they might find themselves immersed soon. Furthermore, Kyndt and Baert believed that entrepreneurs grow as learners because their learning outcomes rely upon going through both educational and real-life experiences in a student-centred environment [51].

Therefore, Eltanahy et al. developed an interdisciplinary E-STEM model (Fig. 3) through an exploratory sequential design where 12 STEM academic leaders were interviewed to explore how entrepreneurial practices could be incorporated into STEM education [24]. Additionally, 134 responses were collected from (science, technology, engineering, mathematics, and business) teachers to a questionnaire explaining the challenges that might eliminate this incorporation in the United Arab

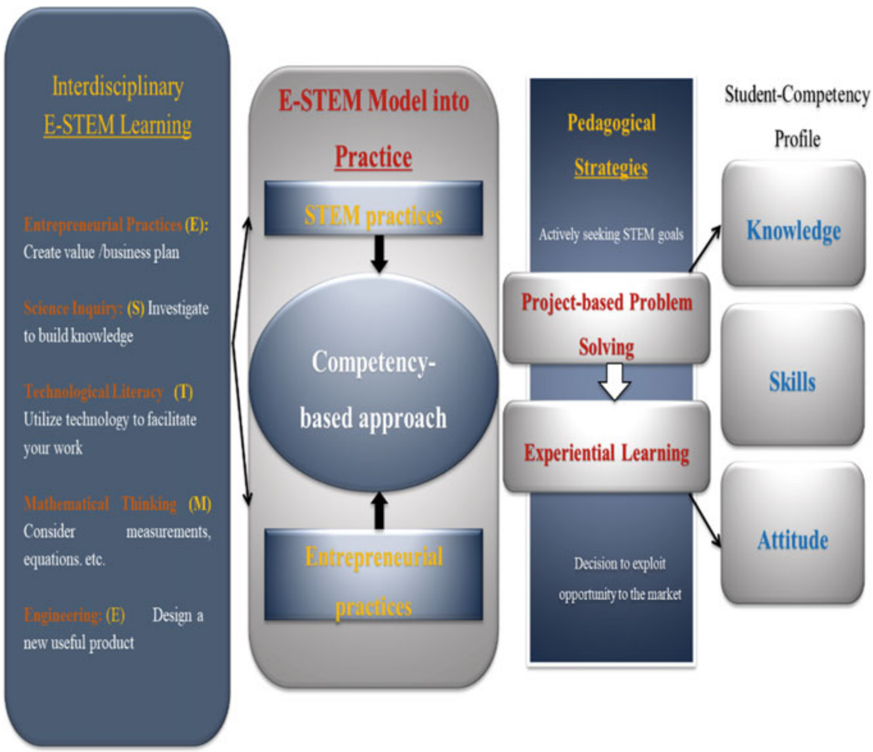


Fig. 3 Interdisciplinary E-STEM model [35]

Emirates. The results revealed that teachers supported implementing PjBL and PBL or design-based problem solving to apply E-STEM practices in the high school. Additionally, leaders explained that the E-STEM model should adopt experiential learning through competency-based practices to enhance entrepreneurial competencies of high school students through focusing on value creation more than venture creation. The driving force behind developing the E-STEM model is the fact that early learning experiences that emphasize realistic investigation are extremely beneficial in maintaining students' interest to continue working in the same field in the workplace [52].

Students' competency profile and building blocks are considered when designing the E-STEM model and introduced in the following.

5.1 Student-Competency Profile

Teaching today's STEM students with an innovative method to become future entrepreneurs is recommended as a step forward to support the economic growth of a country [3]. Accordingly, incorporating entrepreneurial activities into STEM education can encourage STEM students to practice self-employment tasks by integrating business activities inside and/or outside the school to experience an entrepreneurial work position.

Infusing entrepreneurial practices into STEM education has a double benefit effect because students, instead of developing either cognitive competencies through STEM education or non-cognitive competencies through entrepreneurial practices, the integration between them increases students' opportunities of acquiring both types of competencies. This means that the combination of both types of educational practices (entrepreneurial and STEM) via the implementation of E-STEM model can give adequate attention to both cognitive and non-cognitive competencies. For example, creativity, planning ability, critical thinking, decision-making, communication, and adaptability are fundamental competencies in the labour market; they are not exclusively related to entrepreneurial education and can also be developed through STEM education [35, 53].

Since not all competencies are needed in all situations, educational programs should target a set of selected entrepreneurial competencies to suit the context of the education level. Aligned with the entrepreneurship education literature [8, 51, 54], twenty entrepreneurial competencies were suggested by Eltanahy et al. to form a student-competency profile [1]. This profile includes the basic abilities that have been conceptualized as necessary for an entrepreneur to be able to start a new business. The selected range of key competencies (knowledge, skills, and attitude) involves both cognitive and non-cognitive qualities that are essential for generating new entrepreneurs via integrating entrepreneurial practices into STEM education [51].

- Entrepreneurial knowledge involves seeing business opportunity, financial awareness, product functionality, insight into the market, and marketing.
- Entrepreneurial skills include creativity, planning ability, critical thinking, problem solving, decisiveness, persuasiveness, networkability, marshalling resources, need for achievement, and analysing.
- Entrepreneurial attitude includes perseverance, independence, curiosity, initiative, and risk-taking.

The E-STEM model adopts the core entrepreneurial competencies that enhance students' abilities to discover business ideas in order to deliver their STEM designs to the market. Instead of placing an emphasis only on teaching the content or developing the skills needed for the workplace in a different setting, and then, hoping for students to realize the connections of this knowledge to real-life situations, the interdisciplinary E-STEM model seeks not only to locate applicable connections between E-STEM disciplines but also provide a relevant context for learning experiences.

5.2 Building Blocks of E-STEM Learning

The E-STEM model was guided by a 'input-operation-output framework' proposed by Dietrich, Zhang, Klopp, Brunken, Krause, Spinath, Stark and Spinath, who explain the building blocks of scientific competencies in the social sciences and distinguish between Input, Operation, and Output concepts [55]. According to this framework:

- Input refers to the 'What?' question or the content delivered to students.
- Operation refers to the 'How' question or the process of delivering and applying the new information.
- Outcome refers to the personal characteristics that should be developed in the learning process.

This model is advantageous because its level of generality is relatively high. New educational models such as interdisciplinary E-STEM that target competencies can make use of this framework and draw on its concepts for more theoretical clarity.

Drawing on the input-operation-output framework, Fig. 4 is created consisting of the four main building blocks to better perceive the E-STEM model.

In Fig. 4, The block of 'input' is represented by the content integrated from both STEM and entrepreneurial learning. Incorporating entrepreneurial practices into STEM education represents the block of 'operation' where a variety of cognitive activities is used to process the input. The block of 'output' refers to the content conveyed to add new value and create a STEM design. The whole model targets the personal characteristics of students focusing on the development of their entrepreneurial competencies.

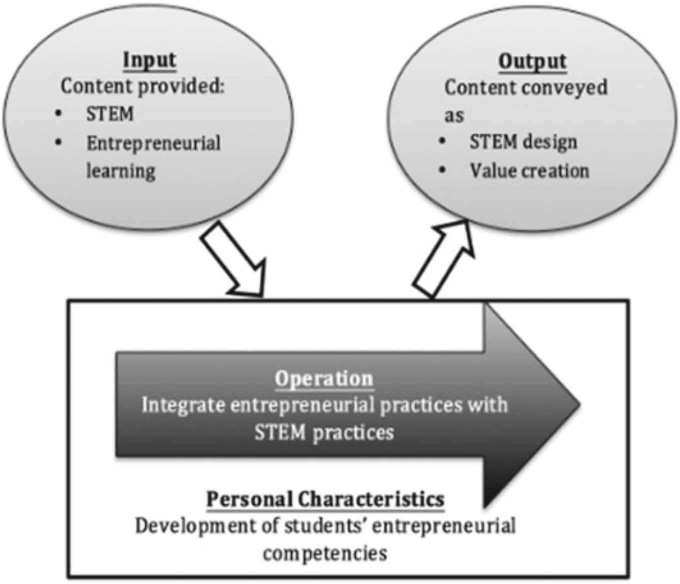


Fig. 4 The main building blocks of E-STEM model

5.3 The E-STEM Model: From Theory to Practice

Most pedagogical frameworks of STEM disciplines commonly focus on teaching the theoretical foundation and the basic concepts of each course [37]. To overcome this, Eltanahy et al. proposed a strategic plan that pays more attention to practices than theories when implementing the interdisciplinary E-STEM model in high schools. This implementation plan includes activities that guide students to work on an E-STEM project which can add value to society such as forming collaborative groups, brainstorming ideas to decide on the best design that add value to their communities, and constructing a prototype to examine or create interest in their projects. A prototype refers to a simple model to represent a proposed model to be tested and discussed with an interested audience before actual implementation of this product [35]. Incorporating these activities would create a platform to support the three key aspects (learning context, authentic activities, and the culture) that are naturally linked to the situated cognitive theory [26]. Seven main activities of the E-STEM strategic plan and their relevant forms are introduced in the following.

- **Activity 1—Ability Determination of Each Student**

The student-competency profile should be introduced to STEM students to determine their strengths and weaknesses as well as competencies. For this purpose, Table 1, presented below, can be used by students to assess their own abilities, and

Table 1 The form of the ability determination of individuals

Student-competency profile			
Cognitive entrepreneurial competencies		**Non-cognitive entrepreneurial competencies**	
Knowledge	Skills		Attitude
Seeing opportunities Financial awareness Product functionality Insight into the market Marketing	Creativity Planning ability Critical Thinking Problem solving Decisiveness	Persuasiveness, Networkability Marshalling resources Need For success Analysing	Perseverance Self-confidence Self-knowledge, Initiative (pro-activity) Risk-taking
• Use the competencies listed above in the students-competency profile to determine your strengths and weaknesses as well as the competencies that you are working on to develop			
Ability determination of each student			
Strong competencies		Weak competencies	Developing competencies
.			

record their self-assessment in this form. This activity will help teachers to initially create cooperative groups of students to work on E-STEM projects.

- **Activity 2—Making Collaborative Groups**

According to the strengths and weaknesses determined by each student in Activity 1, students' collaborative groups should be created with different abilities to work on the E-STEM model. The activity of creating collaborative groups helps teachers to establish expectations and norms for each group. Moreover, it prepares students to be part of a team and gives them opportunities within the activity to develop leadership and assign roles and responsibilities for all students, where even those who are struggle can contribute to the success of the group.

- **Activity 3—Brainstorming**

Each group provides some ideas about the E-STEM projects that they would like to work on. At this step, students should discuss the need and the value of each idea to select the best E-STEM project for implementation. Students should learn that productive group brainstorming runs a balanced conversation where equal opportunities and time are given for everyone to contribute. Students should be asked to think deeply and challenge themselves to generate innovative ideas for E-STEM. Students, then, will be asked to analyse strengths, weaknesses, opportunities, and threats (SWOT analysis) of each idea to land on the perfect idea.

- **Activity 4—SWOT Analysis**

Each group of students should perform SWOT (strengths, weaknesses, opportunities, and threats) analysis as a planning process to evaluate the idea of each E-STEM project they proposed, by explaining the strengths, weaknesses, available opportunities, and threats that they are expecting to face during the implementation. The SWOT analysis tool (see Table 2) will be used to record these responses in order to compare and choose the best ideas. Furthermore, students should identify the available and the necessary resources required to achieve each project. This activity develops students' awareness of all accessible factors and elements to be critically discussed. This is a good opportunity to think of creative solutions to overcome the threats and/or to determine all new principals to pursue.

- **Activity 5—Prototyping**

In this activity, students create a prototype and present it. School conferences or class presentations should be designed to give students opportunities to convince the surrounding community of the need for their E-STEM project and create interest before actual implementation. During the presentation, students introduce their prototypes as inspirations for those ideas or simulations of future projects that come later. They should focus on the value proposition of this sample model and discuss the benefits that can serve the target audience. In addition, surveys should be administered during the conference to clarify whether people accept or reject their ideas. This activity will help students to discover and correct any design errors to enhance the functionality of their project.

- **Activity 6—Launching the E-STEM Project**

After creating the prototype and getting feedback from others, students make the final changes in their project and launch it. Instead of placing an emphasis on only teaching the content or developing the skills needed for the workplace in a different setting, then hoping the students will realize the connections to real-life situations, the interdisciplinary approach used to implement the integrated E-STEM model seeks not only to locate applicable connections between E-STEM disciplines but

Table 2 The form of SWOT analysis of the proposed E-STEM project

Information analysis of the proposed E-STEM project			
Strengths (S)	**Weaknesses (W)**	**Opportunities (O)**	**Threats (T)**
.			
Resources: (Funding, equipment, products, training…etc.)			
Resources available		Resources needed	
.			

also provide a relevant context for the learning experiences. Students should understand the value and the need of their proposed design as well as the target audience that will gain benefits from this service.

- **Activity 7—Business Plan**

A business plan should be designed to help STEM students work more deeply on the cognitive competencies that emphasize entrepreneurial knowledge, such as product functionality, insight into the market, marketing, and financial awareness. The business plan form, developed for this activity, is presented in Table 3.

The business plan in Table 3 allows students to learn and apply more entrepreneurial knowledge regarding their E-STEM project to enhance functionality of their E-STEM designs, marketing, and financial awareness competencies.

Table 3 The business plan form

<table>
<tr><td colspan="4">E-STEM idea</td></tr>
<tr><td colspan="4">What is your E-STEM idea? What is its name?</td></tr>
<tr><td colspan="4">What makes your idea different?</td></tr>
<tr><td colspan="4">What does this name say about your project/business? Is it unique? Memorable? Easy to pronounce?</td></tr>
<tr><td colspan="4">Product functionality</td></tr>
<tr><td colspan="4">How will your product/service stand out from the competition? What is its function?</td></tr>
<tr><td colspan="4">Why will people want your idea? Is it needed?</td></tr>
<tr><td colspan="4">Insight into the market</td></tr>
<tr><td colspan="2">Top competitor(s):</td><td colspan="2">Equivalent product/service:</td></tr>
<tr><td colspan="4">Target Market and Demographics</td></tr>
<tr><td colspan="4">Who are your target audience? Who are your customers? Ex. Kids, teenagers, men, women…etc</td></tr>
<tr><td colspan="4">What is your target market passionate about?</td></tr>
<tr><td colspan="4">Marketing</td></tr>
<tr><td colspan="4">How will you get the word out about your service/business? Networking? Online (website, social media)? Posters? Newspapers? Email?</td></tr>
<tr><td colspan="4">Where will you make your service or sell your product? Finding customers?</td></tr>
<tr><td colspan="4">Financial awareness</td></tr>
<tr><td>Pricing</td><td colspan="3">Profit</td></tr>
<tr><td>How much will you charge?</td><td>Sale price of item:</td><td>Cost of item:</td><td>Profit:</td></tr>
<tr><td>What is your competitors’ charging? (If applicable)</td><td colspan="3">How much will you make on each sale? (Profit = income − expenses)</td></tr>
<tr><td colspan="4">What will you do with the money you make? Reinvest in a business? Save for college? Donate?</td></tr>
</table>

6 Conclusion

Incorporating entrepreneurial practices into STEM education is essential to create a new generation of students who are entrepreneurially literate. E-STEM learning can be achieved through experiential learning using hands-on activities, where authentic learning opportunities are provided. Social constructivist strategies such as PBL and PjBL are effective pedagogical strategies that enhance E-STEM learning. To facilitate the implementation of E-STEM in the classroom, the E-STEM model was (Fig. 3) developed by Eltanahy et al., embracing the integrated knowledge and practice-based pedagogy and has potential to enhance the student-competency profile that includes a variety of cognitive and non-cognitive competencies required to act entrepreneurially [1]. The E-STEM model acts as a guide for curriculum planners to be able to initiate a seamless sequence of a new E-STEM course that provides high school students with meaningful entrepreneurial learning opportunities and allow them to communicate more successfully with their community. This reflects that restructuring STEM education to incorporate entrepreneurial practices can address difficulties inherent in generating learners for a complex workplace where blurred boundaries of disciplines are the prevalent challenge.

In the light of the theoretical assumption and research results discussed in this chapter, the main principles of Integrated E-STEM Learning are suggested as follows:

1. E-STEM learning should contribute to the cultivation of entrepreneurial STEM-literate students because entrepreneurial literacy and competencies are essential to equip learners with the basic knowledge, skills, and attitudes for future careers.
2. E-STEM learning should incorporate integrated practices of the main pulleys of E-STEM acronym to make use of scientific inquiries, mathematical thinking, technological tools, engineering designs and entrepreneurial acts that all support the science reform endeavour.
3. E-STEM learning involves useful STEM designs in a situated learning environment where innovation, creativity, invention, and entrepreneurship values are emphasized.
4. E-STEM learning should focus on the development of the student-competency profile that contains the core entrepreneurial competencies (cognitive and non-cognitive) needed to overcome workplace challenges.
5. E-STEM learning should be implemented via an interdisciplinary approach where new knowledge is embedded in integrated practices to solve real problems and add values to society.
6. E-STEM learning should engage students in real business practices through enhancing entrepreneurial literacy to provide new solutions, construct new knowledge, and offer new values to the local community.
7. E-STEM learning adopts the theoretical perspective that relies upon education through entrepreneurship to enhance high school students' entrepreneurial key competencies.

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5 An Entrepreneurial STEM Teaching Framework: Integrating Business and STEM Education

Gillian Kidman, Roland Gesthuizen, Hazel Tan, and Holger Dielenberg

Everyone has an idea, but it's really about executing the idea and attracting other people to help you with the idea.

(Jack Dorsey [1], CEO Twitter)

Abstract

The STEM education movement recognises the need to explore entrepreneurship education in conjunction with the STEM curriculum. Emulating the behaviours and expectations of the real world with the development of goods and services will enhance STEM problem-solving. This chapter examines the entrepreneurial approach of using STEM technologies and practices to solve a real-world problem by examining an Australian business case study. We present how a commercial makerspace hub adapted its practices during the COVID-19 pandemic to mass-produce medical equipment. An engineer (Author 4) reached out to STEM educators (Authors 1, 2, and 3), to create a 'Brains Trust'. We adopted the 4-D cycle of an appreciative inquiry as our methodology. Following

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the research and ideation process, a combined team of engineers, educators, and health workers undertook a design sprint to rapidly-produce a novel face-shield design, registered it for use as "therapeutic goods" then scaled up for mass production. The resultant award-winning product launched an expanded business and demonstrated a successful example of manufacturing sovereignty during the extended economic disruption. We deconstruct this case study to focus on what we, as STEM educators, learned from the appreciative inquiry process in a business setting, and how this applies to educational settings. We highlight the attributes integral to this entrepreneurial STEM endeavour—critical and creative thinking, problem-solving, flexibility, resilience and use of failure, a growth mindset, and managing risk and uncertainty—reconstructing these attributes to create an entrepreneurial teaching framework for teachers and learners of STEM education lacking business acumen.

Graphical Abstract

Keywords

Appreciative inquiry · STEM · Entrepreneurial mindset · Teaching framework · 4-D cycle

1 Introduction

Entrepreneurship is defined as creating something new, for-profit [2]. To describe it, entrepreneurship goes beyond the consideration of profit, and involves an individual's ability to innovate and to "come up with new ideas, solve problems, generate creative solutions, and take action to pursue opportunities" [2, p. 1682]. This definition builds on earlier definitions of entrepreneurship [3, 4], with creativity and innovation being emphasised as core attributes over time. However, defining entrepreneurship is also widely variant across disciplines [5]. The multi-disciplinary nature of entrepreneurship often means definitions are borrowed from marketing, accounting, finance, management, sociology, psychology, and engineering [5], and is now entering the education discipline.

The science, technology, engineering, and mathematics (STEM) education movement is now recognising the need to explore STEM entrepreneurship education in their curriculum, often trying to match the behaviours and expectations of the real world with the production of goods and services to solve a problem [6]. A number of questions thus arise: *How* should entrepreneurial STEM teaching be done? *What* should it involve? *How* can we move away from teaching and assessing knowledge that is solely information-based, and instead enhance the learning of entrepreneurial mindsets and the associated skills and values? *How* can STEM educators include entrepreneurial education in their curriculum if they themselves do not have business acumen? Can one teach to develop a STEM entrepreneurial mindset if one does not have a STEM entrepreneurial mindset of their own? [7].

STEM education is known for its attempts at interdisciplinary education, to break down the science, mathematics, engineering, and technology silos, but rarely do we emphasise the business side of STEM in the real world. In fact, by incorporating a business acumen, we are transforming STEM into STEAM—the inclusion of the Arts (Humanities including the nature of society). Being a successful business person requires strong creative soft skills: a creative mindset, the ability to think outside the box; flexibility, the ability to try new things, experiment and pivot your ideas and approach; and resilience, the tenacity to forge through adversity and not give up. Soft skills counterbalance the hard skills taught in STEM. Incorporating business acumen into the STEM curriculum introduces the vital soft skills inherent in creativity. It is this creativity that is necessary to succeed in the real world. Research exploring entrepreneurial education specifically for STEM is sparse [6], and may partially explain why STEM educators without a business acumen, like Authors 1, 2, and 3 do not automatically include economic viability into our STEM curriculum—we lack the awareness and mindset and oversimplify the entrepreneurial mindset to be a business mindset.

The aim of this chapter is to examine the development of the entrepreneurial mindset in a team of STEM educators (Authors 1, 2, and 3) during participation in an entrepreneurial business endeavour using STEM technologies to solve a real-world problem. The chapter is based on the premise that for an entrepreneurial mindset to be developed as a component of STEM education, the STEM educators themselves first must develop an entrepreneurial mindset and then provide opportunities for students to engage in developing an entrepreneurial mindset. Many teachers lack the training and continuing professional development to teach the entrepreneurial mindset [8]. We begin the chapter with a consideration of research literature pertaining to the entrepreneurial mindset and the notion of it being a continuum. The review of literature is then extended through a consideration of appreciative inquiry as an approach for exploring organisational growth. The essence of the chapter is an Australian business case study (*Space Tank*)—a commercial makerspace hub—in which practices were adapted during the 2020 COVID-19 pandemic to mass-produce medical equipment. We conclude with a discussion of how our entrepreneurial mindsets developed and the potential impact of this experience on our work as STEM educators.

2 Entrepreneurial Mindset and Its Continuum Notion

In the introduction, we have provided a definitional overview of entrepreneurship. What follows is consideration of what it means to have an entrepreneurial mindset for educators, and how it can be identified. There is scant literature pertaining to the development of the entrepreneurial mindset in educators, therefore we go outside of the education discipline for guidance, and then relate the research to STEM education.

Nadelson et al. argue that an entrepreneurial mindset is not a fixed way of thinking or a single entity [5]. Rather, the entrepreneurial mindset should be considered as a continuum upon which multiple dimensions can be located [5], involving cognitive, behavioural, and emotional aspects [9]. We include a selection of developmental dimensions published in the literature [4, 5, 10]. We consider these to be particularly relevant to the growth of the entrepreneurial mindset in educators and learners. The STEM educator needs to recognise that students are "potential entrepreneurs" [11, p. 12], and so teaching needs to develop students':

1. thinking that is visionary and creative, and based on curiosity
2. ability to take risks when opportunities arise
3. self-motivation, and self-regulation
4. tenacity and resilience when faced with failure
5. ability to be innovative and a user of novel approaches
6. ability to identify goods and services with unexpected value
7. understanding that resources once transformed into goods or services have a monetary value
8. an approach to resource allocation that involves sequencing, low commitment, and reallocation of resources.

Each of these eight developmental dimensions is multifaceted. As a collective for the education discipline, individual dimensions are likely to be developed as a synergy with other dimensions. Of these eight dimensions, we see two groupings.

The first is with dimensions 1–5 inclusive. These are all well suited to STEM education as they are all promoting the use of problem-solving—a common STEM teaching strategy. In some ways, these dimensions are *generic* [12, 13] and can be used across the curriculum. Dimensions 6, 7, 8 and 9 are very much oriented towards the marketing of goods and services or the establishment of a business (business acumen dimensions). It is with these latter four dimensions that we contest most STEM educators would have the least experience. Thus, these dimensions may not be included in STEM teaching.

STEM education is somewhat divorced from business principles and is rarely collaborative with the varying forces in the real world. For example, the traditional model of teaching uses disciplinary silos and examination-based learning. Yet, STEM teaching advocates collaboration, but the collaboration does not extend beyond the academic pedagogy. We contest that dimensions 6–8 inclusive are critical in the development of an entrepreneurial mindset for STEM educators. Dimensions 6–8 inclusive are concepts not commonly found in STEM education, so may well be unfamiliar to STEM teachers. Given the uncertainty and unpredictability of society and the labor market demands [14, 15] now and in the future, these dimensions are in much need of development in STEM teachers and students alike. Career and social benefits abound for students with a developed entrepreneurial mindset [5].

As these dimensions are seen as developmental, the implication is that a continuum would exist in terms of the practices of educators and the articulation of entrepreneurship (see Fig. 1).

Educators who are, in general, less inventive in their teaching [5] across the eight dimensions are likely to be at the lower end of the entrepreneurial mindset continuum. Although they might have success as a STEM educator developing dimensions 1–5, without a business acumen, they will struggle with dimensions 6–8 and ultimately be placed at the lower end of the continuum of entrepreneurial mindsets. Conversely, educators who are innovative, use “problem solving, seek

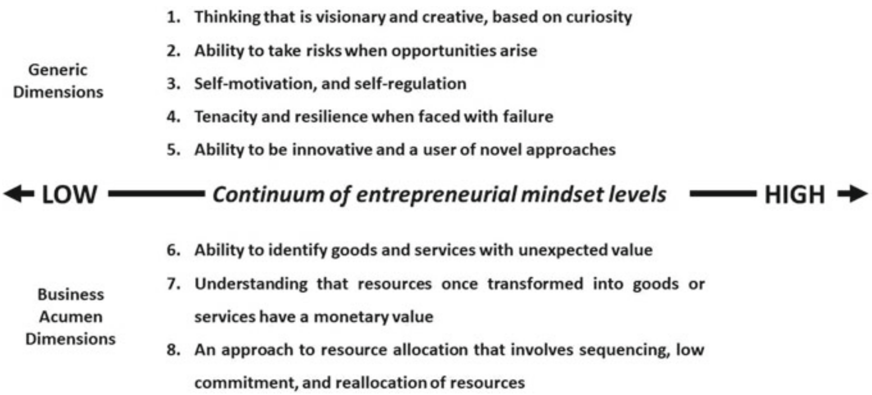

Fig. 1 Continuum of entrepreneurial mindsets. *Source* based on [4, 5, 10]

novelty, are highly curious, and engage in a high level of creative problem solving would be defined as being at the higher end" [5, p. 115] of the continuum of entrepreneurial mindsets. Such educators promote dimensions 6, 7, and 8 synergistically into the developmental work of dimensions 1–5.

This notion of dimensions 6–8 being integrated into dimensions 1–5 common to STEM teaching is important to develop an entrepreneurial mindset in STEM education. We recognise the real world is intertwined with complex and evolving parts that are not arranged as rigid and siloed school subjects, yet this is how we present knowledge and skill development to students. This strongly suggests that contemporary curriculum and pedagogy remain out of step with the dynamics of the real world. Collaboration between different subjects is imperative. "The complexity of the problems which students face will require an interdisciplinary approach and collaborative learning" [16, p. 435]. This is where the development of an entrepreneurial mindset in STEM education becomes a necessity for career success and national competitiveness. Yet, there is scant research guiding the development of an entrepreneurial mindset in the educator that will allow them to develop a similar STEM entrepreneurial mindset in their students.

3 Appreciative Inquiry for Entrepreneurial STEM Education

An appreciative inquiry is an approach commonly used to explore an organisation's strengths. The strengths of practising entrepreneurs can be explored from a constructivist's perspective [17] to reveal the processes engaged in during entrepreneurial enterprise activity. The appreciative inquiry allows for an orientation towards entrepreneurial experiences to be revealed. By accessing the strengths of an organisational system, and via broadening the capacity of stakeholders to engage in change [18], the appreciative inquiry promotes a positive value orientation that shifts ideas of change from those considering problem solving to those championing the strengths and the positive attributes of the whole. Change, therefore, is based on the intentional examination of what has or is best practice in the past and what could be grown from that past for the future. This shared image of the future is inspiring, bold, and motivates people to co-create it [18]. Past successes are valued and used to understand and transform the current reality.

4 Methodology

The methodology of appreciative inquiry, arising from the critique of the inadequacies of conventional problem-driven action research, starts with a positively framed topic [19]. It is based on collaboration and co-creation rather than on facilitation as is action research [19]. This approach is distinctive and highly relevant to the present context as it requires the inclusion of everyone who has a stake in the future and encourages positive emotions to assist with resilience and moving past failure.

What follows is a case study with a focus on how we (Authors 1, 2 and 3) developed our entrepreneurial mindsets over a six-week period. To begin our story, we introduce Space Tank, a Melbourne-based makerspace company (see Vignette 1). This study uses the 4-D Cycle of appreciative inquiry [19] to appreciate the root causes for Space Tank Studio's entrepreneurial success as they undertook the social enterprise of rapid prototyping a product that was to support community workers during the COVID-19 pandemic. This 4-D Cycle (*Discovery, Dream, Design, and Destiny*) is most commonly used in appreciative inquiry research spanning many fields such as computer science, nursing, economics and social sciences [19]. The 'discover' phase provides a description of the best aspects of practice. Here we explored existing face shields locally available. In the 'dream' phase, positive core values are identified and applied to an ideal future. During the 'design' phase, the ideal future is crafted. In the 'delivery' phase, the ideal future is enacted. The usefulness of this approach is beginning to be explored in educational contexts [20].

Vignette 5.1

Space Tank—Who Are They?

Space Tank [21] is a community-focused business makerspace with a mission to *Act Local* and *Think Global* focus, providing socially beneficial outcomes for creative, business, and community ecosystems. Located in the industrial heartland of Melbourne's northern suburbs, Space Tank is a for-profit social enterprise and Australia's leading and award-winning makerspace and product development incubator, supporting manufacturing companies and hardware start-ups. Founded in 2013 by Author 4, it has grown to offer products and services in three business areas: (i) *Space Tank Studio* where product developers, designers, and manufacturing start-ups develop skills and bring ideas to life. The makerspace studio environment provides affordable access to private studios, industrial machinery, prototyping technology, business development, mentoring, and co-working fabrication space. (ii) *Space Tank CoLab* offers student internship programs for the development of healthcare and assistive technology solutions. Students gain authentic human-centric design experience, exposure to entrepreneurial thinking, and hands-on fabrication experience. (iii) *Space Tank Design* is at the heart of Space Tank. Here they leverage resources and collaborate to develop innovative Assistive Technology solutions in the disability and aged care space.

Space Tank Studio—What Did They Do?

The Covid-19 pandemic revealed a supply-chain vulnerability. Australia was sourcing personal protective equipment (PPE) from overseas manufacturers, and with the onset of the Covid-19 pandemic, supply was not ensured. Space Tank Studio responded to an Australian Government call for the supply of health PPE. Space Tank Studio seized the moment to conceive, design, and manufacture face shields in Australia. Author 4's foresight of realising the need for PPE in the general community, outside of health care was correct. As the pandemic took hold in Melbourne, Space Tank Studio undertook a "design to manufacture to market" [22] p. 6] sprint in 6-weeks to release the Rapid Shield as a PPE. The Rapid Shield, presented in Fig. 2 is available to the community (aged care workers, General Practitioners, beauticians, hair salons, physiotherapists, bakery staff, and so on [22]) who do not have access to the Government PPE supply. The Rapid Shield is a 100% Australian-made product, replacing imported face shields. Rapid Shield is also 100% recyclable. It has a unique flatpack design and can be produced at 250,000 units per week [22]. In a matter of seconds, a flat sheet of polyester (polyethylene terephthalate) film can be folded, pinched, and joined with a rubber band to create a Rapid Shield, easily adjusted between a small, medium, and large head size from the positioning of the rubber band. The Rapid Shield was awarded two prestigious design awards: the 2020 Museum of Applied Arts and Sciences (MAAS) Good Design Award; the 2020 Australian Good Design Award [22].

As outlined in the vignette above, Space Tank Studio undertook a "design to manufacture to market" [22, p. 6] sprint in 6-weeks to release the Rapid Shield. Authors 1, 2, and 3 became a Brains Trust (a group of individuals that Author 4 and his colleagues could turn to for assistance and opinion). As Melbourne was in a prolonged lockdown, a *WhatsApp* chat group was set up by Author 2 as the communication channel. The chat rapidly grew to a size, if printed, to be 24 A4 pages containing design sketches, photographic images, and conversations. It was these 24 pages and our reflections and later media releases that became our data source. Through this data, Authors 1, 2, and 3

Fig. 2 The Rapid Shield. *Source* used with permission from [21]

were able to study the intentions, social interactions, behaviours, and reflections of the Space Tank Studio sprint team. Our methodological approach was ethnographic—we participated in a design sprint, and collected rich, holistic insights into Space Tank Studio's views and actions. The WhatsApp chat documented the culture, perspectives, and practices.

During the 6-week design sprint, the Brains Trust grew to include entrepreneurs, fabricators and manufacturers, additional educators, and intensive care unit (ICU) nursing staff and a health organisation. The increased Brains Trust meant we could get feedback from stakeholders (ICU nursing staff) on the growing number of prototypes. We wanted to experience the sprint as it evolved, and not prejudice the data by undertaking a coding analysis ahead of a completed data collection. The timeline of events or the process of the 6-week design sprint provides the structure for the remainder of this chapter.

5 Results

As Author 4 informs us, the overall design process focus is often based on what is currently available, and improving upon that. In our COVID-19 context, the focus was initially based on existing face shields and production methods:

> We continued studying existing methods and designs including 3D printing and chose to improve an open-source DIY (do it yourself) folded concept which has also been championed by Queensland and Cambridge Universities. Even the folding concept presented ergonomic issues, multiple parts, and manufacturing challenges. So, we continued to push all of our aggregated criteria through a reduction/improvement and parts elimination process to identify the simplest, most effective, and low-cost manufacturing solution that would address the essence of intended use [21].

Simply designing and manufacturing a face shield product to meet societal demand was not sufficient. Cognizance must be given to the business side of the venture. The design process in STEM education emphasises product creation, often neglecting economic viability:

> Our methodology followed documented prototype iterations, pivots, and production efficiency modelling to find the best cost/benefit ratio. With every design iteration, we incorporated a feedback loop of field evidence and results from product trials. While economically rationalising our design to the bare minimum, we were mindful to maintain a high degree of style. We want people to feel proud and cool when wearing health PPE [21].

To make sense of this data source, and our growing entrepreneurial mindset, we needed to turn to the 4-D Cycle of an appreciative inquiry [19] to explore what Author 4 and the Space Tank Studio team (including the Brains Trust) did to achieve Rapid Shield success. Although the 4-D Cycle is cyclical, as the name suggests, we present the four processes of the cycle below in a linear format out of necessity.

5.1 Process 1—Discovery

This process involves *appreciating* the existing strengths. Space Tank Studio mobilised the Brains Trust, and together we conducted a situational analysis of face shields and manufacturing, to discover "What gives life? That is, appreciating and valuing what is best of what is or has been" [20, p. 1225]. Conversations were had, and the Brains Trust grew into an assistive technology network consisting of entrepreneurs, fabricators, manufacturers, educators, and health organisations. Interdisciplinary connections were championed and mobilised. A rich description of a dual positive core emerged—firstly, the tangible and intangible strengths, capabilities, resources, and assets of Space Tank Studio, and secondly, the tangible elements of existing face shields and the local market analysis. We wanted to know what elements of face shields already existed that could contribute to a new and improved locally produced face shield. By knowing "what gives life", we felt empowered—we had imaginative capacity, and importantly we had the drive to succeed that would embrace the occurrence of failure. Whilst navigating failure is a complex and highly nuanced pedagogical process adopted by teachers, there is limited research about how this is approached in the STEM classroom. An entrepreneurial classroom would be one that offered activities exploring risk in a balanced way that gives justice to the topic and does not threaten or frighten students.

The Brains Trust agreed on the need for producing a product that had removed the "middle person", so a customer could order directly from Space Tank, and use the product without assistance from a third party to keep the cost/benefit ratio optimal. Our explorations revealed that many devices required a middle person and that Space Tank Studio was better to move towards a direct production and direct supply. Author 1's reflections revealed the need to consider that the real-world design processes must consider manufacturing efficiencies that enable scalable production workflow—or risk failure. In the context of this inquiry, the use of STEM is a consequence and a driver of real-world conditions. However, in the classroom, the use of STEM is isolated from the real world. The aim was for an output of 500 face shields per day. It became clear to Author 1, that in a STEM design process, the business—Space Tank Studio—is in itself a well-defined contextual system [23]: the environment (including the current pandemic), society (people as individuals and collectively—our culture and technology) and economy (revenues, costs, and profit).

5.2 Process 2—Dream

This process involved our *dreaming* of "what might be" by expanding on "the best of what is" [24]. Collectively we explored the attributes of the face shield we wanted to produce—an environmentally friendly face shield directly available to consumers and ready for use. The outputs of our Dream process included creative images and an initial prototype of a face shield made from black polypropylene found in the Space Tank Studio office. This was a familiar process to Authors 1, 2, and 3 as it mirrors our work in STEM education—find what is lying around and reuse it. Conversations shifted to accessing a local supply of PET plastic—a critical resource for our mask production. Authors 1, 2, and 3 were rapidly introduced to concepts like cost/time efficiency, cost volume for efficiency, a parallel production process, and the target price per unit. Then, an order for 10 million face shields came in from the Government—yet we had no PET plastic. Amazingly, Author 4 made a huge investment risk on 3 large laser cutters and a computer numerical control (CNC) router to bring production capacity to approximately 4500 face shields per day or half a million over 6 months. During this process, Author 2 continued to dream as to how our face shield could be an adjustable one size fits all. During this dreaming process, the Brains Trust imagined the 'tomorrow'—tomorrow being the time when we had our precious PET plastic resource and were designing prototypes and exploring the cost/benefit ratios. We were dreaming of a PET plastic future!

5.3 Process 3—Design

This process was enabled by the supply of PET plastic. Whilst the sketching and drafting of face shields had been progressing prior to the PET plastic arrival, the formal Design process enabled Space Tank to realise their dream—and the Rapid Shield was a reality. New activities were required. Author 4 turned to the Brains Trust to find out how we could fast-track the certification of Rapid Shield so that it would meet AS/NZS 1337.1-2010 product standards for personal eye protection (protection for the eyes and faces of persons against common occupational hazards). Author 4 shared a Google Drive to collect ideas. For the first time, the Brains Trust was stuck for ideas so Author 2 began inviting more people into the Brains Trust. The addition of new people resulted in a STEM teacher sharing links that helped to unpack the physics and mathematics behind mask-wearing. This alerted the Brains Trust to consider this modelling of the effectiveness and design of our masks with shields. We were reminded that the design brief was to focus on the face-shield—to reduce the number of parts as much as possible, ideally, limit it to one material, make it as light as possible, easy to assemble, ideally flat packable and we needed a fast fabrication. Author 2 solved the one size fits all challenge. He suggested a series of small holes to retrofit the plastic with an elastic band that would expand according to the size of the head. Author 1 was delighted with how the flat-pack designs were developed, especially considering the designer's skill of looking at a 2D image and then mentally transferring the sketch as a 3D prototype. This form of visual-spatial and relational thinking is a component of Author 1 and Author 3's research—hence Author 1's interest in this design process. Later, the engineering skills of the Space Tank Studio engineers developed an ingenious and innovative solution that allowed a controlled topological deformation to the face shield as it was folded and pinched to reshape itself. This was essential to ensure the final structure would sit on the forehead in the correct position, and not slip or move during the wearing. Unfortunately, most of the people in the Brains Trust could still only contribute to this via WhatsApp as we were still in lockdown. However, the momentum we had previously established around creating a face shield was maintained. Creativity discussions overrode cost/benefit ratios discussions. Authors 1 and 2 were able to obtain prototypes to be critiqued by health workers, and then fed back the information to Author 4. Adjustments were made, and further rounds of stakeholder critique occurred. Author 4 needed to move Space Tank from where it was—producing 4500 face shields per day to the goal of producing 18,000 face shields per pay [21]. A collaboration with Signum—one of Australia's leading food packaging companies, saw Space Tank enter the final process of the appreciative inquiry being able to deliver 50,000 face shields per day [6].

5.4 Process 4—Delivery

This process concluded the sprint and revealed the path forward. We had production and now had to deliver! This process presented a whole new challenge involving management practices, human resource processes, and customer service systems. These are subsystems essential to "sustain the design from the dream that it discovered" [25, p. 182]. The Brite Disability Employment Services agreed to handle packaging and distribution for Rapid Shield creating new employment opportunities for disabled workers. Word of mouth resulted in sales with major cosmetics retailers (MECCA Cosmetica) in Australia and New Zealand, the Australian Taxation Office, fashion retailers around the country, speech pathologists, disability organisations, small medical clinics to name but a few. Sales are consistently increasing at 10% per week [6].

6 Discussion

STEM education and entrepreneurship rarely occur in the same school curriculum. In this chapter, we contest that this is due to the lack of business acumen in most STEM educators. Thus, to facilitate the development of an entrepreneurial mindset amongst teachers, they need assistance understanding the relevant aspects of the business world. Authors 1, 2, and 3 were able to begin the process of developing entrepreneurial mindsets from participating in a 6-week design sprint. The 4-D Cycle of the appreciative inquiry provided the structure for Authors 1, 2, and 3 to study the business process of STEM innovation. Below we discuss our learnings from two considerations. Initially, we consider the indicators of Space Tank's business success. We then discuss how we have reinterpreted this business success into an entrepreneurial mindset we can utilise in STEM Education. In this discussion, we present an entrepreneurial STEM mindset teaching framework to facilitate the development of entrepreneurial mindsets in students and teachers alike.

6.1 Identifying the Indicators of Success in Businesses

Authors 1, 2, and 3 consider their quest to develop an entrepreneurial mindset a success. Our success was gradual, approached with caution, any achieved as a collective. When we examine the Space Tank Studio and its Rapid Shield case study through the eyes of an entrepreneur, we can see that the Definition stage of an appreciative inquiry allowed the Brains Trust to work with their collective wisdom and diversity. It was with considerable caution that the Brains Trust worked through the myriad of questions and suggestions; we picked through the strands of different problems from the complicated, tangled, and shifting fabric of the pandemic crisis. The real world is a much messier and more complex place than how it is framed in the classroom. The Dream stage required considerable imagination by the Brains Trust for a better place and a better world. It required a degree of passion and drive to persist in looking at the world with an optimistic mindset. This gave the Brains Trust permission to move to the next design stage—to set the exploration boundaries and work towards a specific design brief and solution, taking stock of people, resources, and specialist skills. Only then could we tap into the Brains Trust's collective decision to move forward through the logistical challenges of implementing and scaling up production.

Space Tank Studio's Rapid Shield innovation can also be considered an entrepreneurial success. Authors 1, 2, and 3 now recognize that there are four perspectives to a business venture that combine to enable success: (i) who the business does its work for, and with; (ii) what the business does now and in the future; (iii) how, where and with what the business does the work; and (iv) how the business defines and measures its success [26]. How the business responds to these personal, social and economic perspectives highlights the uniqueness and success of that business [27]. Using these four perspectives as a guide, and using the notion of building blocks that are associated with these perspectives [26] we get an understanding of how Space Tank Studio achieved success over time. We use the notion of building blocks to indicate concepts that describe a business model [26]. Building blocks, often described as questions and consider the "organization's chosen definition of success, and if the answers are informed by our best understanding of how to realize that goal, then the result will be a business model that is more likely to enable the desired outcome" [26, pp. 133–134]. Table 1 provides a summary of the entrepreneurial concepts we encountered during the 4-D Cycle of the 6-week "design to manufacture to market" [21, p. 6] sprint. In Table 1, we can see that a number of building blocks are interrelated across the processes in the 4-D Cycle of the appreciative inquiry—Stakeholders, Resources, and Activities. Thus, a successful business model like the one that Authors 1, 2, and 3 experienced as part of the Space Tank Brains Trust, indicates that there is a need to consider these as core building blocks when a business creates, delivers, and then captures value (measured financially) [26]. We consider the stakeholders, resources, and activities to be the root causes of Space Tank's business success in terms of Rapid Shield. Stakeholders, resources, and activity relate to the four perspectives of business ventures noted above. At each stage of the 4-D cycle, there were interactions

Table 1 Building blocks of business success

4-D cycle	Building blocks	Space tank business model concepts
Discovery	Goals	The goals of Space Tank. their definition of success: environmentally, socially and economically?
	Costs	How Space Tank chooses to measure the costs incurred by its business model (environmentally, socially, economically)
	Stakeholders	How each person in the Brains Trust is involved in the Space Tank 'business'. The role of each person. Examples: STEM educator/teacher, health worker, employee, investor, owner, supplier, community and regulator
	Relationships	The relationships with each stakeholder must be established, cultivated and maintained by Space Tank
	Resources	The tangible resources (physical materials including fixed assets, raw materials and human beings) and intangible resources (energy, relationship equity, brand, tacit and explicit knowledge, intellectual property, money—working capital, cash, loans, etc.) required by Space Tank to achieve its goals
	Activities	The value adding work, organized into business processes, required to explore Space Tank's valued co-creation
Dream	Resources	The tangible resources (physical materials including fixed assets, raw materials, and human beings) and intangible resources (energy, relationship equity, brand, tacit and explicit knowledge, intellectual property, money—working capital, cash, loans, etc.) required by Space Tank to achieve its goals
	Activities	The value-adding work, organized into business processes, is required to conceptualise Space Tank's valued co-creation
	Governance	The stakeholders who get to make decisions about including additional stakeholders, the goals of Space Tank, and its value propositions and processes
Design	Resources	The tangible resources (physical materials including fixed assets, raw materials, and human beings) and intangible resources (energy, relationship equity, brand, tacit and explicit knowledge, intellectual property, money—working capital, cash, loans, etc.) required by Space Tank to achieve its goals
	Activities	The value adding work, organized into business processes, required to design Space Tank's valued co-creation
Delivery	Stakeholders	How each person in the Brains Trust is involved in the Space Tank 'business'. The role of each person. Examples: STEM educator/teacher, health worker, employee, investor, owner, supplier, community, and regulator
	Resources	The tangible resources (physical materials including fixed assets, raw materials, and human beings) and intangible resources (energy, relationship equity, brand, tacit and explicit knowledge, intellectual property, money—working capital, cash, loans, etc.) required by Space Tank to achieve its goals
	Activities	The value-adding work, organized into business processes, is required to deliver and maintain Space Tank's valued co-creation

Source adapted from [26]

between the building blocks of stakeholders, resources, and activities. The perspectives and backgrounds of different stakeholders, who might be playing different roles, added value during the enterprising activities as they interacted with the resources. These interactions occurred dynamically and spontaneously. They were spurred through the positive appreciative stance taken, yet critical and reflective in nature. As Authors 1, 2, and 3 reflected on the stages, they also considered the constraints and weaknesses arising from personal knowledge, economic, socio-political, and environmental contexts. This addresses the critique of appreciative inquiry as being overly positive with little self-reflection [19, 28].

6.2 Developing Entrepreneurial Mindset Through STEM Education

In the field of STEM education, entrepreneurial education programmes in primary and secondary schools are rare, but if offered they are generally aimed at developing knowledge, skills, and attitudes in entrepreneurship such as creativity, opportunity oriented, proactivity, and innovation [26, 29]. Thus, Authors 1, 2, and 3 have not been exposed to programmes that explicitly train people to create and manage start-ups or with a strong business focus. In light of this, using problem-solving, communication, and team-building that focussed on monetary value creation was a learning curve. The dynamics were different from the problem-based or project-based or inquiry-based learning that is commonly associated with STEM education pedagogical approaches [30]. We could not have developed our entrepreneurial mindsets without the opportunity to act as a Brains Trust. However, this opportunity was unique and few educators can experience such authentic learning. It is for this reason that we recognise the need for a conceptual framework to assist all educators to develop an entrepreneurial mindset to advance their STEM teaching and learning.

6.2.1 E-STEMM Teaching Framework

The participants in this Brains Trust aspired to make our world a better place to live. We now need to consider how we can apply this unique experience to other projects used by educators in the classroom. We present the *Entrepreneurial STEM Mindset Teaching Framework* (E-STEMM Teaching Framework) (see Fig. 3) to help educators to develop entrepreneurial mindsets. This framework has been constructed based on the learnings of Authors 1, 2, and 3. With an entrepreneurial mindset, educators can plan STEM experiences for their learners by adopting the 4D cycle (Discovery, Dreaming, Designing, and Delivery) of the appreciative inquiry [25] methodology. Such a methodology creates an innovative solution by collaborating to build a passion and drive to solve a tenacious, real-world problem. The remainder of this chapter outlines an entrepreneurial teaching framework for educators of STEM education who, like Authors 1, 2, and 3, lack business acumen. The E-STEMM Teaching Framework resembles the 4-D Cycle of the appreciative inquiry [19] in its outer layer, however, we have included an additional process—that of *Definition* to precede the Discovery

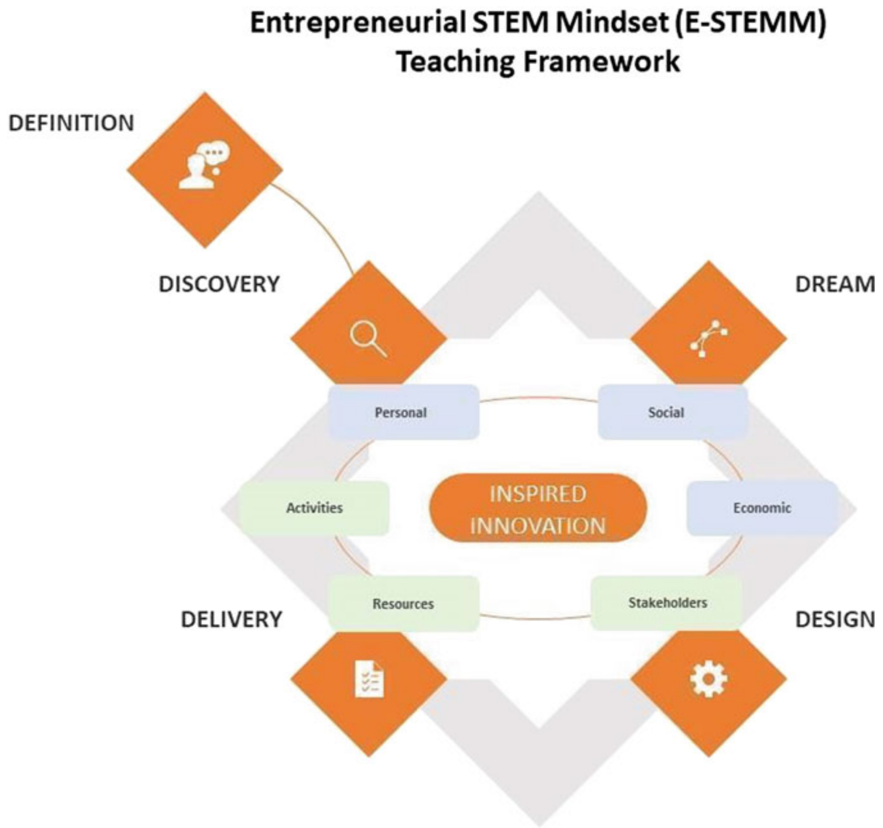

Fig. 3 E-STEMM teaching framework. *Source* original to the Authors

process [25]. There is an inner layer of six entrepreneurial perspectives that require consideration throughout the entire STEM learning experience but particularly in the Design and Delivery processes. In this inner layer, we have integrated the three inter-related entrepreneurial building blocks (stakeholders, resources, and activities) with the three economic perspectives (personal, social, and economic) into the appreciative inquiry process.

In the classroom context, the educator will need to include the **Definition** process where the focus of the Business's agenda for innovation is clearly identified, and the scope and goal of the inquiry are defined. In the context of this chapter, the Definition process occurred before the Brains Trust involving Authors 1, 2, and 3 was formed, so it was not included in the Results and Discussion sections above. The Brains Trust was informed that Space Tank Studio had earlier considered and rejected the following: the manufacturing of thermal imaging cameras for the noncontact monitoring of temperature, wearable heating units for staff working in the field, foot-operated switches for turning appliances on and off, drones for spraying chemicals, fever helmets and anti-virus snoods, and even facial recognition masks that allowed a nurse to contact-free unlock and open their phone or medical device.

Following the Definition process, the teacher needs to introduce the students to the **Discovery** and then the **Dream** processes in Fig. 3. These two stages are based upon dialogue. Brainstorming, discussions, and *asking the right questions* will assist the class in identifying what already works, what the strengths and affordances are of the current solution, and what success looks like. The Dream process will involve the students using their imagination to envisage 'what could be'. A dual 'imagining' is needed where the students imagine past successes and strengths, and then reimagine these as possibilities for an improved future. The Dream process builds on the 'what is best' as determined in the Discovery process. By permitting the students to Dream, and build on known 'what is best' knowledge, the teacher is facilitating creative thinking. This then leads to better outcomes throughout the Design and Delivery process.

The **Design** process is often characterised by the use of a design model, for example, the Stanford-D design process [31]. The teacher will structure the overall process with what is called the double diamond model [32] that spans the process from conception to production. The two diamonds represent a process of exploring an issue widely (divergent thinking) and then taking a focused action (convergent thinking) [31]. Unfortunately, for practical considerations, many classroom projects stop at the midpoint when a prototype has been built, but this leaves an untold story—that of the second diamond that spans issues about pitching the idea, selecting a prototype to scale into production, sourcing raw material and issues of quality control, packaging and user training—the entrepreneurial building block perspectives of the inner layer of the E-STEMM framework highly valued by Authors 1, 2 and 3 following their appreciative inquiry with Space Tank Studio. The challenge realised by Authors 1, 2, and 3 was how we could best represent these six integrated perspectives in the classroom in an authentic way that students and teachers alike could appreciate. STEM classrooms wanting to embrace an entrepreneurial mindset that spans making across traditional subject disciplines and silos needs to give due consideration to this dilemma to foster joint decision making [31]. Both diamonds must be considered.

Teachers in a STEM classroom often focus on the design brief when students are working on a solution, and omit the delivery aspect of the innovation. An entrepreneurially inspired approach would give due consideration to how the product is packaged, how it is transported, how it should be assembled, and how it should be sustainably and safely disposed of. This is the **Delivery** process in the E-STEMM Teaching Framework, and highlights the inner layer of the E-STEMM Teaching Framework. Although the entrepreneurial building block perspectives in this layer influence the other processes of the 4-D Cycle of appreciative inquiry, they are particularly important when considering the Delivery process. In this inner layer, we have integrated the three inter-related entrepreneurial building blocks (stakeholders, resources, and activities) with the three economic perspectives (personal, social, and economic). This integration is intended to open the thinking during the STEM design process to include business concepts, via the eight dimensions [4, 5, 10, 11] outlined in the review of literature above, and therefore develop an entrepreneurial mindset, so that the client or the societal need is given due consideration. When considering STEM education practices through a connective analysis with other forms of knowing, the result is a deeper form of wisdom. Intuition and the realisation of other possibilities provide access to a level of understanding that emerges as an inspired innovation. In a STEM classroom, the designers need to go beyond the design of the face shield. They must also connect with the person wearing the face shield, they must consider the workflow of the person wearing the shield for an entire day. Whilst this empathy is routinely a consideration in the STEM Education classroom, it is often challenging to consider ways of doing this. For example, the Brains Trust sought feedback from a number of ICU nurses required to wear PPE and face shields for 8–12-h shifts.

The integration of the inner and outer layers of the E-STEMM Teaching Framework also characterises the necessity of collaboration. Commonly, in education, and indeed in STEM education, student teams work on individual or small group projects. Class timetables and even assessment means students are sometimes isolated and kept apart with inter-team contact discouraged or strictly controlled. Students are not encouraged to collaborate and share ideas with other design teams. Opportunities for reflection and observation are also controlled. These restrictive practices need to be reconsidered, as they do not mirror real-world practices. The creation of a learning environment that permits the wider group sharing of ideas would be particularly useful as it replicates our experience with the Brains Trust. However, this may be confronting to some teachers who rely on projects for assessment.

7 Conclusion

This chapter described an immersive experience of three STEM educators in the world of business and proposed the E-STEMM Teaching Framework to help develop the entrepreneurial mindset of students and teachers. The three STEM educators had the privilege of a 6-week workplace learning experience akin to an internship. During this time, they formed and expanded a Brains Trust that undertook a “design to manufacture to market” [22, p. 6] sprint in 6-weeks to release the award-winning Rapid Shield. Authors 1, 2, and 3 did not have business acumen, so they had no background or expertise in developing entrepreneurial mindsets in their STEM students. However, following their 6-week workplace learning experience, they were able to identify the personal, social, and economic perspectives needed during a design to market sprint, as well as the essential building blocks of stakeholders, resources, and activities of a business model.

The E-STEMM Teaching Framework integrates the business perspectives, the building blocks of a business model, and the appreciative inquiry process. Critical to the framework, and to a “design to manufacture to market” [22, p. 6] is the collaboration of interdisciplinary stakeholders. Author 4 approached Authors 1 and 2 to build this Brains Trust to solve a manufacturing challenge that combined intelligence, expertise, and specialist skills. The resultant learning for the educators involved moving away from the STEM content delivery and assessment to the realisation that STEM education requires an entrepreneurial mindset. They learned of the entrepreneurial approach to solving problems: by taking time to learn from the client and dream; by pitching ideas to solve complex challenges, and by rapidly developing then scaling up a project towards mass production.

> We want to be able to turn to our neighbour and say "Hey can you make gowns? Can you make face shields and masks and gloves for us?" and the response should be "yes of course we can". That's how Australia should be working. What we've demonstrated is that it's possible. [21] (Holger Dielenberg, CEO/Founder Space Tank)

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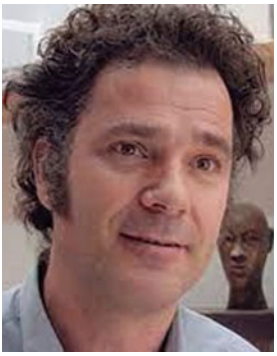

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Part II
Example Practices for Fostering an Entrepreneurial STEM Mindset

Increasing the Pro-entrepreneurial Attitude of Students Through Interdisciplinary Action in STEM Related Fields

6

Andrzej Kozyra, Anna Gnida, Dariusz Halabowski, Robert Kippen, and Iga Lewin

Environmental challenges are among the most pressing issues facing STEM professionals today.

Michael Milligan

Abstract

Since 2014, the Silesian University of Technology (Poland), at the Faculty of Automatic Control, Electronics and Computer Science has developed an

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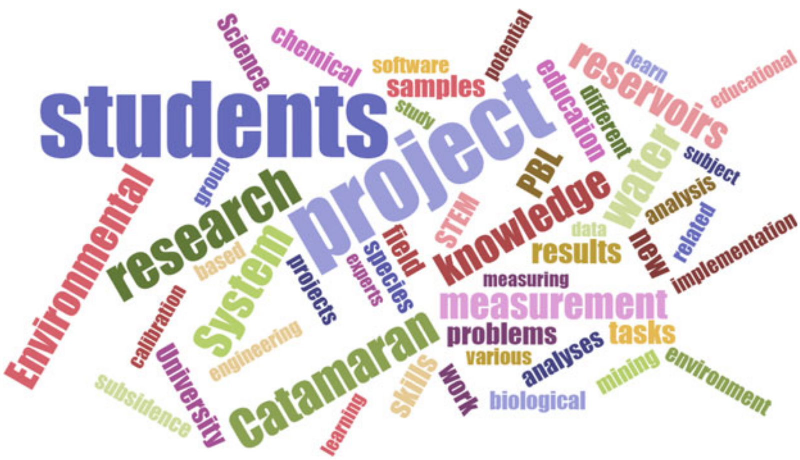
autonomous measurement platform, enabling the performance of physical and chemical analyses in water reservoirs. Students from various fields of study (Automation, IT, Chemistry, Environmental Engineering) learn to work in interdisciplinary teams by carrying out various tasks. These tasks are carried out in cooperation with experts being representatives of other science fields or representatives of industry. Students were asked to improve and optimize the platform functionality as well as recognise the possibility of commercialising the final product. Namely finding potential customers for the platform and determining the direction in which the platform should be developed so that it could find stakeholders. Students encountered many problems, such as, standardised measurements or practical obstacles, which prevented effective cooperation with potential business clients. This approach helped students participating in STEM education to realise that a good and interesting project in their discipline does not ensure success in the business sphere. Often, market expectations are different to what the product creators imagine, which makes it difficult to introduce innovative products to the market. Recognition of customer expectations can help to change the approach to the developed product, its properties and the approach to its commercialisation, as shown by the conclusions of the survey on the expectations of potential customers. By implementing the discussed engineering project, students acquired many skills that are the basis of entrepreneurial thinking, such as the ability to make decisions in changing conditions, self-assessment of their actions, communication skills and cooperation in a group. All these new or improved skills resulted in increased motivation to continue acting and approaching new engineering challenges with a focus on new, innovative solutions.

Graphical Abstract



Keywords

Project-based learning · Higher education · Environmental education · Interdisciplinarity · STEM education · Learning outcomes

1 Introduction

"Environmental challenges are among the most pressing issues facing STEM professionals today", says Michael Milligan, Executive Director & CEO of ABET, the global accreditor of college and university programmes in STEM (Science, Technology, Engineering and Mathematics) disciplines [1]. In today's polluted world, especially in the age of climatic and environmental emergency, care for the environment should be one of the priorities for humanity. The available and terrifying statistics show the contamination of each element of the environment with different types of pollutants. It is very important to apply appropriate measures and enable the visualisation and sharing of results so that they are legible and understandable, not only for specialists but also for a wider group of interested parties. The priority should be to increase environmental knowledge and awareness among young people, especially among young engineers. Working in a group, solving problems, conducting environmental research and gathering information may have a better outcome than theoretical lectures that do not involve any problem solving or project-based approaches to teaching and learning. In this innovative educational environment, students acquire practical skills and at the same time, have the opportunity to verify that their knowledge allows them to solve practical problems. Working in small groups is recommended for the implementation of PBL, due to the increase in understanding of the problem and improvement in terms of responsibility and communication, which results in more creative ideas and deepened cooperation [2]. Implementation of projects in small groups, in the form of Project Based Learning (PBL) can be achieved thanks to financial support by the European Social Fund implemented as a part of the Operational Programme Knowledge Education Development (OP KED). One of the beneficiaries of the OP KED is the Silesian University of Technologya public technical university in Gliwice, Poland. The University took part in a competition aimed at the improvement of teaching quality organized by the National Centre for Research and Development (an implementing agency in Poland) as part of the OP KED. The project "Silesian University of Technology as a Center of Modern Education based on research and innovation" (SUTasCME) was among 100 positively assessed projects from all the universities in Poland that took part in the competition. Over EUR 6.4 million has been allocated to the project which was implemented from 01/04/2018 to 31/03/2022.

The main goal of the project SUTasCME is to carry out fundamental changes in the field of education, based on research and innovation at the Silesian University of Technology, in order to better prepare graduates to meet the challenges of the modern economy and society. One of the important tasks of the project is the introduction of the PBL subject (or the so-called PBL project) and multi-disciplinary teaching methods at the Silesian University of Technology. This consists of replacing few subjects being a part of study plan with a broad, interdisciplinary subject carried out by groups of several students from different disciplines. At this point, the reader should be made aware that in Poland there is no practice of free choice of educational courses. A list of subjects, their form and number of hours are defined for a given field of study and specialization. Making changes to the study plan requires the Dean's consent to implement an Individual Study Plan, which is issued only in particularly justified cases. Qualifying an eager student to complete the abovementioned PBL subject requires consent for an Individual Study Plan, subject to certain conditions. The learning outcomes realized within the PBL subject must be the same as the learning outcomes that a student would have to achieve if they followed a traditional study plan. The group participating in the PBL subject course includes students from various faculties, with interests in various fields of science, exchanging knowledge in a given topic from their different perspectives and developing their communication skills across faculties. The supervisor of the PBL project is a university employee who sets out the most important objectives of the project for the students. As well as setting up the objectives, the ability to commercialise an idea and learn how to get potential investors interested in this idea, rarely mentioned in engineering studies in Poland, is also an important aspect of education [3]. Therefore, apart from the supervisor, there are experts from different faculties and subject areas within the university and from other international universities along with business representatives potentially interested in the engineering results of the project. Each project has a financial budget of about 2–3 thousand euros for the purchase of, for example, measuring equipment and necessary devices, and materials. A more accurate description of the PBL dependencies can be found in the project description [4].

PBL projects have been implemented continuously at the Silesian University of Technology since 2018. Every semester, the list of proposed PBL topics is announced to students of the entire University. Projects to be implemented are selected on the basis of a competition. Many projects have involved ecology and sustainable development, e.g., "Bioremediation of land contaminated with persistent organic compounds supported by deep oxidation processes", "Ecological alternative of concrete—geopolymers based on combustion by-products and extraction by-products: an examination of mechanical features and determination of the environmental impact of used waste materials embedded in building structures", "Innovative solutions in the protection of groundwater against pollution—Technology of Horizontal Slice Barriers". Within each competition, a project/subject related to the Catamaran System was qualified. The Catamaran System is an autonomously floating platform equipped with a control and measurement system, enabling physicochemical measurements in surface water reservoirs. In this chapter, first, environmental issues influencing PBL projects are introduced. Next, the case of one project that lasted one semester will be described. Achieved results of the project are, then, presented, and the problems that arose in the implementation of the PBL project are discussed.

2 Environmental Problems and Issues as an Inspiration for the Themes of the PBL Project

This section aims to outline the environmental problems that have become the driving force and motivation for the creation and improvement of the Catamaran system dedicated to freshwater ecosystems and forming the subject of this PBL project. Among the top contemporary stressors for freshwater ecosystems, climate change, biological invasions, freshwater salinisation and cumulative stressors are the most important [5]. Salinisation, which is associated with an increase in the concentration of dissolved solids, can be a natural or anthropogenic process. Anthropogenic (secondary) salinisation that is caused by human activity within the catchment has become a hot spot internationally due to its adverse effect on freshwater ecosystems [6]. The Upper Silesian Coal Basin (USCB), one of the largest hard coal basins in the world, is located within the upper Vistula and upper Odra catchments (Poland, the Czech Republic). The exploitation and processing of hard coal affect both anthropogenic salinisation of inland water and climate change. Poland is one of the largest coal users worldwide, consuming 77 million tonnes of coal per year. In the USCB the extraction of hard coal to the earth's surface is connected with the necessity to pump out underground mine waters that are highly mineralised. The mine waters contain an extremely high concentration of salts, mainly chlorides and sulphates, as well as nutrients, but they also contain heavy metals and radionuclides [7]. To prevent the underground mine waters from inundating the mine workings, they are pumped to the surface and are initially discharged into settling ponds or directly to reservoirs and rivers, thus causing their pollution (anthropogenic salinisation). Secondary salinisation affects aquatic organisms in multiple ways, including direct toxic effects and changes in the chemical processes in the water [8]. In secondary salinised ecosystems native species are replaced by invasive alien species, more tolerant to water pollution and a decrease in aquatic biodiversity is observed [9–11]. The secondary salinity of aquatic environments of the USCB is higher than the salinity of the Baltic Sea and is similar to the salinity of the North Sea (about 35‰). Examples of such secondary salinised environments in the USCB are mining subsidence reservoirs located in Czułów (a district of the city of Tychy, Upper Silesia, Southern Poland). These originated from the subsidence of ground over the exploited hard coal seams in the 1970s. The reservoirs have been reclaimed and the water banks have been partially concrete-lined and stabilised with waste rock and slag. The reservoirs are stocked with fish and used by anglers and hunters [12]. European legislation, i.e. the EU Water Framework Directive (EU WFD) has required the achievement of the good ecological status of waters in the Member States by 2027 [13]. Therefore, based on the assumptions of STEM education, out of concern for the condition of the aquatic environment in the context of the EU WFD, the Catamaran System for environmental research in selected secondary salinised aquatic environments of the USCB was implemented by using STEM and entrepreneurial skills.

2.1 Using STEM and Entrepreneurial Skills to Achieve the Goals of the PBL Course

Monitoring the condition of water reservoirs is necessary, for example, to make decisions about remediation treatments, as well as to research the influence of various factors on the chemical composition of water or biological life of the reservoir. In particular, such research is important if the water body is used for recreation, especially when its resources (e.g. fish) are used for human consumption. The water quality monitoring process has traditionally consisted of manual water sampling and ex situ laboratory analysis. The main difficulty in sampling and analysing such a water environment is the logistics of the process because the reservoirs cover a large area, have a varying depth, and their banks can be overgrown, which makes it impossible to take samples from the shore. With the increase in the size of the reservoir and the depth, the stratification of the local physico-chemical and biological conditions increases. A manual sampling limits the number of samples taken for analysis, and their random or undefined location may affect the interpretation of the results. To improve the process of monitoring surface water bodies by standardising measuring points, increasing the number of samples and replacing laboratory analyses with online in situ analyses, it was planned to create a vessel equipped with numerous sensors for water components. Similar solutions have also been tested in other research units (e.g. [14]). In order to overcome the above-mentioned inconveniences and improve the process of sampling and analysis of samples, the following goals were set for the students of the PBL project:

1. to create a system that would allow for an accurate mapping of the state of the secondary salinised mining subsidence reservoirs and could be introduced to the market in the future, and
2. to follow the influence of mine waters on the condition of the mining subsidence reservoirs and their biocenosis.

To achieve these goals, several sub-goals were defined: improving the design of a measuring watercraft created in previous projects; improving the calibration system, taking and analysing samples in the laboratory to verify the Catamaran's work, collecting and analysing biological samples.

The aim of the educational side of the project was to involve students in the implementation of the above scientific objectives, through the use of PBL, STEM education, and entrepreneurial skills. In this study, we will mainly focus on STEM and implicitly focus on entrepreneurial skills. STEM education involves the simultaneous use of four academic disciplines, i.e. science, technology, engineering and mathematics, through a contextualized, coherent and comprehensive way of applied and practical teaching [15, 16]. Entrepreneurial skills involve (a) identifying new business opportunities, (b) creating new products and services, (c) managing innovation within a firm, (d) being a leader or a communicator, (e) building up a professional network, (f) commercialising a new idea or development, and (g) successfully managing a business [17]. This study mostly refers to the new product or service creation and commercialisation of a product. The various activities and selected tasks that were given to the students are shown in Fig. 1.

During the PBL-based project, students learned through experience and experienced the world in practice. Part of the project was carried out based on theoretical knowledge in STEM disciplines, such as mathematics, chemical engineering, microbiology and computer science. However, applying this knowledge in practice came down to experimenting by "trial and error" and searching for the best available solution. Students had to think for themselves, find the cause of certain outcomes and draw conclusions from the conducted experiments, and the results of one part of the research were necessary for the next research step. Due to the multidimensionality of the research goal and interdisciplinarity, students were required to work both individually and in groups. All the disciplines relating to STEM education applied to our project so as to foster the development of students' competence.

Some of the activities concerned the improvement of the Catamaran System, which made it possible to assign different tasks to students. The tasks in the project varied, but the individual components were designed to reach one goal for the product.

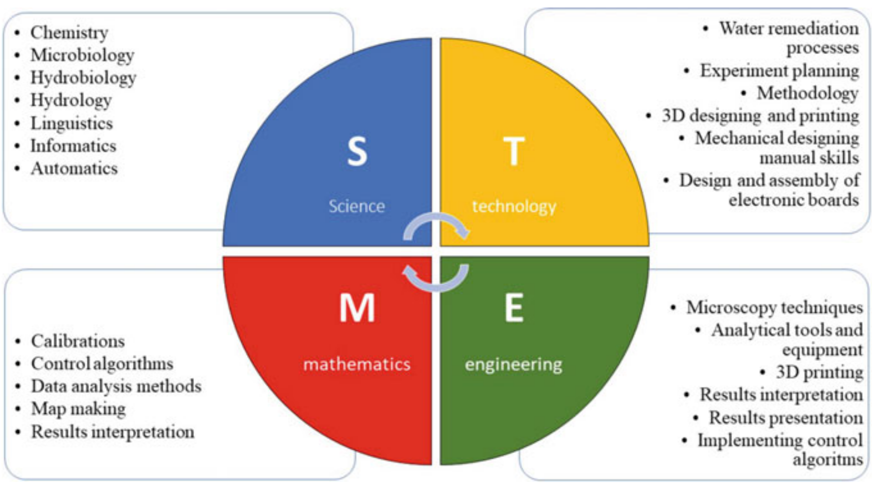


Fig. 1 STEM education approach in PBL Catamaran System projects

2.2 Catamaran System Description

From the very beginning, the Catamaran System was conceived as a basis on which various didactic tasks would be implemented. The entire system was built solely as part of various teaching activities. Currently, it consists of a floating, remotely controlled platform (the Catamaran) on which control and measurement devices (Measurement system) are mounted. To overcome the low budget issue, students showed great creativity and built the hull of the Catamaran with ventilation pipes. The electronics housing is a plastic toolbox and the depth sampling device was made from a garden hose winder. The data collected by the Catamaran is sent by radio to a base station on the shore (a computer with software system). The base station software allows you to control the location of the Catamaran, control the measurements and collect measurement data locally and send the data to a database on the Internet. Additionally, a device was built to enable automatic testing and calibration procedures of sensors mounted on the Catamaran (Fig. 2).

The software enables the performance of automatic measurement tasks according to a previously prepared scenario, online data presentation and procedures for making maps of water reservoirs. The whole Catamaran System is very extensive, which makes it difficult for students to get to know all the details. Therefore, the system has a modular structure. Individual measurement modules are separate devices that communicate with the rest of the system using the industrial Modbus protocol. The tasks related to controlling the drives and determining the position, orientation and obstacle detection (Lidar) are performed by a separate electronic module (main module). Like the hardware structure, the software also has a

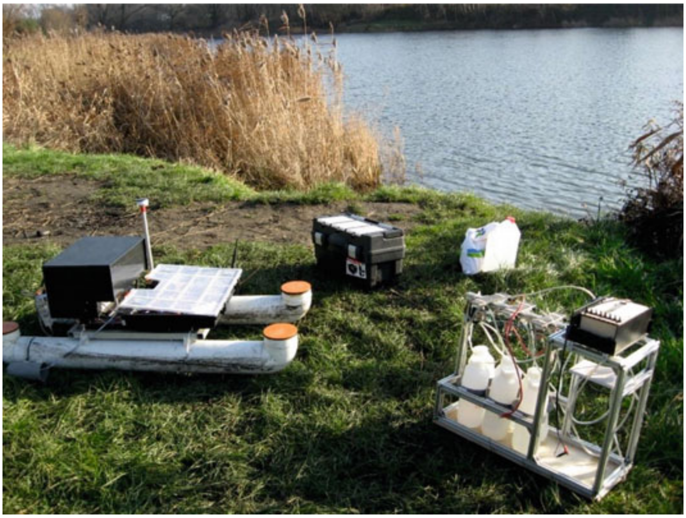


Fig. 2 The Catamaran system. Left side—Catamaran with measurement system on board, right side—automatic calibration device

modular structure. The measurement data is stored in real-time in the local MS Access database and the remote MySQL database on the Internet. The other applications use databases. This allows for the effective implementation of subsequent tasks, as the group of students responsible for them needs to know only some of the details of the system. Furthermore, the Catamaran System is used not only in PBL projects but also as a component of various forms of educational activity (traditional laboratory classes, thesis, etc.).

The Catamaran System provides the opportunity to conduct research and projects that enable students to broaden their knowledge, develop scientific commitment and skills in many fields that greatly facilitates STEM education. How the different STEM disciplines presented in Fig. 1 can be supported by the Catamaran system knowledge and skill is as follows:

- Mechanics: manufacturing, modification of the hull, cells for measuring specific quantities, drive construction, 3D printing of elements, e.g. bow, stern, propellers;
- Electronics: designing and constructing electronic circuits of measurement modules (e.g. chlorophyll detection in water, ion-selective measurements), devices for testing sensor calibration, a visual track, and of a track enabling manual control;
- Automatics: automating sensor calibration and measurement processes, designing and constructing position and orientation control systems;
- IT: developing software for simple microprocessors in modules on the Catamaran, software for the main module (e.g. autonomous navigation along a given trajectory by avoiding obstacles), software for visualising the work of the Catamaran and measuring modules in the base station and on the Internet. Sensor malfunction detection diagnostics. Developing measurement analysis and map generation software;
- Chemistry: calibrating the online measurement system, online measurements, manual water sampling and chemical analyses;
- Hydrobiology and ecology: taking environmental samples for further chemical and biological analyses in the laboratory, performing biological analyses of collected samples, identifying plants and animals in samples, combining the results of biological research with the physical and chemical parameters of the water;
- Economics: researching the market of potential business partners, researching the market of potential customers, searching for the types of measurements potential customers are interested in.

In addition, students learn about the methodology of conducting scientific research, data analysis and writing scientific papers. Some of the work resulted in publications by supervisors and experts together with students. Most of the publications are in Polish, presented at conferences dedicated to students at different levels of education (e.g. [18–20]). However, the results of one of the projects have been published in an international scientific journal [21].

3 PBL Project Realisation (Case Study)

The project was designed to analyse the impact of saline mine waters that are discharged into mining subsidence reservoirs from a post-mining area on the chemical composition and fauna inhabiting these reservoirs. In addition to the overall aim, the project also involved smaller sub-goals such as improving the operation of the Catamaran System. This section introduces the early stages of the project, field research, data collection, and the data analysis.

3.1 Project Initialisation

The first step of the PBL project, entitled "Catamaran—An autonomous system for the analysis of physical and chemical properties of water reservoirs", was the selection of an appropriate research team. Supervisors are teaching staff of the university, while experts are researchers of other research units or business representatives. The project supervisor had to find experts from various fields of science: computer science, automation, chemistry, and environmental engineering. The role of supervisors and experts was to encourage and guide students from selected fields. The proposed topics of PBLs were announced at all university departments, and all students had the right to sign up for the topic in which they desired to participate. There was a general panel, which presented the subjects of PBLs (in the form of posters). The team implementing the topic was selected based on the students' skills.

3.2 Project Schedule

At the beginning of the project, a schedule was created to enable more effective work. The initial period was designed to thoroughly familiarise students with the subject of the project, the science of taking measurements and the topic that was introduced by experts. The subsequent phases of the project involved individual and common tasks. Six particular tasks are presented in Table 1.

As seen in Table 1, the main flow of knowledge between students takes place from the left to the right. Reverse thinking is used as follows to make the knowledge flow easier to understand:

- To create maps, you need to have the results;
- The results are recovered based on calibration;
- Calibration solutions are used for calibration;
- To be able to measure effectively, you must have a working device.

Every week, meetings were held to discuss the knowledge exchanged and the results obtained. Periodic meetings were also organised with hydrobiology experts

Table 1 Students' tasks during the PBL project

Task 1 and knowledge flow →	Task 2 and knowledge flow →	Task 3 and knowledge flow →	Task 4 and knowledge flow →	Task 5 and knowledge flow →	Task 6
Refactoring of the main module code	Preparing buffer solution and calibration curves	Manual collecting of bottom sediment samples	Automatic calibrator improvement	Creating Modbus frame translation to exact values	Creating spatial maps in QGiS
Making a new drive	Manual collecting surface water samples	Treatment and preparation of bottom sediment samples	Creating automatic calibration recipe	Creating a database for translated values	Automation of maps creation
Improvement IMU working	Water sample chemical analysis	Identification of benthic macroinvertebrates using a stereoscopic microscope	Creating an algorithm to calculate parameters of the Nernst equation	Creating moving average and moving median filters	Map analysis and results comparison
New pump mounting	Calculation of water quality indicators			Analysis and results comparison	
Making a new hull					

from the University of Silesia in Katowice and with the designer of the measuring equipment. These meetings were of great importance, especially in the initial phase of the project. The meeting outcomes helped decide on the goals that would be better to implement, such as the making of surface maps in QGiS (geoinformation software) and the implementation of research on the migration of invasive alien species. Moreover, the experts were able to provide information on the current knowledge about the research area, including biota and quality of water.

3.3 Preparation of the Catamaran System for Field Research

Based on the particular and common tasks, the Catamaran System was developed and piloted as part of the field research. The field research area, approximately 40 km from the University, meant that the students had to be specially prepared for taking measurements. We practised field measurements several times on a reservoir about 1 km from the University. As a result of the practices, written procedures and checklists were developed, which showed students the importance of well-organised work and the required modifications to make the research possible. Thanks to the procedures and the checklists, the group could ensure that nothing was forgotten (the procedures concerned packing the equipment, checking the sensors before taking measurements and carrying out tests on each water reservoir).

While piloting the research, many hardware modifications were made, in particular, the calibrator system was modernised to speed up the checking of all sensors and the reliability of electronics and software was improved. A serious problem that the group had to solve was how to enable the system to operate for many hours without access to power. To overcome this problem, voltage converters and a charger for charging the Catamaran's batteries from a car were purchased from the project budget. Electronics and software modifications were discussed with an industry expert. Thanks to this, students learned about the approach to research and development in the private sector. This made them realize that to be sure that the task in the project will be performed correctly, the equipment must be of good quality, and the purchase must also be profitable. This will help them to appreciate the importance of controlling project costs, even down to the smallest elements, as they have an impact on the cost of building the entire system and consequently the profitability of system production.

4 Field Research

Field research involved a very intense day for the whole group. The group prepared the equipment and travelled to Czułów. The research was carried out together with experts and hydrobiologists from the University of Silesia in Katowice. After testing the system and making sure the sensors were measuring correctly, each of the mining subsidence reservoirs in Czułów was circled by the Catamaran. At the same time, water samples were collected for independent analyses of physical and chemical parameters in the laboratory and the same number of benthic macroinvertebrate samples for biological analyses. These samples allowed for the verification of the correctness of the measurements taken with the Catamaran System and made it possible to determine the quantities that could not be measured with the Catamaran. The interest of students in the project is evidenced by the fact that although the whole process required intensive work from dawn to dusk, no one complained about fatigue and everyone actively participated in the measurements (Fig. 3).

4.1 Chemical and Biological Analyses of Reservoir Samples

Randomly collected water samples were subjected to analyses of the following parameters: ammonium, nitrates, nitrites, phosphates, chlorides and total organic carbon concentration, water hardness, alkalinity, pH, temperature and conductivity. All analyses were performed in triplicate and the results were then averaged.

Fig. 3 Students during research on mining subsidence reservoirs in Czułów

Biological samples of benthic macroinvertebrates were collected for analyses using quantitative methods. The benthic macroinvertebrates were separated from the substratum using a stereoscopic microscope and then counted and identified to family and species level according to relevant keys.

The results of the chemical analyses were compared and correlated with the biological analyses.

4.2 Market Research and Commercialisation Possibilities

One of the tasks set out in the project was to explore and show students how to start the process of commercializing a product. A business partner with the knowledge and the ability to undertake the production of a similar system was sought. This company produced specialised vehicles for underwater work. The company wanted students to focus on the customer-related aspect of commercialisation and posed the following questions: Who would be interested in using such a system? What measurement capabilities do potential customers need?

To assess the suitability and demand for our Catamaran System, a questionnaire was created by students (under the care of a supervisor) and sent to the following institutions: analytical laboratories, research centres, sanitary facilities, waterworks, measuring equipment producers, Provincial Inspectorates for Environmental Protection, users of fishing circuits, and fire guards. To familiarise potential customers with the Catamaran, a leaflet was prepared to present the device and its specification and sent together with the questionnaire. Additionally, a basic market analysis was conducted on the attractiveness and the dynamics of the market for small surface-floating research vehicles. Students found several systems with similar capabilities available in the world and compared their functionalities and prices with the ones built under the project.

4.3 Analyses and Map Making

During the project implementation, students created maps showing the distribution of individual measured values in mining subsidence reservoirs. An example of the effect can be seen in Fig. 4. In Fig. 4, the intensity of the red color corresponds to the conductance value—from the white colour, meaning the conductance value of 1976 μS cm^{-1} to the darkest red, corresponding to the conductance value 2038 μS cm^{-1}.

Fig. 4 Example map: conductance value in one of the mining subsidence reservoirs in Czułów

5 Results and Discussion

This chapter aims to indicate achievements in the field of science, but above all to present the educational results of striving to educate students who are sensitive and not passive to environmental problems, and at the same time use engineering skills to counteract these problems in an entrepreneurial way.

5.1 The Achieved Results, the Reasons and Its Potential Impact

5.1.1 Scientific Effects of the Project

The conducted analyses in mining subsidence reservoirs in Czułów (Upper Silesia) showed relatively high conductivity, hardness, concentrations of nutrients and chlorides. In consequence, the saline waters of reservoirs currently do not meet the requirements of the EU WFD. Although the reservoirs are stocked, the caught fish are unsuitable for consumption due to water pollution. Therefore, some measures should be taken to prevent the freshwater environments from further degradation caused by the discharge of the mine waters. The occurrence of two euryhaline (tolerating a wide range of salinity) invasive alien species: the New Zealand mud snail *Potamopyrgus antipodarum* (Gray, 1843) (*P. antipodarum*, gastropod) and *Gammarus tigrinus* Sexton, 1939 (*G. tigrinus*, gammarid) in reservoirs with significant conductivity values was recorded. The results of the PBL project confirmed the progressive invasion of these two species in the reservoirs.

P. antipodarum was probably transferred to Europe in the nineteenth century in freshwater tanks and barrels, filled in New Zealand's streams and carried onto ships; after the journey, they were rinsed with water at the mouth of the River Thames. These gastropods later spread across almost all of Europe. *P. antipodarum* as a successive invader can be transferred by birds, insects, fish, anglers and their fishing tackle, hulls of boats and ships or in their ballast water. The wide tolerance range of *P. antipodarum* to environmental factors, active and passive dispersal, parthenogenesis and a high reproduction rate explain its invading success [9]. *G. tigrinus*, native to the Atlantic coast of North America, was deliberately introduced into heavily polluted rivers by the potash mining industry (the Weser and the Werra, Germany) in 1957 to compensate for a decrease in native gammarid species. *G. tigrinus* then began to spread both via the canal-river routes and the brackish Baltic Sea. *G. tigrinus* has replaced the native invertebrates in most of the colonised habitats. Its invasive potential is related to higher fecundity, an earlier start of the breeding season, predation pressure and tolerance to a broader range of environmental conditions compared to the native species [22]. *G. tigrinus* has been recorded in Upper Silesia since 2010 [23]. The fact that mining subsidence reservoirs are stocked with fish, entices many anglers whose fishing tackle can transfer invasive alien species to reservoirs that have not been colonised before. This clearly shows significant human influence on the environment, known as anthropopressure.

It can take the form of degradation (reduction of the value of natural elements) or devastation (destruction of the natural environment).

To limit the negative impact on ecosystems, principles of sustainable development can be introduced in an attempt to preserve the environment and its values for future generations. While stocking secondary salinised reservoirs is clearly a positive strategy to restore biological life, it can be associated with dangerous after-effects, starting with benthic macroinvertebrates. Many species have become extinct or been replaced by those less sensitive to pollution and more adaptive to anthropogenic changes in the environment. The mining subsidence reservoirs constitute new habitats for euryhaline species and create migration routes for invasive alien species. Both *P. antipodarum* and *G. tigrinus* can transmit parasitic diseases to which native species are not resistant [24, 25]. They compete for food resources and habitats with native species, impact food webs, displace and replace native fauna and contribute to the decline in biodiversity in aquatic ecosystems. Invasive alien species may pose a threat not only to native fauna but to ecosystem services, public health and the economy. What is more, their impact can be mediated by environmental factors such as climatic warming. Therefore, it is necessary to further monitor their migration routes, rate of development and analyse and assess the risk of such threats.

In-depth knowledge of students on environmental problems has become a new motivation to carry out tasks related to the improvement of the Catamaran and conducting field research.

5.1.2 Educational Outcomes of the Project

In addition to the benefits mentioned in the earlier part of the article, such as increased environmental awareness of students, working in a real project, and interdisciplinarity, the project gave students an opportunity to integrate the learning outcomes of different subjects and allowed them to gain the learning outcomes needed to pass the semester. Among them are data analysis skills, programming and environmental knowledge. It is worth taking a closer look at the effects associated with the environment. In the normal education mode, students of the Automation department would not have a chance to acquire environmental knowledge, which includes:

- Knowledge of physical and chemical processes occurring in the internal and external environment, as well as measurement techniques used to determine the parameters that describe them;
- Knowledge of the concepts and laws of inorganic and organic general chemistry, applicable in environmental engineering;
- Knowledge of the biological processes occurring in the environment, about processes accompanying the neutralisation of pollution and reclamation of degraded areas;
- Basic awareness of hydrological phenomena, processes related to the circulation of water in nature, phenomena occurring in geo-ecosystems, as well as water management and protection of its resources;

- Ability to describe and explain the mechanisms of physical, chemical and biological phenomena occurring in nature;
- Knowledge of basic conceptual and terminological categories in biotechnology and the field of mathematics, hydrobiology, physics, chemistry, statistics, biometrics, computer science and environmental protection (natural terminology);
- Ability to identify measurement systems and techniques and knowledge of procedures related to environmental monitoring.

Thanks to the research, the students also acquired practical knowledge about the functioning of the aquatic environment; they learned to carry out measurements of pH, conductivity, temperature, the concentration of dissolved oxygen, nitrates and chlorides in the water as well as analysing biological samples.

Students gained an awareness of the delicate changes that may disturb the functioning of aquatic ecosystems. It turned out that education about environmental problems was not limited to the project team, but was passed on. The parents of one of the students were surprised that gastropods from New Zealand could migrate to Polish water bodies. Another student, during conversations with friends, told them about the research he had conducted in the mining subsidence reservoirs in Czułów. This encouraged one of his colleagues to visit this place and take photographs of these anthropogenic habitats.

One of the things that students definitely gained from the project was experience in working in a larger team. It certainly developed their communication skills. During the project, they had to share information, discuss problems together and explain different things to each other. Together, they could find better solutions to problems. Participation in the project forced students to be independent and to do their research.

As a result of market analysis, it was found that the currently used devices are most often used to measure depth, flow, turbidity, physical and chemical properties of water. Few devices allow for autonomous and automatic sampling. None of the commercially available devices allows for simultaneous sampling and measurement of physical and chemical, meteorological and hydrological parameters. The conducted survey studies showed that most institutions are not even interested in testing the developed device. Nevertheless, those respondents who expressed interest would be more inclined to opt for renting together with service rather than buying. The survey results revealed that a company offering selected measurements would be more interesting for customers than the purchase of the device itself. This aspect of the project showed the students that the practical application of the effect of their work depends on many factors, and even the best engineering solution will not necessarily find an application adequate to the originally planned one.

Another business-related task faced by the students was the planning of expenses and the execution of purchases in accordance with the State University procedures. This required, inter alia, the performance of a tender competition. Students reported that the use of State and European funds is associated with a lot of bureaucracy.

To sum up, individual work allowed students to build a sense of agency and risk taking. On the other hand, working in a group enabled the exchange of knowledge and experiences, and thus showed the need for mutual respect and appreciation of other people. It showed that everyone can both be a donor and a recipient of valuable tips that can be further used in the implementation of subsequent tasks. Therefore, the students realized that it is profitable to take the risk of taking up new challenges, acquaintances and topics, as it often leads to obtaining tangible results.

5.1.3 Students' Expectations and Experiences of the Project

During the project, a survey was conducted among the students. The questions in the survey targeted their reasons for getting involved in the project, their expectations, the problems encountered during its implementation, and what they most appreciated about it.

The main reason for students to join the group was found as a willingness to acquire new practical knowledge. The nature of the project enabled the practical use of theoretical knowledge and its practical testing. Another reason was that the students found its goal and theme interesting and relevant to their interests, such as modelling, electronics and programming. They also recognized that the project could help them develop in scientific terms (performing research, writing publications) and improve their soft skills, such as project management, communication and teamwork. Students also believed that during the project they would work more in laboratories and would be able to perform their tasks with greater liberty because of the clear division of responsibilities and relatively small project group. Students were interested in broadening their knowledge in the field of environmental protection and the opportunity to learn new things, including those differing from their field of science.

Regarding the expectations for the project, a pre-survey showed that students wanted to learn something useful during the project involvement. The group hoped that the project would be an interesting experience. One of the students expected that it would help increase self-confidence in performing laboratory work. Another one mentioned that taking into consideration his lack of experience in interdisciplinary projects, he expected to improve his knowledge of branches of science that otherwise would be impossible to learn. Another student wanted to implement changes to the Catamaran that would prove to be useful for his future employers.

It was not always easy, sometimes some issues appeared. One problem that students encountered during the project implementation related to clarity. Students found some parts unclear at the beginning and required a more extensive explanation from the others. Another problem was the fact that the project lasted quite a short time, and its goal was quite ambitious and required a tight schedule and a lot of good organisation of students' time and self-discipline. However, it was not a vain effort, after the project ended, students stated that they had learned useful things, which would help them in their further education. For example, when students were asked about what they had learned in the project, one student responded to this open-ended question as follows:

I got to know the difficulties and problems with measurements with various sensors in terms of electronics, data processing and calibration.

When students were asked about their experience of the project and what they appreciated the most, they expressed that they reached their goals, such as mastery of subject content, critical thinking, application of knowledge and communication skills, which were in tune with a similar educational project [26]. Students appreciated the project due to its interdisciplinary character; they learned about some topics from other fields of science. This allowed them to look at their work from a different perspective. Furthermore, they appreciated increasing practice in the educational programme and combining theory with real-world applications that partly coincide with other educational outcomes [27].

When students were in an open-ended question asked to submit their idea for research related to environmental/environmental research, one of the automation student stated that:

Similar research as with the Catamaran on lakes could be carried out with a drone in the air to measure the values of various air parameters and determine the pollutants on a 3D scale. The project would require some costs and a very thorough consideration of the methods used in it. The inspiring factor is the Catamaran.

As seen in the quote, the student was inspired by the Catamaran and proposed changes for and different uses of the Catamaran, which may be useful for future employment.

5.2 Discussion of the Problems That Arose in the Implementation of the PBL Project

To achieve the goals of the project, enable the implementation and analysis of scientific research, and achieve sensible results, it was necessary to adopt an appropriate schedule at the very beginning. The timetable needed to be quite strict since the project lasted only one semester. This was hampered by the fact that it had to be concluded in the autumn and winter. This is because in winter, there was the danger that the water in mining subsidence reservoirs would freeze, which would make it impossible for the students to navigate the Catamaran around the reservoirs. For this reason, all research had to be carried out as soon as possible. Therefore, there was a great emphasis on efficient schedule and organisation and preparation of field tests. All of this was caused by the desire to obtain at least an initial estimate of the composition and diversity of the reservoirs. Understanding environmental problems by studying the environment and learning about the effects and causes of its degradation influences the development of an approach to environmental development and management in a sustainable manner [28].

For the reasons mentioned above, the work schedule had to be prepared in such a way that all Catamaran System improvements were included as early as possible. The equipment had to be reliable and dependable. Great stress was placed on eliminating all errors from the vehicle control software. The construction of the Catamaran itself required improvement as well. An important aspect of its improvement was also the acceleration and refinement of the calibration of its measuring devices. Once all the tasks were included in the schedule, it was possible to determine the dates of field tests. Planning and designing projects is an important aspect of the success of the project [29], therefore it was taken into account during the educational process to improve the entrepreneurial competences of students.

A very important issue that had to be taken into account during the project was the safety of those involved in the project. While the safety of workers in the laboratory is ensured and the students know the rules of safe work, work in the field carries many additional, unpredictable risks. People who are very focused on carrying out research tasks often forget about the world around them, which carries the risk of falling into the water. Therefore, we adopted the rule that even small tests on the reservoir must be performed by at least two people, and emergency equipment was always to hand.

During the measuring process, it turned out that the people using the studied reservoirs and the surrounding area (walking, fishing) were also interested in the results. Anglers encountered by students asked about water pollution in the tested reservoirs and its possible impact on the health of people eating local fish. However, not all anglers had a positive attitude about the project. Despite obtaining the written consent of the reservoir manager (the Angling Club), some anglers complained that the Catamaran and circulating students disturbed them. Students had to learn to solve these problems and defuse any potential conflict [30]. The preparation of benthic macroinvertebrate samples for taxonomic identification using a stereoscopic microscope is time-consuming and requires accuracy. The identification of organisms to the family and species level is not easy and requires expert knowledge. Each field of science has its terminology and working methods. To work together, students had to learn the terminology used by hydrobiologists, chemists, electronics engineers and computer scientists. Being open to new challenges, willingness to learn new areas and exchange of experiences are some of the important sociological skills of an entrepreneur [31] that our students could acquire. Learning about working methods is also time-consuming.

Unfortunately, the timing of the project was too short and field studies could not be repeated, as they could only be conducted in the spring. However, the hardware, software and operating diagrams have been refined in such a way that research can be carried out without any problems by other interested parties. Moreover, the system created by the students in this and previous programs allows them to research places where it would be impossible for researchers to access without such equipment and to complete it in a shorter time. In the future, it will allow the implementation of further research and didactic projects oriented towards environmental research.

6 Conclusions

As a result of the discussed course, it was possible to achieve the scientific goals of the project consisting in improving the Catamaran System and testing it by conducting research in the field. Execution of PBL in STEM-related subjects has many benefits. For example, the interdisciplinarity of the task gave students from different fields of science a chance to exchange their experiences and knowledge. While students from the Faculty of Environmental Protection were learning about the use of automated measuring equipment and detecting its stronger (simplicity) and weaker (precision) sides, students from the Faculty of Automatic Control, Electronics and Computer Science learned about the consistency of hydrobiological processes and the anthropogenic impact on nature in both micro and macroscale. Furthermore, during the project, students learned the terminology used by their co-workers (for example concentrations of solutions expressed in different units), which has educational value because in future tasks there is a possibility that team members will have to adapt to people from various professions and communicate with them, despite differences in their understanding of approached topics.

The project helped students improve hard skills that are commonly used in entrepreneurship and STEM education. Such skills allowed them to get acquainted with the business-related problems of the project's commercialisation, market research, budget planning, and execution. Students learned to face challenges, make decisions and take responsibility for them. They saw that, just as a product requires improvement, e.g. in view of the clients' needs, they also have to improve their skills, learn new things, learn from mistakes and look for new ideas. Students also had an opportunity to expand their soft skills such as teamwork, the ability to divide and execute tasks and solving unforeseen problems. By engaging students with an interesting topic, they could learn how to critically evaluate data to reach evidence-based conclusions and communicate with stakeholders.

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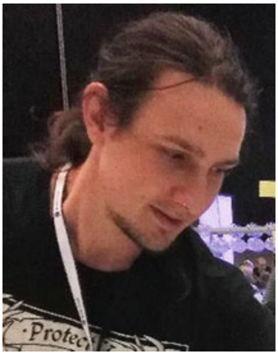

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7 From Think Tank to Shark Tank: Engineer to Entrepreneur

Lynne M. Pachnowski, Karen B. Plaster, Brad M. Maguth, and Nidaa Makki

Nearly everything that changed the world started out aiming to solve a problem that mattered.

Luis Perez-Brevia [1]

Abstract

Infusing entrepreneurial concepts in engineering education can create a broader frame of reference for an aspiring engineer. The entrepreneurial-infused STEM program, "Think Tank to Shark Tank: Engineer to Entrepreneur", began as a summer camp for students ages eleven to fifteen in 2014, and evolved into a curriculum program that can be implemented in formal and informal learning settings. The elements of the curriculum have been structured to engage the participant to create an invention concept that is relevant to their lives, and then simulate the process of moving the idea throughout the stages of concept development, prototype development, business plan development, and then finally, the pitch to potential funders. Through many iterations of curriculum revision, we have identified several key engineering, inventor, and entrepreneur

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concepts that are highlighted throughout the camp, including “pain point”, “patents”, “prototype”, “price point”, “plan”, and “pitch”. Feedback from teachers demonstrated that implementing an entrepreneur framework around their science curriculum created a new motivation for some students who may not have traditionally been motivated to engage in STEM activities. The curriculum provides a structure for children to not only explore STEM innovation, but also explore the possibility of sharing their innovations with a larger community.

Graphical Abstract

Keywords

Engineering education · Entrepreneurship education · Enterprise education · Middle school camp · STEM education

1 Introduction

The concern about shortages of scientists and engineers to spur innovation and power the economy is definitely a global issue [2]. In addition to the need to urgently recruit and prepare engineers, the ongoing COVID-19 pandemic has also profoundly disrupted the global economy.

More specifically, in the U.S., since the beginning of the twenty-first century the looming shortage of engineers in the workforce brought engineering into the elementary and secondary school curriculum. For example, in his book, *The World Is*

Flat, Thomas Freidman identified the lack of replacement for retiring U.S. engineers as “the quiet crisis” [3]. Shortly after 2008, the U.S. federal government dedicated funds for each state to encourage the development of engineering programs and curricula in schools. By 2011, the National Research Council’s report “Specialized STEM Secondary Schools” stated that there were about 90 selective public STEM high schools around the nation [4]. The number of informal STEM opportunities for children has equally increased with the rise of such experiences as Coding Camps and Robotics teams and competitions. Similarly, there are calls in Europe to increase the number of scientists [5]. Aydeniz and Cakmakci stated that the discourse on STEM education reform from the U.S. has overtaken the literature space [2].

The impact of the pandemic has been particularly detrimental to small businesses in the U.S., as many of them closed during that time [6]. As millions left the workforce and small businesses shuttered their doors, a clarion call emerged on the importance of Entrepreneurial Education and on developing an entrepreneurial mindset in students in schools at the primary and secondary level to strengthen the lives of individuals, rebuild communities, and instill innovation, resilience, opportunity recognition in a post COVID-19 world [6].

While there is an increase in focus on engineering education and entrepreneurial mindsets in K-12 (school age) contexts in various countries, a review of the literature reveals fewer efforts focus on addressing integrating the two. However, by integrating engineering education and entrepreneurial education, children are shown the relevance that product engineering has in bettering lifestyles and are simultaneously exposed to efficient, time-honored strategies to get the product into the marketplace. In the U.S.’s subject-oriented curriculum, entrepreneurship resides in the social studies content and engineering resides in the STEM content. However, while an engineer’s goal is to solve a problem, that engineer may benefit from knowing how to take the solution to market. An entrepreneur’s goal is to take a product to market, but they may benefit from knowing how to make innovations to it. Introducing both of these subjects also brings more application and relevance to what may seem to be theoretical exercises. This chapter presents a model, *Think Tank to Shark Tank*, for integrating engineering and entrepreneurship components in a summer camp, an informal recreational and learning experience for school-age children, that we piloted and continually revised in one state in the U.S. over several years. The design of this one-week camp addresses the need for convergence of these two initiatives of Engineering Education and Entrepreneurship Education.

We present the evolution and implementation of our curriculum, *Think Tank to Shark Tank*, that blends principles across engineering and entrepreneurship and is geared for students in middle grades (ages eleven through fifteen). We begin by grounding within research the need and rationale for developing a meaningful curriculum within this area of inquiry. Afterward, we discuss how we employed an iterative curricular design to structure and embed guiding concepts in both engineering and entrepreneurship throughout the ten curriculum sessions while leveraging the talents of area educators and industry professionals. Finally, we describe lessons learned and our work with in-service and pre-service teachers when developing and facilitating the implementation of the curriculum. This program and curriculum provide a real-world setting for participants to explore both engineering and entrepreneurship. Through this curriculum, youth explore *inventor concepts* and *entrepreneurship concepts*. Engineering becomes relevant and purposeful and engages all types of learners (analytical, creative, artistic, athletic, etc.) in both science and social studies.

2 Curriculum Integration—Engineering and Civic Entrepreneurship

2.1 Engineering Education

The focus on STEM literacy has shifted from individual science and mathematics disciplines to teaching these academic concepts through an integrated approach that weaves science, technology, engineering, and mathematics to solve authentic, real-world problems [7, 8]. However, the curriculum structure in schools has subjects taught in silos leading to a lack of relevance of these subjects to students' everyday lives. There are various models to curriculum integration with learning approaches centering on real-world problems as a focus of instruction such as the Problem-Based Learning (PBL) model. In this model, students are presented with a real problem to solve, such as suppressing exterior noise in a library or controlling invasive plant species along a park walkway. More specifically, engineering design problems provide an excellent vehicle to emphasize the relevance of mathematics and science to real-world problems to keep students interested in pursuing further studies in those fields. By integrating engineering and technology into the curriculum, students can see the relevance of these subjects in their everyday lives [9]. For example, many older children have been exposed to or have their own cell phones. Engaging them in a project to increase the battery life of a device or recharge the battery in a new, innovative way can be innately motivational.

One approach to facilitate this integration can be seen in the Engineering Design Process (EDP) [10–12]. Pre-college experiences of engineering principles often revolve around the EDP. The EDP is displayed typically as a cycle that moves the engineer through a series of stages from asking, imagining, researching, and planning to creating, testing and improving. By following this process, the student engineer can articulate a problem and then find a solution to the problem.

Along with the recent U.S. national initiative to increase STEM in pre-college formal education, the following are opportunities that have been developed for both formal and informal educational settings for children to be exposed to engineering concepts at younger ages. One example of a school-age program is Project Lead the Way [13]. Project Lead the Way provides an engineering-based curriculum and trains teachers from schools who wish to host the program to implement engineering in the classroom. Another example is Engineering is Elementary, an award-winning engineering curriculum for schools created by the Museum of Science in Boston, Massachusetts in the U.S. [14]. Opportunities to expose children to engineering principles in informal settings, such as after-school clubs or summer camps have also become more readily available. For example, the Girl Scouts of America have added over twenty STEM-related badges for girls to earn since 2017. They also partnered with the U.S. Smithsonian Science Education Center to create STEM-related activities that Girl Scouts could do independently or with their troop [15]. Girl Scout STEM Badges include a "Think Like an Engineer" badge curriculum focused on girls in grades four and five and other Mechanical Engineering-related badges for the younger grades such as race car, balloon car, and paddle boat design challenges. Another informal educational STEM curriculum is Rockets Away [16]. It is a middle childhood curriculum designed by The Ohio State University that focuses on the concepts of force and motion and has participants design one of several rockets while learning about physics. Another example is "Camp Invention", developed by the National Inventors Hall of Fame, originally housed in Akron, Ohio [17]. The summer camp curriculum targets children ages five to twelve where they engage participants in activities and connects them with inventors. Schools, museums, universities, or other community organizations can host a week or several weeks of Camp Invention opportunities for children in the summer. These examples illustrate the proliferation of STEM programs in school settings.

2.2 Entrepreneurship Education

The nineteenth century economist Jean-Baptiste was one of the first economists to study entrepreneurship. Say [18] is credited with conceptualizing an early entrepreneurial mindset, or set of qualities, understandings, skills, and dispositions of entrepreneurs. This early entrepreneurial mindset has grown and adapted over the years. Today, this mindset includes a particular set of skills, attitudes, and behaviors that help students recognize opportunities, innovate solutions to problems, collaborate with others, and adapt to new information by actively engaging with their environment [19]. Advancing an entrepreneurial mindset should be a core objective within engineering education [20].

"Entrepreneurship education" has emerged as an umbrella term for many different programs and initiatives aimed at preparing youth for a successful future. In many respects, the focus of entrepreneurship education has been to cultivate or incubate future small and medium-sized businesses as a solution to unemployment and for economic growth. Variations on the meaning of the word entrepreneur and their work exist across published research and even practice. Some initiatives focus on being a business owner, obtaining venture capital, while others may focus on small business start-ups [20]. In order to better understand entrepreneurs, Saras Sarasvathy [21] used her dissertation to interview 42 skilled entrepreneurs. She found that entrepreneurs think effectually as well as believing in a yet-to-be-made future that can considerably be shaped by human action. Thus, entrepreneurship education centers on advancing a portfolio of habits, values, dispositions, and ways of knowing and thinking that help learners discover and realize the opportunity, take an informed risk, and value creation [22]. This form of training prepares learners through active and experiential learning opportunities to take a calculated risk and own, invest in, or manage new business ventures.

The relevance of engineering problems can be extended to students' everyday lives with the integration of entrepreneurial mindset, which is typically not addressed in STEM or specifically engineering classes. Several of the STEM curriculum examples presented in the previous section have students create a solution to a problem. However, extending the problem to ask further, "Who else can use this solution? How much would you sell it for? Can it be produced sustainably and profitably?" Then, engineering becomes relevant and relatable to a student's life. There are efforts to integrate entrepreneurial mindset in STEM programs at the college level [23, 24], but not yet at the pre-college level.

In the United States, entrepreneurship education, also referred to as enterprise or entrepreneurial education globally, has increased prevalence and importance in the school-age curriculum [25, 26]. As a result of the 2018 reauthorization of the Carl D. Perkins Career and Technical Education Act, states in the U.S. have the requirement to provide entrepreneurship education as part of career and technical education. The Act has also led more states to require entrepreneurship education courses in high school, growing from 36% in 2015 to 98% of states today [25]. Entrepreneurship content has traditionally been embedded within courses and programs such as Business and Management, career education, marketing, economics, and social studies. While standalone entrepreneurship courses have grown in the school-age curriculum in the U.S., they tend to be elective in nature with youth having to elect to add these courses to their schedules. Only 27 states report entrepreneurship content embedded within a course required for high school graduation or promotion [25]. This lack of requirement may be due to the nature of the school-age curriculum in the U.S. which sorts classes into the categories of mathematics, science, language arts, and social studies, sometimes making it difficult to know where a cross-disciplinary topic like engineering entrepreneurship will fit. With the increase in entrepreneurial curriculum in many U.S. states, research also suggests investments in teacher training have not kept pace with new curricular mandates [25]. Investments are needed to prepare and support educators to build their confidence, knowledge, and capacity to deliver high-quality entrepreneurship education [27, 28].

According to Hardie et al., conceptually, entrepreneurship education curricula have been designated to teach youth *about*, *for*, and *through* entrepreneurship [27]:

- Learning *about* entrepreneurship includes learning the "what" and "how." For instance, key vocabulary, models, and theories.
- Learning *for* entrepreneurship entails helping youth gain the technical and practical information necessary to start and manage a business.
- Learning *through* (or in) entrepreneurship is to experience real-life ventures and enterprises.

Kleiman found that learning *through* entrepreneurship education (i.e. by simulating or engaging directly in the process) is the most effective [29]. It provides an authentic pathway for learners to identify/see themselves as entrepreneurs and leverages learning through hands-on and authentic learning experiences. However, Hardie et al., in their review of forty-five published studies across nine countries, found that while entrepreneurship content is increasingly written into the K-12 curriculum, rarely do students experience this type of curriculum-learning *through* entrepreneurship [27]. Others support the notion that an entrepreneurship mindset can be taught and learned successfully in classrooms and communities [30–33]. Still others have found that high-quality, experiential, classroom instruction can improve confidence, problem-solving, communication, and even empower youth to start and run businesses [28].

Different curricular models and conceptualizations exist in entrepreneurship education to prepare these future financial and business leaders, such as Junior Achievement [25] and Lemonade Day [34]. Both programs have a proprietary curriculum. Junior Achievement finds business professionals to implement their lessons in schools. Lemonade Day, developed in 2007, provides its curriculum online and uses its site to share success stories. Besides cookie-selling, the U.S. Girl Scouts provide a business-development badge curriculum that links the study of business to the sales aspect. The Young Entrepreneur Institute and its Pitch Challenge [35] create opportunities for young inventors to enter a contest with their pitch. North Carolina State University recently developed the Design and Pitch Challenges in STEM website [36] which includes STEM challenges, videos of inventors and entrepreneurs, and a set of challenges.

3 The Development and Structure of the Think Tank to Shark Tank Curriculum

The Think Tank to Shark Tank curriculum was initially conceptualized when STEM Education faculty in the School of Education at The University of Akron in Akron, Ohio, considered creating a summer engineering camp. In order to prepare youth with topics across engineering and entrepreneurship, faculty developed an engineering summer learning experience, but with a twist. We thought, "What if kids were challenged to think of an invention, learn how engineering can be used to create it, and pitch it to people in the business community to receive feedback?" The curriculum has evolved through various iterations of implementing it that are discussed below resulting in a structured curriculum that provides a unique learning experience for formal and informal learning settings.

3.1 Inspiration and Basic Foundations

There were three points of inspiration that, together, influenced the content and design of our curriculum. The first was previous experiences hosting LEGO competitions for students between nine and fourteen years old. The second was an American television show known as "Shark Tank" where entrepreneurs present their product pitches to a panel of venture capitalists. The third was the introduction to the concept of a "pain point" by one of our engineering professor colleagues. These three elements inspired the Think Tank to Shark Tank curriculum and have given it a unique edge.

The FIRST LEGO League (FLL) tournament [37] is a team-based competition for students between the ages of nine to fourteen and includes three components: robotics, innovation challenge, and gracious professionalism. In the innovation challenge, teams present an innovative solution to a current world issue to a panel of judges. Examples of past real-world issues include food spoilage prevention or increasing access to water. Similar to the FLL competition, we wanted young participants in the camp to be challenged to design a product and refine it. Our university and, specifically, the School of Education, has been the host of the district finals in our area since 2012. These events are always inspirational for both youth participants and judges. The STEM faculty in the School of Education believed that we could create a week-long summer event for students ages eleven through fifteen that also focused on solving a real-world problem using the Engineering Design Process.

The U.S. television show, "Shark Tank", from the ABC Network, provided the inspiration to add a component of pitching the product to a "shark tank" at the end of the camp. This hit television show depicts citizens with product concepts pitching their ideas to wealthy investors (venture capitalists). Participants' goals are to capture hundreds of thousands of dollars from their new partner(s), leverage the partner's knowledge to create a business from their product, and become wealthy themselves. The show's popularity is centered around finding out what the Sharks think of the product and whether they think there is a market for it. The feedback the Sharks provide the participants is invaluable, whether they invest in the product or not. Making the connection to our summer experience, we asked, what if, after determining their product and designing it using engineering principles, the participants presented their concepts to a friendly panel of local entrepreneurs, or Shark Tank, at the end of the camp? The Shark Tank would provide that motivational piece that would keep participants engaged and focused on a final experience much like the anticipation of a piano recital keeps young piano students engaged in their lessons and would provide useful feedback on their weeks' worth of innovation and engineering.

Finally, the third inspiration emerged from a conversation between a chemical engineering professor and another STEM Education professor about the concept of a "pain point", and how it can be a mode of inspiration for engineers. The "pain point" often can become the *need* that begins an engineering design process. Merriam-Webster dictionary defines "pain point" as "a persistent or recurring problem (as with a product or service) that causes frequent inconveniences or frustrates customers". We incorporated this concept in the summer camp by asking our young campers to identify a problem that needed to be solved in their own life. This aspect, we found, would become a unique characteristic of our program that other curricula did not have. It also provided the "hook" that engaged the learners early on in their camp experience. With this hook as the opening piece, the shark tank pitch as the closing piece, and the engineering and entrepreneurship concepts to join the two, we had the basic structure of our camp curriculum.

The week-long summer camp was named, “From Think Tank to Shark Tank”. It has run for more than four years during the summer and in online formats during the pandemic. Many of the concepts that have been further developed in the curriculum align with primary and secondary school engineering and social studies standards in the U.S. The activities were designed to be very inquiry-based in nature.

3.2 Designing the Curriculum

Using the foundation components of a pain point, invention engineering, and Shark Tank, we designed the curriculum for students ages eleven to fifteen. We structured it in alignment with an Engineering Design Process [38, 39]: identifying the problem, researching and planning a solution, creating a solution, then testing and improving the solution.

The curriculum is divided into ten sessions requiring a facilitator or a teacher to implement it. The facilitator or teacher has the flexibility to implement the sessions in a one-week intensive experience with morning and afternoon sessions, a ten-week after-school extra-curricular activity, or selecting elements to implement within a course (see Table 1 for session topics for each of the ten sessions). The summer camp ran for a five-day week for six hours each day plus a lunch break. “Sharks” or, in our case, local business owners that were recruited, are invited to attend as guests on the final morning to hear the participants’ pitches. In the afternoon, a showcase for parents and friends followed the pitches. The latest draft of the curriculum and the companion materials and videos can be found at our website, https://uakron.edu/education/think-tank [40].

In developing the curriculum, we were concerned about the feasibility of going from concept to product to pitch in one week. We have been implementing activities using the engineering design process, but could we get through it in only two to three days to allow enough time for the business design process? We

Table 1 Think Tank to Shark Tank camp session topics

Session 1: pain points	Problem identification and potential solutions
Session 2: market	Customer identification, intellectual property
Session 3: engineering	Engineering design constraints and what engineers do
Session 4: prototype	Design and develop a model of your product
Session 5: entrepreneurship	What is an entrepreneur and how do they get started?
Session 6: selling and target market	Target market, cost and supply and demand
Session 7: advertising	Promote product logo, commercial, brand slogan
Session 8: preparing to pitch	Create poster and notes to share with “sharks”
Session 9: pitch	Present to sharks
Session 10: open house	Invite family and friends to view ideas

considered the age level of the students that we were gearing the program to and concluded that going from concept to design within five sessions was feasible, given their level of understanding, attention span, and need to move to new activities quickly. These products were, after all, primarily theoretical.

Current business design practices support the fast pace of this design process. Organizations such as Google and Netflix use a concept known as a "sprint", or a "design sprint" in design thinking, to develop new ideas in a short period of time [41]. We incorporated the design spirit concept in our curriculum, to encourage the participants to delve quickly into an idea or invention. Given that our youth participants only work on their ideas for a week, they can focus on developing their idea, the market interest, and the best sale strategies concisely rather than feeling pressured for perfection or getting the "right" answer.

After piloting the first iteration of the curriculum, we confirmed that not only was the ten-session camp feasible, but that it was a promising concept. After brainstorming during the first session, the young engineers/entrepreneurs combined a bit of business research along with patent research. Then they moved into the engineering design process, before then learning how to build a business. We allowed a little time for the testing, refining, and optimizing stages in our curriculum before the pitch, but it was encouraged to complete these stages after the feedback from the Sharks.

3.3 Emerging Key Concepts

The curriculum components that transformed this curriculum from one of engineering (e.g., developing a concept, creating a product) to the features of entrepreneurship (e.g., developing a company around a scientifically-based invention) can be categorized as inventor concepts and entrepreneurship concepts. The elements of both concepts start with the letter "p," which makes them memorable for students and facilitators. While the inventor concepts include the *pain point*, *patents*, and *prototype,* the entrepreneurship concepts involve *potential consumers* or customers, *price point*, the *plan* for the business, and, of course, the *pitch to potential investors*. The seven videos created for the web-based materials were adapted from these concepts. In the following, we will discuss each element and how it can be integrated into secondary schools' engineering curricula.

3.3.1 Inventor Concepts

Pain Point

We all have pain points as we move through the day or week. "If only a backpack would …" or "I wish that my afterschool event was …" An inventor takes that pain point and says, "If I made this …" or "If I modified that …" to make something that doesn't already exist. Sometimes it might just be creating something unique such as a distinctive bowtie like the ones 9-year-old Moziah "Mo" Bridges developed [42] or Ellie Casano who used a teddy bear to cover an IV bag so that kids in hospitals would not be stressed [43]. Our camp started with this concept and had participants brainstorm "pains", using the Idea Snowball Fight, where participants write their ideas on a sheet of paper, crumple it, and then, throw it. Everyone picks up a sheet (idea snowball) on the ground and reads the idea. The idea is argued with the whole group regarding its potential and the required improvements. After conducting a discussion, the participants, or young inventors, interview relatives and friends about their pain points. One summer, one inventor team developed a theoretical washer/dryer concept where the washer emptied the clothes into the dryer below which was inspired by their mother.

Patents

After identifying a potential product in the pain point phase, participants learn about patents, intellectual property, copyright and trademarks. They investigate the U.S. patent database to see whether anyone has already come up with the same idea. We encourage the young inventors (participants) to search their ideas in the patent database on Google [44]. If this idea is not found in the database, the participants research similar products available in the market. Exposure to the database and contents can be intimidating or empowering. Participants who may be overwhelmed by all the information can rely on camp facilitators or other teachers/leaders to help them identify what information can be discerned at their developmental level.

Prototype (and Its Optimization)

This is the creative part of the experience. Using any materials, participants find an opportunity to construct a visual representation of their invention idea. All participant ideas are encouraged from low-tech materials, such as cardboards to high-tech solutions, such as designing the invention on the modeling program, Tinkercad, and then printing its prototype on a 3-D printer. The patent research should also inform the prototype development process by providing other models to emulate or improve upon. Prototypes offer an opportunity for discussion among participants such as whether the prototype needs to be tested to determine the required revisions for the optimization of the product. The visual representation of their products is where the application of the engineering design process is applied and discussed.

3.3.2 Entrepreneur Concepts

Potential Consumers/Customers

After creating the prototypes, participants, or young business developers, are encouraged to conduct focus groups and survey potential customers to identify their interest in the product. The participants also consult family members, friends and people in the community about their product and come back the next day with their reports. The prototype is adjusted according to the customers' needs based on the results.

Price Point

Once the participants obtain ideas from others regarding what someone might pay for their invention, they conduct research to see what competing products charge. They consider if their product would appeal to a different market who might pay more for an added feature or who might be happy to pay less for similar features. The participants also research how much it would cost to produce the item to see if they would make any profit and, if so, how much. Using all this information, the participants set a price point. This activity can lead to a discussion about how a price point can graphically be represented as the intersection of a supply curve and a demand curve. This is also an excellent example of integrating mathematics.

Plan (The Business Canvas)

The potential customers and price point are all elements of a business plan. While a business plan is several pages long and goes into great detailed planning, perhaps a better planning tool could be the Business Canvas [45] developed by Alexander Osterwalder and Strategyzer, a business consulting firm headquartered in Switzerland. Strategyzer's Value Proposition Canvas template is a one-page planning tool that helps the participant, or young business developer, consider the relationships between the product and how it may relieve the consumers' pain point, and the "gain creators" or the benefits your customer expects [46]. It also has the business developer consider the potential customer's tasks that the product will help improve ("jobs"), what the potential benefits of the product will be to the customer ("gains") and the potential drawbacks or "pains".

Pitch

If the participants (young inventors/entrepreneurs) need startup funds to help start the hypothetical business, then they will need to learn how to pitch the product to potential investors. With only five minutes to present to the shark tank, the budding inventor/entrepreneur prepares a presentation to get feedback on viability, prototype, price points and calculations behind it, and communication techniques. The participants often do not need to be reminded that the "pain point" that inspired their invention may be a great place to kick off the presentation. It is also a great opportunity to field questions and prepare impromptu answers for panel members.

3.4 Formalizing the Curriculum

With the addition of entrepreneurship concepts in the camp curriculum, the STEM Education professors engaged the Social Studies Education professor to help integrate the content from the business side of the curriculum. The STEM faculty are part of a newly-created U-STEM (Urban STEM) Center within the School of Education. The Social Studies Education professor is also the campus-based Barker Center of Economic Education director. Our centers were designed to purposefully break down existing siloes and walls between disciplines, programs, and partners to create bridges of interdisciplinarity. Thus, this curriculum's evolution was a natural byproduct of existing interdisciplinary and community work being completed in our College's centers.

The camp using the Think Tank to Shark Tank Curriculum has been offered every summer since 2014 (except in 2020 and 2021) on campus with continuous revision and refinement. In 2019, with funds from Burton D. Morgan Foundation, the camp developers formalized the curriculum. They published it online as a participant workbook, a teacher/facilitator handbook, and seven videos based on the seven main topics of interviews with local entrepreneurs, engineers and business owners. Materials can be found at https://uakron.edu/education/think-tank. Other community partners have also piloted the curriculum and included the local Urban League summer camp, the Boys and Girls Club, and a high school engineering enrichment group.

The Think Tank to Shark Tank camp has been integrated into the teacher education curriculum through implementing the program as a teacher workshop and incorporating it into pre-service teacher-required courses. During the Summer of 2019, the curriculum developers hosted a teacher institute to provide teachers from the region an opportunity to pilot the curriculum and provide feedback. Approximately twenty secondary teachers participated and experienced the curriculum from the learner perspective by engaging in all the tasks from establishing the pain point to the pitch to the shark panel. The in-service teacher workshop allowed teachers the opportunity to engage in the weeklong camp as participants and included the final presentation to the Sharks. Throughout the workshop, the curriculum developers would often break from student mode to teacher mode to discuss why activities were specifically arranged and how the teachers could incorporate them into their classroom. The curriculum developers also held focus groups with the teacher/participants to obtain suggestions for revision to the curriculum materials and the videos. The feedback was used to revise the written materials and design a format for the videos created during 2020. One teacher participant, who was an engineering teacher at a local STEM middle school, shared that the curriculum added an aspect to his class that many students found engaging. For some students, he said, just solving the problems was interesting enough.

3.5 Distinguishing Our Curriculum

After designing, implementing, and promoting our curriculum, several components emerged that are unique from other curricula. We reviewed several existing informal STEM and Engineering camps and curricula to help us understand what already works well and how we could differentiate ourselves. We found one curriculum [36] that integrated an engineering design challenge and a pitch. However, the problems that needed to be solved were provided to students in advance. In contrast, our curriculum had students determine their own "pain points" from their home or school lives. Aside from the North Carolina State University curriculum, our curriculum was the only one that integrated engineering and entrepreneur concepts in an informal learning environment and enabled the participants/learners to *choose their own problem that they wished to solve*.

Another unique feature of the Think Tank to Shark Tank curriculum is that it provides an experience where a participant takes the role of an entrepreneurial engineer in a quick, exploratory manner and encourages personal study and independence. On the one hand, a young person may study engineering and find herself becoming employed by a large corporation and learning the "system" or even solving an existing problem for the company. To paraphrase one 35-year veteran of a large tire manufacturing company who volunteered to work on a STEM school curriculum committee years ago, he said, "When I started working for (company), I had all these ideas about what I could help the company do. Then, I learned that I had to spend the next two years learning what the company had to teach me about how things get done here". However, that same engineering student who finds herself working on developing a new product that she would like to take to market on her own requires independent and collaborative personal skills necessary for successful entrepreneurs, The Think Tank to Shark Tank curriculum encourages participants to learn engineering concepts, but also to design, plan, and communicate their concepts independently or in small groups to become their own boss and build companies on their own.

4 Outcomes of the Curriculum

4.1 Examples of Student-Created Products

Every year, the participants surprise us with their original and thoughtful creations. For example, a team of participants, inspired by visiting their grandfather in the hospital, created the "Shake Awake," an alarm clock that would shake your bed to wake you up. Apps have been created to find friends, order unique spices that cannot be found locally, or find an item in a drawer. Other products that have been invented include a reusable paper sheet, a pair of shoes that can be changed from flats to heels, and a bracelet that will spray your hands to stop them from being sweaty. Samples of participant posters can be found in Figs. 1 and 2.

While the products that participants developed are mostly theoretical, some have attracted the attention of local business owners who were acting as our guest "sharks." At one camp, one of the community volunteers who served on the Shark Tank wanted to talk more to the participant (a teacher in our teacher institute camp) about his app concept because the volunteer shark thought it had potential.

To optimize facilitation of the program, we have consistently revised the program with multiple iterations of the camp based on reflection and instructor feedback and thereby, have outlined six recommendations below for an effective implementation. Activities related to concepts of entrepreneurial processes, entrepreneurial traits and behaviors, financial literary, business foundations, and risk management are included in the curriculum and are consistent with the National Content Standards for Entrepreneurship Education [21].

Fig. 1 The pet plaza

4.2 Components of the Camp

4.2.1 Group Size and Diversity

We recommend limiting groups to two or three members. This recommendation is consistent with research on the most effective cooperative learning groups [47, 48]. There is enough work to keep the participants busy and many times, the team needs to divide the work amongst the group members to get everything done within a week. Participants select their groups based on the pain point they want to solve. Some are passionate about the problem that they are solving while others are more interested in working with their friends.

During the camp experience, participants are exposed to other campers with various strengths. Each participant is equipped with a unique set of skills, but one set of skills does not guarantee success. For instance, someone who is artistic may be enthusiastic about creating a marketing campaign and creating a logo for the product or producing a commercial. A participant who has more developed analytical thinking skills may have more of an affinity for identifying the stages of developing the product and compiling all the components of the project. Doing

Fig. 2 Sweat shopper

mathematics and applying engineering and science concepts are not the only important disciplines, but participants may discover that communication and creativity are also essential aspects to sell their idea to others.

4.2.2 Flexibility with Resources and Time

We found that with each iteration of the camp, both facilitators and participants became more ambitious with their choice and use of technology. When we implemented the first summer camp in 2014, participants required a great deal of assistance with video editing. They created tri-fold posters with markers rather than using digital tools and 3D printing was something that they only saw in our presentation. Within a few iterations, participants began creating computer-aided design (CAD) drawings for their 3D printing and videos for commercials that were edited on their phones without any assistance. Participants also customized their posters using computer software which allowed them to insert graphics and professionally share their concepts. On one occasion, facilitators invited local professionals to the camp to present a workshop on 3D printing. However, instead of presenting to the whole group of campers, the session evolved into a one-on-one and small group assistance session as the campers began to show their preliminary work to the professionals and asked for suggestions. Facilitators who are flexible and open to opportunities may find that new opportunities become available to all.

Our published curriculum suggests having the participants create television commercials as a way of learning about marketing products, but even marketing modalities have evolved, as well. Participants may choose to use influencers on YouTube, Twitter, or Tik Tok as part of their marketing plan along with or instead of using television commercials.

4.2.3 Ensuring Realistic Expectations

The facilitators have found that some participants may want to create a working prototype or model of their idea. However, with the compressed time of the camp, this is not always feasible. Instead, we have had participants consider communicating their ideas in more abstract ways. We have them consider what would be the best way to represent their idea given the constraints. For instance, if the participants are developing a smartphone app, instead of creating the complete, functional app, we might have them demonstrate the concept through pictures showing how each screen would appear to the user on the user's phone. Another area where participants' expectations may be high, but time will not allow for perfection, is the creation of marketing components, such as television commercials. Participants have had to modify their initial video plans once they began production, realizing time and resource limitations.

4.2.4 Creating an Environment for Exploration

We have hosted our summer camp at a university with its own Makerspace where the participants had access to 3D printers, green screens, poster printers and craft items to build models and/or posters. We also had access to employees of the Makerspace who knew how to operate the equipment and answer any questions about them. However, a formal Makerspace environment is not necessary to implement a successful camp. A "low tech" camp environment can easily be created by assembling recycled materials such as water bottles, milk cartons, and newspapers along with clay, markers, crayons, paint and paper. The participant's creativity will provide the rest.

4.2.5 Revising an Existing Product as an Option

Participants' product ideas do not have to be original; making a current product better can be just as effective. For instance, a team may decide to improve a backpack or a phone app instead of creating a new, innovative product.

One product design strategy that can be shared with a team that is being encouraged to improve a product is the Minimum Viable Product (MVP) strategy developed by Henrik Kniberg [49]. In this strategy, given limited resources, the inventor shares with customers a version of the product that has just enough characteristics of the actual product that the customer can provide feedback on the product. For instance, an inventor who is interested in creating a product to improve transportation may present a potential consumer with two tires. The customer provides feedback about the product and the inventor then creates a skateboard. The inventor works through each different iteration using feedback from the potential consumer to eventually create a car. However, he will get there faster if the inventor modifies the skateboard rather than the tires. Using this strategy, the participant needs to determine what type of prototype will obtain the most helpful feedback that can be used to improve the product for the next iteration.

Two alumni of our university used the MVP strategy to improve their product. They invented a product called Saucemoto [50], a device that can be clipped onto a car's vent and intends to solve the problem of dipping fast food into a sauce container with only one hand. The inventors visited our camp and shared how their original creation only allowed the user to use one type of container. However, after customer input, they realized that in order to grow their market share, they would have to design something that would fit many containers. Just like the skateboard that was refined by consumer feedback by disappointed customers, the inventors of Saucemoto refined their invention in order so more customers would be satisfied. Young participants can be encouraged to refine a product based on unfavorable feedback in order to reach a larger market.

4.2.6 Problem-Solving and Perseverance

Problem-solving is a main component of the camp. Not only did the participants develop a solution to a pain point, but they were also resourceful and demonstrated persistence when working through obstacles as they arose in the design process. The participants were adventurous and eager to try new things. When they came to an obstacle, they either worked through it or changed course. It was not uncommon for a participant to change their product mid-way through the camp and still provide a presentation for the Sharks at the end. Problem-solving and the perseverance to see one's problem to the end are skills and habits of the mind that are incorporated within the Mathematical Practices the U.S.'s national Common Core Standards for Mathematics [51]. The Mathematical Practices are skills, habits, and strategies that are intended to pervade all of elementary and secondary school math classroom experiences.

5 Extending to Teacher Education

Traditional teacher preparation programs do not often expose preservice teachers to the work of engineers and entrepreneurs. Therefore, they may not have the background knowledge and skills to implement engineering or entrepreneurial education in their classrooms [52, 53]. In order to expose teachers to understand who engineers and entrepreneurs are and what they do, we extended modified versions of the camp to primary and secondary pre-service teachers through their teacher preparation coursework. These interventions provided pre-service teachers with innovative ways to look at their content while exposing them to engineering and entrepreneurial mindsets. Teachers and pre-service teachers were engaged in the opportunity to implement real-world problems into the classroom along with an introduction to engineers and entrepreneurs who do this type of work.

In designing the pre-service teacher curriculum, we used the results from the evaluation of the teacher institute. Teachers who participated in the 2019 Summer teacher institute tested the curriculum in their school setting and reported in focus groups and surveys that it provided an organized and enriching framework to teach an interdisciplinary unit. This is because of the apparent connections between engineering and an entrepreneurial mindset and the opportunities to integrate science, social studies, language arts and mathematics. One teacher participant, an engineering teacher at a local STEM middle school, shared that the curriculum added an aspect to his class that many students found engaging. He said that just solving the problems was interesting enough for some students. However, when introduced to the idea that a solution could become a product and eventually a business, he found an added aspect of motivation for the students that were not previously there.

6 Going Forward

This chapter presented an overview of the Think Tank to Shark Tank program, which provides a unique curricular experience that engages students in real-world problem solving. Our goal of developing an engineering-based curriculum for young learners took on a new purpose when we integrated civics-based concepts of entrepreneurship into the curriculum. The informal education setting enabled us to blend these into a cross-curricular curriculum that is engaging, creative, and analytical. The result is an integrated curriculum that increases participants' understanding of engineering design concepts such as constraint and iterative design and also helps them develop an entrepreneurial mindset. Our implementation, reflection, and revision process with youth, pre-service teachers, and in-service teachers helped refine the program and reinforced the need for this curriculum.

Just as the camp participants revised and refined their inventions, this curriculum has been revised and refined based on feedback from teachers who reviewed and piloted the curriculum. The materials have been developed at a reading level for middle grades (ages eleven to fifteen) for use in formal and informal educational settings. We believe that after modifying the materials according to the ages of the audience, they can be used with young inventors of earlier grades as well as the later ones. However, integration into the secondary classroom may require specific adjustments in order to make the materials fit within those teachers' timeframes and curriculum.

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8 Educating for STEM: Developing Entrepreneurial Thinking in STEM (Entre-STEM)

Briga Hynes, Yvonne Costin, and Ita Richardson

> *Don't let anyone rob you of your imagination, your creativity, or your curiosity. It's your place in the world; it's your life. Go on and do all you can with it and make it the life you want to live.*
>
> *Mae Jemison, first African American woman astronaut in space*

Abstract

The events across society and business influenced by COVID-19 demonstrate that we live in a volatile and uncertain world. Whether events are shaped by the pandemic or other crises, digitalization, political instability, economic downturns, and a globally stretched healthcare system, each requires significant knowledge of science, technology, engineering and mathematics (STEM) to solve problems. In the face of unprecedented challenges and opportunities, there is a dissolution of the traditional silos within the technical and scientific disciplines, and further between scientific knowledge and transferable skills such as creativity, innovation and problem solving. Thus, learning for and in STEM will need to go beyond mere transmission of knowledge within STEM disciplines to the possession of transferable skills of creativity, ingenuity, and the

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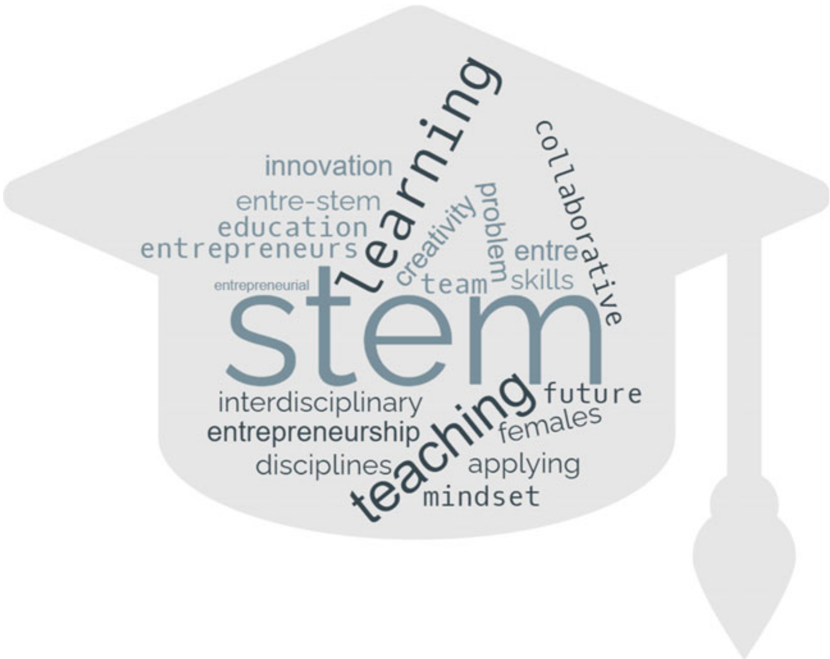
ability to work collaboratively. A realistic understanding of the broader business, social and ethical contexts within STEM will be required. Our findings propose an Entre-STEM unifying framework for use by a range of STEM stakeholders ranging from educational institutions, policy makers, educators, and funding agencies as it provides a common baseline to work from and enables more consistency in guiding programme design, implementation and evaluation. We suggest that Entre-STEM is a means of achieving this, delivering on the correct mix of technical knowledge in an applied context-relevant manner.

Graphical Abstract



Keywords

Problem based learning · STEM · Entrepreneurship · Entre-STEM

1 Introduction

Advancements in automation, digitalization and globalization are characterized by the fusion of the digital, biological, and physical worlds. Innovations are being created at a previously unparalleled rate giving stronger priority to science, technology, engineering and mathematics (STEM), solving unpredictable economic and societal challenges in an agile and responsive manner. This need has accentuated during the COVID-19 pandemic, further highlighting the need for STEM graduates who have the interest and ability to work collaboratively with non-STEM disciplines to be creative and innovative.

Consequently, educators need to consider how to educate for applied and transferable STEM workplace skills such as creativity, innovativeness, opportunity identification, cultural awareness, collaboration, and problem solving. When such skills are coupled with technical STEM education, they provide powerful lifelong skills for personal, professional growth and success. Integrating entrepreneurial learning with STEM in a seamless manner is an impactful means of equipping students with applied and transferable skills. Presenting STEM students with an integrative cross-disciplinary perspective enables them to think critically about STEM as a source of innovation, and has the potential to address economic, socio, geopolitical, environmental, and societal challenges.

This chapter is placed at the intersection of the growing literature on entrepreneurial learning and its relevance to STEM disciplines. We discuss the increasing imperative for including STEM learning that is future-fit for the ever-changing workplace needs. We critically reflect on the responsiveness of educators and STEM curricula to meet the needs of business and society. We present a discussion on why students view STEM as challenging, the gender disparity biased towards male students and the disproportion of learners from lower socio-economic groups pursuing STEM subjects. This provides useful information on the perceptions of STEM as potential barriers to participation. We combine insights from the literature on both STEM and entrepreneurial learning to determine their alignment. We review how they, when merged, enhance how STEM students can broaden their knowledge and skills to leverage the potential of STEM beyond technical subject knowledge, and present how this generates mutual benefits for the broader entrepreneurial learning stream.

We demonstrate examples of STEM Entrepreneurial educational initiatives and highlight the importance of educators adopting a novel outside-in perspective, collaborating with STEM stakeholders to inform and collaborate in the design and delivery of curricula. We conclude the chapter with the presentation of an Entre-STEM framework. This can be used to guide the development of Entrepreneurial STEM educational initiatives for the ever-changing STEM industry and societal needs.

2 Conceptualization of STEM Education

Research suggests that future workers will spend more than twice as much time on job tasks requiring science, mathematics and critical thinking [1, 2]. This has the effect of STEM gaining an increased focus and priority in industrial, educational and future skills policies e.g. [3] and in programmes such as the European Union Horizon 2020 funding programme [1]. Taylor [2] echoes this sentiment proposing that for a country to meet the basic needs of its people, the teaching of science is a strategic imperative and during the COVID-19 pandemic, the demand for STEM graduates has never been more urgent. This is consistent with the EU forecast which indicates that employment in STEM-related sectors is expected to rise by around 6.5% between now and 2025 [4]. Similarly, according to the US Bureau of Labor Statistics (BLS) [5], employment projections for STEM show an expected growth by 8% percent by 2029, compared with 3.7% for all occupations [6].

While there is a consensus on the increasing demand for STEM graduates across a range of growth sectors and role types, employers are currently facing a skills gap surrounding STEM-based job roles. We suggest that a number of issues are worthy of debate in trying to understand the root cause for this, thus guiding remedial action to increase recruitment and retention of students to STEM. The perception of STEM and the understanding of what constitutes a STEM occupation have varying interpretations by stakeholders such as students, parents, educators, and practitioners. The descriptors or definitions of STEM can be restrictive if focusing on specific types of roles as opposed to presenting how the STEM disciplines have potential to contribute beyond that discipline, for example, STEM careers for commercial and societal benefits. There is little discussion on the possibility of creating one's own STEM role, which would increase attractiveness for those who may not want to work for someone else or who have STEM ideas that can form the source of a new business. Thus, we highlight the importance of STEM entrepreneurial mindsets and behaviours.

Another issue compounding the supply deficit is the relatively low participation of females in STEM. STEM stakeholders such as students, academics, researchers, employees, and entrepreneurs are highly gender skewed in their composition [7–10]. The reason for the imbalance relates to social and cultural factors [11], such as experience, educational policies, and cultures of gender inequality [10, 11]. Kushel et al. further indicate that the traditional male orientation stereotyping of STEM, a gender-socialized belief system, and a lack of female role models contribute to the lack of females participating in STEM [10]. The lack of STEM 'identity' by female students from disadvantaged socio-economic school and home environments needs to be remedied in order to encourage, enable and support females from disadvantaged groups to feel confident in viewing STEM as a career path [12, 13]. This points to the perception of STEM in that it may be somewhat elitist and male dominated, and therefore too far reaching for females and individuals from marginalized groups. Furthermore, in Ireland, in 2019/2020, while 53% of those enrolled in Natural Sciences, Mathematics and Statistics in third-level colleges are women, only 17% of those enrolled in Information and Communications Technology and 19% of those enrolled in Engineering, Manufacturing and Construction are women [14]. We therefore have particular concerns regarding the gender balance of those in Technology and Engineering (the 'TE' of 'STEM').

The promotion of role models and the creation of new equitable stereotypes of STEM supports such as mentoring, coaching, and networking need to become more realistic enablers for female STEM students. The role of mentoring and competency development was found to be positive, providing encouragement for females in the traditionally male dominated technology sector. For instance, Orser et al. found that while mentoring was a frequently used response strategy guiding females in their career challenges, this was not the same for females in the majority of the technology sectors as there is a scarcity of suitable women mentors [15]. This scarcity also applies to the lack of mentorship opportunities for female STEM entrepreneurs.

Furthermore, the speed of graduate output is not keeping pace with the rate of jobs being created, and this has been accentuated during the COVID-19 pandemic. This leads to a discussion on how educational institutions can increase the speed of supply whilst not compromising on the quality of the graduate and ensuring that graduates possess the correct balance of the 'right' type of knowledge, both theoretical and applied.

STEM education has largely been inclined toward a didactic teaching pedagogy focusing on memorization and recitation of information [16] and siloed into a narrow field of scientific enquiry which does not provide learning experiences that appropriately engage, motivate, and prepare students for STEM careers. Furthermore, the research by [17, 18] questions the relevance of and if the current traditional methods of delivery of STEM education sufficiently prepares students for current and future STEM careers. To address this question and as a means of developing future fit STEM education, we undertake a brief overview of STEM education.

3 Integrating and Connecting STEM Education

STEM education is often presented as the subject matter within a specific discipline without explanation on how this has an impact on social, economic, technological and environmental areas of life. We promote enhancements to the didactic teaching pedagogy previously mentioned, supporting calls for integrative interdisciplinary approaches within each STEM subject, promoted by Fan and Ritz [19]. This was endorsed by Prasad [20] who further indicated that STEM education should integrate aspects of all four discrete disciplines of Science, Technology, Engineering and Mathematics, developing the skills required for process design through creativity, development of technologies and discovery of need-based practical solutions for applications within and across the disciplines. The need for stronger content integration exists at two levels—firstly, merging of different STEM content areas in an activity and secondly, using different STEM contexts to make the content more meaningful, as these disciplines are easier to comprehend by amalgamating the theoretical concepts with their real-world use cases [21]. This is often done, for example, through the use of a capstone project, where individual students or student teams bring together knowledge to develop a product, thus bringing together the concepts they have learned in previous years of study.

As the contexts of STEM are an ever-changing dynamic, an understanding of the elements of sector, industry drivers, and change agents are necessary for effective programme design and delivery [22, 23]. Therefore, to provide context relevant learning, Zollman [24] suggested that STEM education should orientate towards problem-based learning to enable students to solve real problems whilst developing a series of specific affective and procedural STEM skills. Sanders emphasized integration and coordination through applied or experiential learning by resolving real-world problems [25]. Bybee further promotes STEM education as a spectrum that has an "interdisciplinary nature" which should be delivered by solving real problems [26]. Building on this point, Baran et al. echoes the views of STEM education as an interdisciplinary teaching method that integrates science, technology, engineering, mathematics, and broader business knowledge, skills, and beliefs particular to these disciplines to bridge the context and content gap for application [27]. The challenge for educators is the ability to create or mirror the authentic complexity of the STEM world of work to provide that context-rich learning for application for instance through in-company projects, problem-based learning case studies, and competitions.

In summary, STEM is more than a set or grouping of subjects under a broad umbrella of the STEM acronym—it must extend beyond the notion of producing a disciplinary supply of students in Science, Technology, Engineering and Mathematics. STEM education should provide a lived, context-relevant experience embedded in the real world of STEM where disciplines are not isolated or siloed. Thus, the challenge is, in addition to educating students with a command of the discipline and technical knowledge, how to build in the softer skills of application, problem solving, and creativity and innovation. This can be achieved by merging and embedding the language, principles and practices of entrepreneurial learning as part of STEM education.

4 Infusing Entrepreneurial Learning into STEM—Entre-STEM

Entrepreneurial learning and education have historically been about possessing enterprising skills and competencies for starting a new business. Yet, more recently, the focus is on educating students to be enterprising, innovative, creative, opportunity sensing in an existing organization, and not just for start-ups [28–32]. There is an inherent logic in taking an interdisciplinary approach to educating students for entrepreneurship, and to this end entrepreneurial learning-based modules are often incorporated into non-business courses [33–39].

STEM education and entrepreneurial learning initiatives have inherent consistency in their goals and hold strong synergies in their implementation and offerings. Entrepreneurs translate innovative ideas and develop them into products and services. This process requires critical and creative thinking, problem solving, flexibility, resilience, a growth mindset and the ability to manage risk and uncertainty—attributes also integral to STEM careers and industry requirements. Developing entrepreneurial and creative thinking skills heavily relies on experiential learning acquired through learning from others, self-directed learning, reading, conversations, team learning, and critical self-reflection [40–42]. These are also called for in STEM education to meet changing STEM sector needs. Furthermore, entrepreneurial learning is a combination of learning a 'know-what' (knowledge) 'know-how (process)', coupled with 'know-who' (important stakeholders), three important dimensions which should be incorporated into STEM education and to effectively do so requires an evaluation of they can align and fit into current STEM curricula and pedagogies.

When applying entrepreneurship to STEM, educators must distinguish what is the correct balance of knowledge between 'expert' and 'local' that graduates require, irrespective of discipline [43]. The 'expert' dimension comprises explicit, theory-based, academic, professional, or scientifically based knowledge related to a particular discipline or profession. The 'local' dimension comprises forms of knowledge and ways of doing which are practice-based, deriving from experience and problem solving in a specific STEM context. Thus, delivering entrepreneurial learning to STEM students requires a paradigm shift from the prevalent "transmission" model of education, "*where pre-existing fixed ideas are transmitted to the learner*" [44, p. 194] to a teaching approach that is conducive to achieving the high-level skills, knowledge, life-long learning skills, and appropriate personal qualities [31, 45–49].

Effective entrepreneurial learning is based on creative partnerships between academics, learners and practitioners, and is supported by appropriate theoretical immersion (explicit knowledge) and entrepreneurial exposure (tacit knowledge) [50]. Given the focus on applied learning and ensuring that STEM education is constantly up to date with changing STEM sectoral needs, this collaborative and partnership approach is an effective means of ensuring the currency of STEM education.

Therefore, we conclude that STEM should be viewed as a delivery philosophy or a methods approach that integrates within STEM disciplines and across disciplines in an applied industry-relevant manner. Entrepreneurial learning approaches create this setting for STEM, providing a scaffolding on which to incorporate authentic problem-based experiential learning that is both content- and context-relevant for changing STEM career paths. Furthermore, the merging of STEM and entrepreneurial learning resonates a collaborative outside-in view as it works with stakeholders including industry, learners, educators, and policymakers.

5 Entre-STEM Educational Initiatives

A number of Entre-STEM (Fusing of Entrepreneurship and STEM) related initiatives have been implemented at the University of Limerick (UL), Ireland across the categories of education, research and commercialization, and student life. These all adopt an interdisciplinary approach, involving external collaboration and interdisciplinary team teaching and student engagement. These Entre-STEM learning initiatives are presented in Tables 1, 2 and 3 with subsequent evaluation to ascertain their strengths and areas for further development.

6 Education Initiatives

This section evaluates a range of Entre-STEM education initiatives which were implemented in seven modules across undergraduate, postgraduate and teaching collaborations in UL. An overview of the module/programme, student profile, delivery and assessment methods applied are described in Table 1.

With regard to undergraduate programmes, which are in place over the last 20 years, 3rd and 4th year undergraduate students from STEM disciplines participate in entrepreneurial education modules in New Venture Creation, Enterprise Management & Growth and Small Business Consulting. The majority of STEM students completing these modules are male, reflecting the overall profile and cohorts of students in general completing STEM education. In the delivery of these modules, concerted efforts are made to create interdisciplinary collaboration between business and STEM teaching teams, albeit on an informal basis. That said, some challenges are encountered in that the traditional, often siloed, disciplinary faculty structures are at odds with the cross-faculty approach required to support effective interdisciplinary delivery. In our case, while the current undergraduate modules being offered yearly are not mandatory for all STEM disciplines, we are experiencing an increase in the number of STEM students opting-in to such modules. Additionally, there are new STEM programmes who wish to offer entrepreneurship modules to their students, pointing to an increased demand for entrepreneurial education across STEM disciplines. Concerningly, STEM students are typically not introduced to entrepreneurial learning until year 3 of their 4-year undergraduate programme. This reduces the far-reaching multidimensional benefits of entrepreneurial learning that extend beyond skills in setting up a business to those central to the generation of innovative solutions for existing organisations in the commercial and social domains, as these may be derived by introducing entrepreneurship modules at an earlier stage in undergraduate STEM programmes.

Feedback from undergraduate STEM students taking these modules highlight the positive benefits of their experiences in terms of "acquiring practical 'how to' knowledge", "enjoyed the learning by doing of applying STEM", "working with STEM companies", "solving undertaking assignments for companies", being taught "how to learn from making mistakes" and "the benefits of negative learning

Table 1 ENTRE STEM Education initiatives

Programme/module		Brief descriptor	Learner/faculty profile	Programme information	Delivery mode	Assessment	Partnership with and from internal or external groups/stakeholders
Undergraduate	New enterprise creation module	This module exposes students to the process of entrepreneurial and creative thinking and opportunity recognition, and the development of a Business Canvas to validate a new business idea. Delivery provides students with hands-on experience in the creation and validation of a new innovation. Students apply the knowledge they learn in the classroom to real-world business opportunities and subsequently develop entrepreneurial mindsets	3rd year students completing business studies; technology management; equine science; electronics; industrial biochemistry; product design & technology; food science & health; mobile communications and security	Ranging between 200 and 250 students	Interactive face to face lectures and workshops Problem-based learning	Team project and individual assignment	Entrepreneurs from all sectors as guest speakers Agency representatives and entrepreneurs judge pitching session
	Enterprise management and growth module	The aim of the module is to provide students with an understanding of what growth means for the small firm, the drivers of growth, strategies for small firm growth and the challenges of implementing growth strategies	4th year students completing business studies; biomedical engineering; aeronautical engineering; computer aided engineering and design; electronic engineering; equine science; manufacturing engineering; mechanical engineering	Ranging between 200 and 250 students	Interactive face to face lectures Problem-based learning	Team project & individual assignment	Entrepreneurs from all sectors as guest speakers

(continued)

Table 1 (continued)

Programme/module		Brief descriptor	Learner/faculty profile	Programme information	Delivery mode	Assessment	Partnership with and from internal or external groups/stakeholders
	Small business consulting module	This module introduces students to the principles and processes of management consultancy and provides them with the opportunity to adopt the role of a professional management consultant to a small firm context. The module develops knowledge and transferable skills in project management, people and team management, scenario planning, strategy development and implementation, communication and presentation skills	4th year students completing business studies; food science and health; civil engineering; equine science; electronic engineering; industrial biochemistry; wood science and technology	Ranging between 200 and 250 students	Interactive face to face business consulting clinics Experiential/action-based learning	Team project and individual assignment	Industry partnerships Entrepreneurs from all sectors as guest speakers
Postgraduate	Master's in international entrepreneurship management MP6031: establishing new ventures	This module develops entrepreneurial creativity, awareness and specialist knowledge to help establish, manage and grow innovative new ventures across a variety of industry settings, incorporating a range of in-company projects to give a 'real	Postgraduate students completing business studies; civil engineering; design for health and wellbeing	Range between 15 and 20 students; diverse backgrounds in terms of educational disciplines and previous work experience	Interactive face to face Experiential/action-based learning	Team project and individual assignment; Interdisciplinary teams of civil engineering; business; and health and design wellbeing	Industry partnerships Entrepreneurs from all sectors as guest speakers

(continued)

Table 1 (continued)

Programme/module		Brief descriptor	Learner/faculty profile	Programme information	Delivery mode	Assessment	Partnership with and from internal or external groups/stakeholders
		world' experience. Participants explore their own entrepreneurial potential and prepare an investor-ready business plan					
	Master's in international entrepreneurship management & software engineering	This programme develops entrepreneurial creativity, and awareness amongst graduates from Computer Systems, Computer Science, Computer Applications, Software Engineering and Applied Mathematics programmes who are considering business start-up or careers in companies which focus on software innovation. Expertise in both computing and entrepreneurship disciplines to ensure students obtain a more enriched and holistic industry ready educational experience	Postgraduate students completing business studies & software engineering	Ranging between 3 and 5 students	Interactive face to face	Team project and individual assignment; interdisciplinary teams of software engineering and business students	Interdisciplinary collaboration between the Kemmy Business School and the Faculty of Science & Engineering

(continued)

Table 1 (continued)

Programme/module		Brief descriptor	Learner/faculty profile	Programme information	Delivery mode	Assessment	Partnership with and from internal or external groups/stakeholders
Teaching collaboration	Internal collaboration	Teams of teaching faculty are formed to integrate and co-design modules and programmes which reflect best practice and pedagogy across both business and STEM disciplines	Teams of teaching faculty and programme directors	Ranges between 3 and 5 faculty members	Teaching team meetings held at the start and end of semester	Annual course review	Kemmy Business School School of Science & Engineering
	External collaboration	Industry experts; government support representatives are invited to become programme course board members to inform and assist in programme design that meet industry sector needs Client companies are also invited to participate in the business consulting programme where students solve real life problems for them	Industry experts; government support representatives	2 industry experts sit on the course board 10–15 client companies participate in the business consulting programmes annually	Course board meetings held at the start and end of semester Ongoing engagement throughout the semester with both faculty and students	Annual course review Debrief with client companies at end of semester	Industry experts

Table 2 ENTRE-STEM research and commercialisation and institutional supports

Constituent parts	Programme/initiatives	Brief descriptor	Learner/faculty profile	No. of students and ratio of male/female	Delivery mode	Assessment	Partnership with and from internal or external groups/stakeholder
Research & commercialisation collaborations & support	Entrepreneurial, creative & innovative thinking for researchers	Provides students with an understanding of the importance of, and the principles underlying creative thinking, problem solving and innovation as they apply to research in different contexts; adds value to research by evaluating the process of commercialization	Ph.D. students—background in Science, Engineering, Mathematics, Financial Maths	34–62% male and 38% female	Blended online learning	Team project and individual assignment	Science Foundation Ireland; Industry representatives Guest speakers
	Research as an Innovation workshop	The aim of this workshop is to explore research as an innovation and the steps involved in commercializing research and sourcing funding	Ph.D. and post Doc and researchers working in research centers	17–70% were male and 30% female	Interactive and guest speaker	None	UL human resource, UL research office and the Kemmy Business School
Institutional supports	Technology Transfer Office (TTO) Nexus Innovation Centre STEM related research centres	Institutional supports develop innovative activity through the commercialisation of the university's expertise for the benefit of UL and the wider community	Ph.D. and post Doc and researchers working in research centers	Unknown	Supporting commercialisation through research, securing intellectual property, and attracting investment	None	Nexus Innovation Centre Enterprise Partnerships Research Centres (e.g. Epi Stem National Centre; Lero; Mathematics Applications Consortium for Science and Industry (MACSI); CONFIRM

Table 3 Student life ENTRE STEM initiatives

	Programme/initiatives	Brief descriptor	Learner/faculty profile	Events	Partnership with and from internal or external groups/stakeholder
Student life	Entrepreneurship Society	The Entrepreneurship Society is for like-minded students to gather and network, organize events filled with interesting speakers, and participate in mentoring and coaching programs. Members of the society help with all aspects of entrepreneurship, including increasing entrepreneurial confidence; access to networks; developing entrepreneurial leadership skills; Corporate and social responsibility; tenacity; start-up knowledge and resources	All undergraduate, postgrad students are invited to join	Competitions Conferences Enterprise week hackathons, start up bootcamps, workshops	Kemmy Business School UL Student Life Cross Disciplinary Faculty
	Enactus social entrepreneurship	Enactus UL develops projects that help the lives of people in our community, working to create a better, more sustainable world. Students work as a team, combining all of their skills and talents across various disciplines	Interdisciplinary students work as a team, combining all of their skills and talents across the various disciplines to create projects that are making a difference	Each year student teams compete against 9 other national colleges and if successful compete on a global level	Kemmy Business School UL Student Life Interdisciplinary Faculty
	Women in STEM2D	Aim is to empower and support female students studying subjects within the STEM discipline. This society recognises the power of diversity and strive to foster an open and inclusive culture in STEM			

(continued)

Table 3 (continued)

	Programme/initiatives	Brief descriptor	Learner/faculty profile	Events	Partnership with and from internal or external groups/stakeholder
		(https://ulwolves.ie/society/wistem2d). Membership is open to all, regardless of gender to encourage an inclusive environment. This provides members with enhanced opportunities to grow as professionals, leaders and individuals and by driving the attraction, development and retention of talented women within STEM			
	Entrepreneurship Boot Camps	The aim of the entrepreneurship boot camp is to create a student mindset that is solution focused, providing knowledge and skills to design innovative solutions that result in new business opportunities	2nd level secondary school transition students	Students practice their knowledge in purpose-built studios, workshops and computer labs; receiving feedback from experienced mentors and industry experts	Higher Education Authority Kemmy Business School Nexus Innovation Centre Local Schools

experiences" which build their confidence and resourcefulness. This learning extends STEM students beyond their quantitative, technical and scientific 'comfort zone' to the more qualitative, less-structured learning environment where there is no one right or wrong solution.

With regard to postgraduate programmes, our experience commenced with the development of the MSc. in Software Engineering and Entrepreneurship based on the framework presented in Hynes and Richardson [34]. This programme ran for three years (2014–2017) albeit with low participation rates. Students who graduated progressed to successful careers very quickly. Upon review of the programme, a lack of interest amongst students was apparent due to the low number of applications across the three years. Perhaps this was due to a lack of understanding by potential students, particularly from STEM programmes, of the benefits of participating in entrepreneurial education, stemming from the limited interdisciplinarity and exposure to entrepreneurial education in their prior education. The programme review also highlighted that modules came from two distinct disciplines, namely software engineering and entrepreneurship, with little or no integration between them—an issue for consideration in programme redesign. It is important to note no female students participated in this programme across any of the three years, mirroring the undergraduate trend of male students dominating information and communications technology disciplines. We know that there was, and still is, a need for software development companies to develop and grow. However, based on our experience gained through the MSc. in Software Engineering and Entrepreneurship, we question whether students who completed software engineering courses actually understand the importance of becoming educated in entrepreneurship techniques. Furthermore, many software engineering undergraduates at this time got jobs very quickly. Thus, any entrepreneurship possibilities would have to emerge from those employments through students utilizing entrepreneurial skills and competencies developed through the programme in a larger organization in an intrapreneurial capacity, rather than starting their own firms. Hence, it becomes important that the communication and marketing of such programmes highlights that STEM entrepreneurship learning and education has multiple outcomes for self-employment or intrapreneurial roles in existing organisations.

Our most recent postgraduate experience commenced in 2020 where students undertake two entrepreneurship-focused modules. This involves a collaboration between three programmes—the Masters in International Entrepreneurship Management, the MSc. in Civil Engineering, and the MSc. in Design for Health and Wellbeing. The purpose of this collaboration is to provide technical students with softer entrepreneurial and innovative skills for the exploitation of opportunities. It uses design thinking as a means of developing user applications from their technical knowledge. Furthermore, they need to comprehend the stages in moving from design thinking to the validation and commercialisation of technical ideas. They also need to understand the processes for use in existing organisations or in a start-up capacity. To develop this course, interdisciplinary consultation took place with the various programme directors involved on how to best design and fit the entrepreneurship modules into their programme in an integrated manner. There is a strong commitment by all programme directors to deliver on the module. However, some challenges have emerged, particularly with difficulties in finding time for students to work on interdisciplinary projects. Similar to other courses, a limited number of female students participated in the module as there were no females in the MSc. in Civil Engineering, whilst the MSc in Design for Health and Wellbeing programme showed a ratio of 70/30 (male/female).

Central to the design and delivery of the Entre-STEM interdisciplinary modules is the need for strong working relationships across faculties and with external stakeholders. Such relationships help to ensure that content is current and industry-relevant. For the programmes/modules listed, Table 1 shows internal and external collaborations and how these are managed. Internal collaboration is the central starting point where it is imperative that there is a genuine commitment by all faculties involved and that programme directors and module leaders are aligned in their communication, their expectation of what the module will deliver and the role of students in that process. This consistency and collaboration is important to ensure that students understand that teamwork and collaboration are part of the 'modus operandi' of the STEM workplace. External collaborations are important to inform programme content, to provide companies in which students undertake projects, and as a source of guest speakers and mentors.

We have experienced the positive impact of female role models for Entrepreneurship in STEM and thus, we carefully choose STEM role models and case studies which will generate empathy and realistic identity for students to emulate. Additionally, we have become increasingly aware of the importance of diversity. For example, the success of UL in achieving Athena SWAN Bronze Institution Award ensures that educational programmes include diversity (gender, ethnic group, economic and socio economic) of guest speakers, projects and module content.

7 Research and Commercialisation Initiatives and Institutional Supports

Recognizing the importance of STEM research for future innovations and solutions to global challenges, STEM researchers should have the skills and knowledge to investigate potential types of impact beyond technical knowledge which their research can have. This includes knowledge of the process involved in validating and commercialising research as a start up or spin out or as an internal innovation in existing organisations. To this end we have developed a number of Entre-STEM modules with the focus of demonstrating how science-driven solutions and successful research not only have huge potential to stimulate economies, but improve health, society, culture, public policy, the environment and the general quality of life and wellbeing of individuals. Table 2 describes these Entre-STEM initiatives and the linked institutional supports that exist to enable researchers to commercialise their research when bringing it from the lab to the marketplace.

7.1 Commercialisation and Research Initiatives

A novel industry and government-supported (through Science Foundation Ireland) doctoral training programme—the Ph.D. in Foundations of Data Science was launched in 2019. This programme provides students with an in-depth training in the fundamental data-science skills necessary to adapt to the way data and data-enabled technologies, such as artificial intelligence, are transforming the economy. It merges the horizontal themes of Applied Mathematics, Statistics and Machine Learning by applying them to real-world challenges across five vertical themes including Data Analytics, Privacy and Security, Health and Wellbeing, Smart Manufacturing and Networks. The suite of modules includes bespoke modules delivered by the Kemmy Business School on the topics of *Research Impact* and *Entrepreneurial, Creative and Innovative Thinking for Researchers*. These modules provide knowledge, tools and techniques on how research can have an impact on industry, the economy and society.

The outcome of this programme is to produce graduates who will become Ireland's future leaders, innovators, entrepreneurs and employers, thus very much encapsulating the Entre-STEM philosophy at researcher and post-doctoral level. The entrepreneurship modules, introduced in Year 1, are a mandatory part of the programme. This enables students to apply their learning to their other STEM modules and is particularly beneficial when students are on industrial placement. There has been a specific agenda towards gender balance (40% of each gender) on this programme, and of the 34 participating students currently, 13 (38%) are female.

In addition to formal programmes such as the aforementioned, the UL offers a range of workshops provided through the Human Resources Division, Research office and the Kemmy Business School on the theme of *Research as an Innovation*. These are available to all researchers and post-graduate students who are based in the University. Their aim is to provide researchers with an understanding of the potential to generate multiple impacts from research and to investigate if research has potential for commercialization.

7.2 Institutional Supports for Entre-STEM Researchers

Continuing the theme of collaboration is the recognition of the need for institutional support to expand and advance Entre-STEM research which is critical for expansion and sustainability of initiatives. Institutional support exists for students, academics and researchers to commercialise their products. This is done through the Nexus Innovation Centre, Technology Transfer Office (TTO), and various STEM-related Research Centres in Ireland.

7.2.1 Nexus Innovation Centre

This centre provides support and training to start-up companies, staff and students. Nexus is a purpose-built Innovation Centre located on the University of Limerick campus. The Centre is home to a variety of early stage and established start-ups comprising those who have spun-out from research, student entrepreneurs and independent start-up firms who require space to develop their businesses. Nexus provides extensive facilities including laboratories, dedicated office space, co-working spaces and administrative support. Additionally, the Centre offers a range of soft training support, mentoring, business development guidance, marketing, funding, pitching and commercial and IP expertise and assistance.

7.2.2 Technology Transfer Office

The Technology Transfer Office manages the commercial opportunities arising from the research activities of the university. It provides a range of supports, advice and training to enable the successful commercialization of research and technologies to address market needs for maximum societal and economic impact whilst providing a return to the university to further advance its research translation and impact mission. The TTO provides guidance Commercialization, process, intellectual property protection, licensing, creating a spin out company, legal issues to consider in commercializing research and an insight into the range of financial and non-financial support available. The TTO also manages all kinds of interactions with industry, funders, venture capitalists and academic collaborators.

7.2.3 STEM Research Centres

UL builds on its strengths in the areas of Materials, Advanced Manufacturing, Software, Health, and Applied Mathematical Sciences through dedicated funded research Centers. The following is a brief overview of some such centres:

- **Epi•STEM National Centre** has established a research base, consisting of a suite of programmes, projects and collaborations as a foundation for the implementation of medium to long-term strategies to address national priorities in STEM teaching and learning.
- **Lero**, the Science Foundation Ireland Research Centre for Software, is constituted of software engineering researchers from Higher Education Institutions in Ireland. Lero has many international and industrial based collaborators.
- **Mathematics Applications Consortium for Science and Industry (MACSI)** focuses on research in mathematical modelling and scientific computational analysts, working to resolve problems which arise in science, engineering and industry.
- **CONFIRM** is a Science Foundation Ireland research centre in Smart Manufacturing and Data Analytics focusing on specialist research competencies including product and process control, enterprise modelling and simulation, software systems, network systems and internet of things, robotics and control, and materials processing.
- **SSPC**, the Science Foundation Ireland Research Centre for Pharmaceuticals focuses on the development of innovative technologies to address key challenges facing the pharmaceutical and biopharmaceutical industry.

Faculty and researchers in these centres attend available workshops on '*Research as an Innovation'*. Additionally, they can obtain guidance from the UL Research office and from Entrepreneurship faculty on how to transition research for multiple impacts beyond publications.

Given the increasing focus and government expenditure on STEM-related research, we consider the researcher target audience is not given sufficient focus in the STEM educational discussion. Yet, they are charged with the responsibility for generating impact from research. We have received very positive feedback on the range of research Entre-STEM initiatives and suggest there is potential to develop and expand these further.

8 Student Life Initiatives

Acknowledging that important student learning takes place outside the classroom through peer and social learning between and from students, we promote the role of student societies as an impactful means of complementing and augmenting Entre-STEM in classroom learning. Across the university, various formal and informal Entre STEM initiatives have been established and promoted under the umbrella of student life category, including student societies, mentoring programmes, enterprise competitions, boot camps, and hackathons.

These societies extend an entrepreneurial mindset across the student and researcher population in the university, providing forums that expose them to entrepreneurial actions, opportunity identification and social innovation. Through competitions and hackathons, students immerse themselves in interdisciplinary teams, take on STEM entrepreneurial opportunities and generate networking options. Students often focus on the ethical aspects of Entre-STEM activities, learning the importance of viewing STEM beyond subjects and bringing actions that generate added value in social and/or commercial arenas.

The Entrepreneurship Society is targeted at like-minded entrepreneurial students who gather and network, organize events, workshops, guest speakers, and engage in mentoring and coaching programmes. Society members help with all aspects of entrepreneurship, including increasing entrepreneurial confidence, providing access to networks (both national and international), developing entrepreneurial leadership skills, introducing corporate and social responsibility, and providing start-up knowledge and resources. It also facilitates interdisciplinary teams, aiding in design thinking, developing and exploiting business ideas and opportunities (both commercial and social). It runs start-up boot camps, hackathons and submits ideas for entrepreneurship competitions. Further, it has a strong STEM presence. For instance, one of the winners in the UL Foundation awards this year was a student from an Engineering discipline. The co-director of the Student Entrepreneurship Society 2020–2021 is an engineering student, and the Student Society Committee comprises a number of students from Science and Engineering. The students are supported through faculty collaboration and expertise from Local Development Agencies, Financial Banks and the Nexus Innovation Centre.

STEM disciplines provide expertise and solutions that will contribute a more sustainable and inclusive recovery to the multiple business, social and environmental impacts of Covid-19 and to respond to the challenges of the United Nations' Sustainable Development Goals (SDGs) which are delivered through social innovation and the creation of social enterprises.

UL Enactus Social Entrepreneurship is part of Enactus, a global organization empowering third level students to become socially conscious leaders through the power of social enterprise and entrepreneurial thinking. The students display successful models of collaboration between students, academics and business leaders who are committed to solving challenges in local communities. They demonstrate in a very practical manner how future business leaders can extend beyond a purely financial bottom line to a triple bottom line to measure impact in terms of financial, social, and environmental benefits to the community. The annual social enterprise competition is supported by a selection of public and private sector large indigenous and multinational corporations.

In addition, a much-targeted society is Women in STEM^{2}D which aims to empower and support female students studying subjects within the STEM discipline —a typically male-dominated industry. This society recognizes the power of diversity and strives to foster an open and inclusive culture in STEM. Membership is open to all, regardless of gender, to encourage an inclusive environment. This provides members with enhanced opportunities to grow as professionals, leaders and individuals and by driving the attraction, development and retention of talented women within STEM. Industry collaboration and support are central to this Society's activities. Johnson & Johnson offers female students the opportunity to participate in the Women in Science, Technology, Engineering, Mathematics, Manufacturing and Design program (WiSTEM^{2}D), through which they award bursaries to STEM students in third-level education. To date, of the 2nd and 3rd year third-level STEM students, almost 200 students have participated. Through this initiative, students are paired with an employee from the company, and thus have the opportunity to discuss their future in STEM, including the fostering of innovative and entrepreneurial mindsets. The Chemical Engineering society is another student life initiative. This society seeks to unite disciplines and combine STEM knowledge across the university, thus providing a vehicle of engaging students in less formal, and more fun and personal development activities as a means of uncovering untapped Entre-STEM potential. In addition and similarly, entrepreneurship boot camps, where second-level students from local schools across Limerick participated in a five-day Entrepreneurship and Innovation in the Digital Age Bootcamp. The focus of this Bootcamp is to develop Transition Year students' entrepreneurial and innovative mindsets and grow skills in creativity, critical thinking, problem solving, opportunity recognition, communication and collaboration and teamwork. Students will work in teams to develop a new innovation for a commercial or social enterprise innovation and pitch their idea to a panel of judges on the final day of the programme.

9 Developing a Entre-STEM Framework

Based on our review and learnings of the range of Entre-STEM initiatives, we have developed an Entre-STEM framework. This framework addresses the deficiencies of the more didactic STEM learning moving it to a more engaged, industry led collaborative process where content and context are integrated to inform content and pedagogy. The proposed framework acknowledges that STEM education is not a "one-fits-all", and that the diversity of the STEM learner needs to be taken into consideration in the design of content and choice of pedagogy and assessment methods. The Entre-STEM framework, as presented in Fig. 1, provides an overview of the key constituents and stakeholders that require consideration in the development of Entre-STEM educational initiatives.

If we are to increase entrepreneurship in STEM, allowing for companies to be established, to innovate and to grow, we propose that undergraduate and postgraduate educators consider the Entre-STEM framework which we have developed. This contains five main factors (shown anti-clockwise in Fig. 1): student mindset and identity, learner profile, collaboration, innovation, and pedagogy.

9.1 Student Mindset and Identity

Students who attend our classes, regardless of the topic, come to us with a range of backgrounds, experiences and learnings which have provided pre-determined ideas

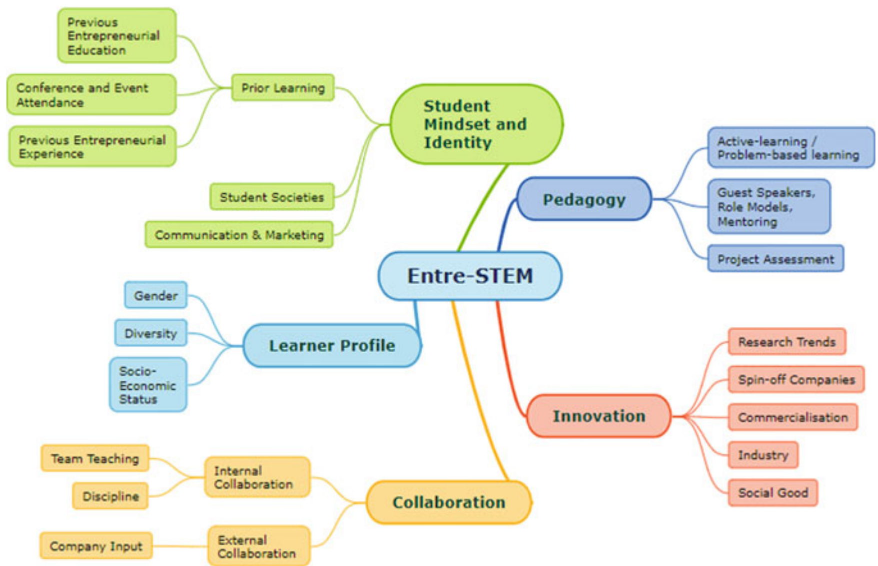


Fig. 1 ENTRE STEM framework

and expectations as to what education will deliver for them. Oftentimes, the Entrepreneurship in STEM class is one which is chosen by the student as they progress through their studies and may only be chosen where the student has some prior learning, be that through, for example, familial experience or having attended events about the topic. For students where entrepreneurial modules are mandatory, this lack of prior experience and of concept knowledge may result in a different learning experience. Thus, in the first instance, educators need to encourage potential students who do not come with prior learning to consider entrepreneurship topics. They need to communicate the potential to a larger audience, ensuring that students without an element of prior learning can become interested.

Additionally, once students attend class, the educator should be aware of the range of mindsets and identities of those who attend. They should consider both what has been brought by students to the class, and what they need to do to maximize the learning of their cohort. Given the diversity of the learner and the lack of knowledge by many students on what Entre-STEM entails, it is important that educators communicate the rationale for participating in such a module and secure early buy-in and commitment. This can be done, for instance, by providing examples of how it will increase employability options, how Entre-STEM can be an exciting career, and what personal and professional development is needed. The many benefits personal and professional of entrepreneur identity are developed through extracurricular student led initiatives such as Entrepreneurship Societies, marketing and promoting the Entre-STEM career opportunities with large and small firms which with reflections on prior entrepreneurial experiences or learning endorse the reality and attainment of impactful Entre-STEM career opportunities.

9.2 Learner Profile

We have previously discussed the importance of having diverse groups in the entrepreneurship classroom. Educators need to take this into account when teaching —how can they maximize the experience of diversity? For example, if one is setting up project teams, what traits need to be accounted for in teams? One may want to ensure that there is at least one female (and where possible more) student(s) on each team, and in addition to create and balance ethical, cultural and socio-economic diversity to mirror as much as is possible the characteristics of STEM student population. Where not possible it is worth having discussions with team members on the need for understanding diversity and inequity when developing Entre-STEM outcomes. If there are international students or students from different disciplines in a class, the educator may consider how teams should be structured in these cases. They could also consider the diversity of projects which are being done by students—they may decide that diversity of topic is an important element to consider. What is important is that the educator considers their classroom learner profile, providing an experience which ensures that the benefits of diversity are achieved to mirror the world of STEM research and workplaces. A suggested means of obtaining an insight into the prior learning or identity of the student is to have them complete an entrepreneurial knowledge and skills questionnaire prior to the first lecture. In our experience, this can provide baseline information to inform content, to enhance language and terminology used in module delivery and to decide on the type of problem-based learning activities to include in the module.

9.3 Collaboration

Given the interdisciplinary and applied nature of Entre-STEM, the design of appropriate educational initiatives should incorporate collaboration and co-creation. This collaboration should take place internally within the university between and within disciplines, with the research office and support offices and externally with public and private sector organizations and relevant professional organizations. In particular, because of the interdisciplinary nature of Entre-STEM, it is important that each relevant discipline is represented to the students. For example, in teaching Entrepreneurship in Software Engineering, students were provided with experiences and case studies from Software Engineering, and their final project was around the development of a Software Engineering business. In this, they used Entrepreneurship principles to develop Software Engineering innovations. Furthermore, teaching staff were drawn from both disciplines so that they were educated on a number of different viewpoints. We also highlight the importance of company input—students need to see where their education can lead, and how STEM companies can be developed through the use of entrepreneurial education and skills.

9.4 Innovation

Ultimately, the purpose of educating students in entrepreneurship is to bring them to a point of at least considering innovation and understanding innovation in its broadest sense. This is done by giving them the skills to move forward with their own innovative ideas, leading them to potentially either starting their own companies, or developing innovations within existing companies. Students need to develop a mindset that innovation is a process which can be applied to any discipline or context. Within many countries, government funding is provided for researchers to consider commercialization of research through spin out companies. For example, in Ireland, Science Foundation Ireland funds STEM research, while Enterprise Ireland provides commercialisation funding. For those students who do not start their own companies, the value of entrepreneurship knowledge and skills is also well recognised within larger established industries. For the Entre-STEM student, it is imperative that they are exposed to each of these types of companies in their education.

Given the increasing prevalence of the United Nations' Sustainable Development Goals as underpinning and informing all sectoral activities, STEM disciplines provide expertise and solutions that will contribute to a more sustainable and inclusive recovery to the multiple business, social and environmental impacts of Covid-19. They will also respond to the challenges of the United Nations' Sustainable Development Goals (SDGs) which are delivered through social innovation and the creation of social enterprise.

9.5 Pedagogy

To provide students with relevant entrepreneurship knowledge, educators must consider from a pedagogical perspective how they are going to impart this knowledge and make it relevant to STEM, taking account of teaching and learning approaches, strategies and assessment. Our experience has shown that the learning approach, along with the inclusion of experiential, problem, project and student based learning, active learning and design-learning, is important and central to effective and impactful pedagogy. This then provides students with the opportunity to, in some way, engage themselves in an Entre-STEM journey, applying STEM to the business world. Given that these various learning approaches significantly improve entrepreneurship skills, we recommend moving away from lecture-based teaching for these groups. These learning approaches position the educator as a facilitator rather than a teacher. STEM students must be facilitated in the move from a passive mode of learning to one in which they take ownership and responsibility for their own learning, and the learning of team members. It can be difficult for them to engage in a less structured learning mode—thus, they need assistance to take risks in learning and to learn to view negative learning episodes as important learning points. As part of the pedagogy, teaching and learning strategies are considered through the use of guest speakers and mentors. The value of introducing students to good and relevant guest lecturers and role models cannot be underestimated. Returning to both the diversity and gender discussion, it is important that, as educators, we set ourselves targets around this. We should work towards gender balance for each, where at least 40% of speakers and role models represent each gender. This sometimes takes some consideration and extra work, but it is imperative that this is done.

In using such learning approaches and strategies, it is important that the educator further carefully considers how they are going to undertake their project assessments. When designing assessment methods, it is important to be mindful that STEM students are likely to be less familiar or comfortable with unstructured assignments or project work and may be challenged by the idea that there is no one right answer. Thus, assessment requires both formative and summative assessment, allowing for process and outcome assessment, adding value for students.

10 Concluding Comments

This level of global disruption brought about by COVID-19 poses very significant challenges including unpredictability and large-scale problems. At the same time, it has the potential to create opportunities, particularly for the scientific domains to continue to innovate and meet the needs of the post-pandemic future. Consequently, educational institutions need to adopt the focus, content and delivery modes of Entre-STEM education. Entre-STEM education should follow intra and interdisciplinary practical activity and problem-based learning approaches to foster a deeper understanding of STEM disciplines. Entre-STEM education is about creating a mindset and a way of thinking and doing, using good practice, and applying entrepreneurial, innovative, and creative frameworks to STEM knowledge.

Whilst there have been advances in promoting entrepreneurial learning for STEM students, challenges still remain in implementation or delivery. We must ensure that it is engaging and that learning is applied in a real-world context so that students gain the softer skills required to be capable of transitioning or amalgamating the theoretical concepts with real-world applications. Given the ongoing calls for increasing education on the topic of Entrepreneurship in STEM, we have recognized that there is a lack of a unifying framework to guide educators on a best practice approach—therefore, we developed Entre-STEM. Thus, we highlight the components that require consideration in the design and delivery of 'fit for purpose' Entrepreneurship in STEM education.

Our review and analysis of the range of Entre-STEM initiatives demonstrates the complexity of its design and delivery, extending beyond the educator as there are institutional and resource issues that are required to support Entre-STEM educational offerings. Institutions must provide support for the creation of learning environments which embrace the complexity of the STEM world. This will encourage critical thinking and problem-solving and the opportunity to immerse and learn with and from STEM practitioners. Furthermore, schools and departments must move from a culture where they are concerned with promoting their own internal goals rather than accomplishing broader institutional purpose and realize that STEM does and should not be a one-department ownership. Interdisciplinary integration is central for this to work, and there needs to be collaborative team teaching and a presence by both disciplines when educating students. Students will then gain the benefit of interdisciplinary learning. It is important to ensure that students do not see Entre-STEM as an add-on to STEM, but rather, as part of how the STEM sector operates. Our proposed Entre-STEM framework contributes to theory and practice by bridging this gap. This framework, with its key factors, drives content and context. Furthermore, it points to topics for consideration in a tailored manner for institutional and programme context.

The Entre-STEM framework has use for stakeholders ranging across educational institutions, policy makers, educators, and funding agencies, as it provides a common baseline to work from and enables more consistency in guiding programme design, implementation and evaluation. It also provides suggestions on delivery methods which resonate with applied and experiential learning and provides educators and students with a broader Entre-STEM network with whom they can engage for further learning. This collective approach demonstrates to each stakeholder, whether internal or external, and to the educational institution, the role they can play in contributing to a more integrated practice-based learning of Entre-STEM. Furthermore, it enables external stakeholders to participate in the design and delivery of programmes to ensure that graduates are gaining the correct applied learning opportunities.

This framework acknowledges that Entre-STEM education is not a one-fits-all scenario—rather it is institutional, resources and learner driven. Therefore, it provides for an ‘a la carte’ approach which can be customized to accommodate different groups and resource (people and financial) constraints.

Finally, Entre-STEM learning should not be confined to formal curriculum modules. Institutions of higher education should endorse the provision of informal and extracurricular initiatives and student societies as together and cumulatively they build a stronger culture of Entre-STEM. This should embrace the continuum of the journey from undergraduate, postgraduate and Ph.D. student—Ph.D. students have been afforded little attention in the literature to date and are worthy of greater inclusion in Entre-STEM educational offerings. This, we believe, will generate a more inclusive Entre-STEM ecosystem.**Authors’ Quote**: *There are many paths which lead to the one end-goal—a creative and entrepreneurial mindset is a crucial navigating compass to arriving at your best end goal.*

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Fostering an Entrepreneurial Mindset Through Project-Based Learning and Digital Technologies in STEM Teacher Education

9

Isha DeCoito and Lisa K. Briona

> *If you always do what you always did, you will always get what you always got.*
>
> Albert Einstein, Genius

Abstract

This chapter explores the potential of STEM project-based learning (PBL) and digital video game (DVG) creation to support and integrate STEM and entrepreneurial competencies in teacher education. Specifically, the authors present and describe three STEM projects and three DVGs, with a focus on entrepreneurial and STEM skill development and growth mindsets in a curriculum and pedagogy methods course in STEM education. The authors maintain that in order for teacher candidates (TCs) to develop entrepreneurial and STEM literacies, they need to integrate entrepreneurial and STEM content and pedagogical knowledge to be able to effectively instruct, assess and design STEM curricula that can foster entrepreneurial skills and support future generations of learners. TCs engaged in several tasks utilizing principles of inquiry, design-based and experiential learning, and reflective practice that fostered entrepreneurial awareness and enhanced entrepreneurial competencies. Entrepreneurial growth is evident in the projects, as TCs provided extensions, thus creating value-added content beyond the scope of the initial assignment. These value-added extensions were also catalytic in developing an entrepre-

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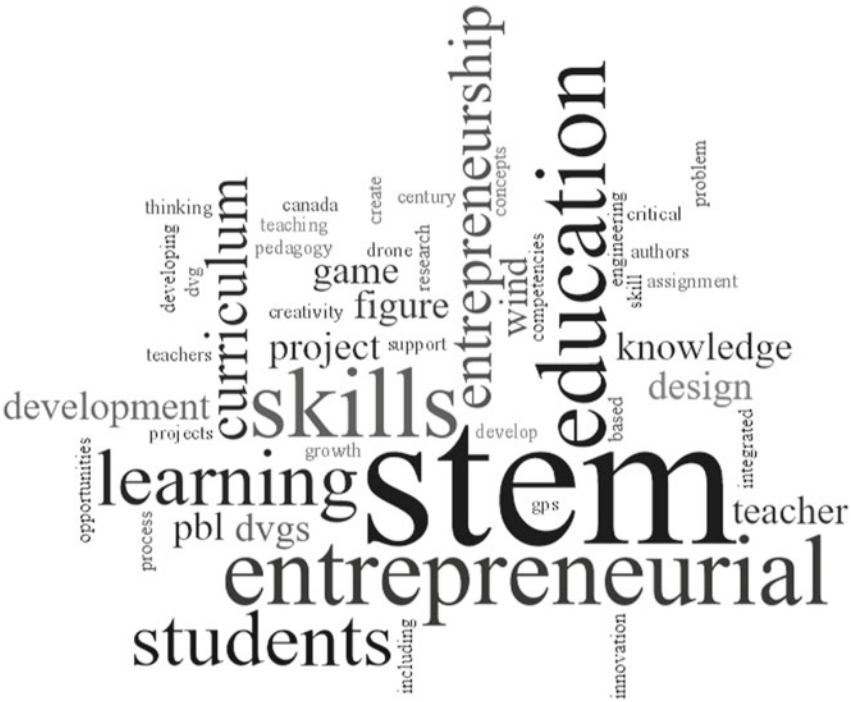
neurial growth mindset. The authors contend that teacher education programs, professional development initiatives, and key stakeholders have a pivotal role to play in developing and supporting students' STEM and entrepreneurship competencies.

Graphical Abstract



Keywords

Innovation · Curriculum · Competencies · Creativity · Perseverance · Motivation · Self-regulated · Experiential learning · Design-based learning · Careers

1 Introduction

Entrepreneurs are the backbone of economies. According to Lin et al. "in OECD countries, small and medium-size enterprises (SMEs) account for about 99% of firms and 70% of all jobs" [1, p. 1]. Despite the importance of entrepreneurship to economies, in Canada it remains a difficult and stressful career, with one-third of all new businesses failing within five years and only one in two companies still open after ten years. Moreover, in OECD countries and others, governments face challenges of low growth, weak trade and investment, and rising, or persistently high inequality [2]. Over the past 20 years, fewer and fewer Canadians have been pursuing entrepreneurship opportunities. For example, between 2012 and 2016, the average number of SMEs created annually was 95,940 and the average number of businesses that disappeared annually was 90,120 [3]. Notwithstanding this lag, Canada is currently undergoing an entrepreneurial resurgence, with 44,700 Canadians starting a business in 2018 [4]. The Business Development Bank of Canada notes that Canada is one of the most entrepreneurial nations in the world, with "more than 1.1 million small and mid-sized businesses, which account for 90% of all private sector jobs, employ 10.7 million Canadians, and contribute roughly $1 trillion to Canada's gross domestic product" [4, p. 1]. The face of entrepreneurship in Canada reflects a younger demographic, including members of generation Z; baby boomers; newcomers to Canada; and women. There has been a significant increase in female entrepreneurs from 49,000 in 1976 to 241,000 in 2018, with parity between male and female entrepreneurs by 2030, if these trends continue [4].

Despite the aforementioned resurgence and prediction, one may query as to what skills successful entrepreneurs possess and when and how should these skills be taught? A recent study by the Institute for the Future predicted that 85% of jobs that will exist in 2030 have not been invented yet! [5]. In terms of entrepreneurship, this means that schools cannot train explicitly for a given career; rather, they must give students the tools to be responsive to whatever the future might bring. In Canada, for example, the Science, Technology and Innovation Council's *State of the Nation* report highlighted Canada's lagging business innovation performance [6]. One of the recommendations of the Council focuses on educational institutions and their role in growing Canada's knowledge and talent advantages by "working to develop curricula that better integrate STEM knowledge with a broader set of business, entrepreneurship and commercialization skills that nurture creativity, intelligent risk taking and ambition" (as cited in [7, p. 115]). This is reinforced by Winkler, Troudt, Schweikert and Schulman who maintain that innovation is central to STEM areas, and that government investment in STEM is essential for increasing the number of graduates with STEM degrees [8]. This heralds the need for STEM education to include different STEM and non-STEM disciplines and curricula within a business and entrepreneurship context.

In this chapter, the authors focus on teacher education in STEM, specifically two assignments in the Curriculum and Pedagogy in STEM Education course in a teacher education program in Canada. The authors contend that in order for teacher candidates (TCs) to develop entrepreneurial and STEM literacies, they need to integrate STEM and entrepreneurship content and pedagogical knowledge to be able to effectively instruct, assess and design STEM curricula to foster entrepreneurial skills in their students. Thus, opportunities and learning environments must be created for TCs to experience and integrate entrepreneurial and STEM skills. In the context of this chapter, TCs were provided with learning opportunities that challenged them to generate innovative and creative designs in STEM education. TCs' creation of STEM projects and digital video games (DVGs) that emphasize innovation, creativity, critical thinking, and entrepreneurial skills are highlighted in this chapter. The two assignments in which TCs utilized their STEM and entrepreneurial skills to design and solve problems are the focus and include:

(1) Project based learning (PBL) in STEM; and
(2) DVG creation.

Both assignments are multifunctional—suitable for assessment as part of the TCs' program, as well as resources that they can potentially distribute (for a fee) to a publisher of science education resources. In the following sections, the authors highlight literature on STEM and entrepreneurship education, and teacher education with a focus on curriculum and pedagogy in STEM. Additionally, the authors present examples of STEM projects and DVGs in the context of the Curriculum and Pedagogy in STEM Education course and highlight explicit connections between STEM education and entrepreneurship. In closing, the potential of PBL and DVG creation to foster STEM and entrepreneurial competencies is discussed.

2 STEM Education and Entrepreneurship

STEM represents a rethinking of traditional approaches to teaching science, technology, engineering, and mathematics; whereby these four disciplines are integrated into one meta-discipline. A major goal of the STEM agenda is to improve the proficiency of all students in STEM, regardless of whether or not they choose to pursue STEM careers or postsecondary studies [7]. Integrated STEM education aims to understand and problem-solve real-world examples in society; those that are rarely solved using the knowledge, tools, and skills from one discipline [9]. This requires an understanding of societal needs, critical and creative thinking skills, engineering-design thinking, and research and experimentation skills, to name a few. Students need critical thinking skills and STEM skills to be successful in today's society, irrespective of the career they choose. In addition, they will also need a variety of fundamental soft skills, such as social skills, leadership, adaptability, and self-management [10], and non-technical abilities. Thus, integrated STEM education can increase retention and understanding of content while promoting the development of both hard and soft skills [11].

According to Torrance and Rauch, entrepreneurship education encompasses "the teaching of skills and cultivation of talents that students need to start businesses, identify opportunities, manage risk, and innovate in the course of their careers" [8, p. 1]. Entrepreneurship education is universal, and is rapidly moving beyond the traditional courses offered, with institutions exploring novel and innovative strategies to create learning environments that foster entrepreneurial mindsets. The IFTF study concluded that in 2030 entrepreneurial traits such as vision, perseverance, creative problem-solving, and learning agility will be critical for all workers to employ [5], along with an entrepreneurial mindset, defined as "a growth-oriented perspective through which individuals promote flexibility, creativity, continuous innovation, and renewal" ([12, p. 968], as cited in [13]). Furthermore, they note the difference between fixed and growth mindsets, with the former being resistant to change while the latter fosters building skills with work and effort. Wardana et al. note that an entrepreneurial mindset has been credited for success in running a business [14].

2.1 Entrepreneurial Skills

Twenty-first century learning skills, identified as being relevant to the current social and economic facets of our knowledge-based society include creativity, collaboration, entrepreneurship, problem-solving, critical thinking, self-directed learning, communication, leadership, innovation, perseverance, and scientific-, environmental-, digital-, and technological literacies [15–19]. As a subset of twenty-first century learning skills, entrepreneurship encompasses critical thinking, creativity, innovation, leadership, and networking/social skills. Additionally, entrepreneurial skills and competencies include inner discipline (i.e., an internal locus of control), the ability to take risk (risk tolerance), proactive motivation, change-orientation (change tolerance), self-esteem, and persistence [16, 20, 21].

Globally, there is a growing demand for students to graduate from high school with the aforementioned skills with a goal of developing entrepreneurial capacities and mindsets that ultimately benefit economies through creativity and self-employment [22]. This requires that education expands its scope to include the development of cognitive skills, as well as a more noncognitive, holistic approach that also promotes career readiness [7, 23], as these are crucial elements in ensuring the future of a STEM workforce. Given the demand for high school graduates to possess skills that will enable them to succeed, including STEM and entrepreneurship skills, one might ask: When should students start learning about STEM and entrepreneurship education? Lackeus recommends a progression model of entrepreneurship education embedded into the curriculum as early as preschool and primary school, building from year to year to develop students' competencies over time [24]. Moreover, Dinis et al. [25] note that early formal entrepreneurship education impacts student attitude, self-efficacy [26, 27] and can influence their career aspirations, as middle school is when most students begin to think about career choices [28].

3 Teaching and Learning STEM and Entrepreneurial Skills

Many students express an early interest in STEM, inspired by their own personal experiences. Through effective STEM instruction, including identification of and scaffolding from prior knowledge, providing opportunities to engage in the practice of STEM disciplines, and tailoring learning experiences to sustain student interest, they become aware of STEM career options. Ultimately, elucidating efficacious methodologies to provide students the necessary support and skills to succeed, as well as opportunities for STEM career discovery and exploration, that can help students translate awareness of STEM career options into pursuit of STEM careers [29] and are essential characteristics of STEM education. Entrepreneurship education fosters skills, cultivates talent, and identifies opportunities and innovation, to name a few [30]. Research suggests that educational attainment increases the likelihood of an individual pursuing entrepreneurship [31]. As entrepreneurship skills can be taught across the disciplines, given our context this warrants that educators align STEM curriculum and pedagogy. The alignment would better foster an entrepreneurial growth mindset to meet the demands of students and communities who are reshaping society and the workplace through innovation and creativity. Ideally, in STEM education students should learn about entrepreneurship, develop entrepreneurial competencies, and should be provided with opportunities to also 'practice' entrepreneurship, through for example, inquiry and design-based learning, experiential learning, and reflective practice [32, 33]. To this end, Komarkova et al. advocate for action learning whereby learners engage with direct experience and hands-on project work, including non-formal education settings, to acquire competences consistent with those of successful entrepreneurs [34]. Moreover, pedagogical orientations should support learning that is student-centered, self-directed, personalized, interactive, cooperative, flexible, project based (including challenge or problem-based), and reflective.

3.1 Entrepreneurship, STEM, and Teacher Education

Research around entrepreneurship education has been mostly conducted in the context of post-secondary education, with graduate or postgraduate students [35]. The literature on entrepreneurship research involving non-university individuals and K-12 (kindergarten (K) for 5–6 year-olds through twelfth grade (12) for 17–18 year-olds) students is sparse [36]. According to Shahin et al. secondary schools play a critical role in innovation and entrepreneurship, stating that childhood and teenage years are the best time to learn entrepreneurship skills and develop an entrepreneurial intention [37]. They reiterate that these years are crucial for developing students' "skills, knowledge, and attributes that strengthen entrepreneurial intent including learning and inspiration in the areas of opportunity identification, creative problem-solving, positive role-modelling, and teamwork, to name a few" (p. 2). The aforementioned are key twenty-first century skills that align with STEM education goals and are of paramount importance in teaching and learning. In order to achieve said goals, teacher education in STEM should focus on curriculum and pedagogy that supports the development of such skills and transforms theoretical knowledge into practice. Learning opportunities that foster creative and innovative discovery would facilitate the development of key twenty-first century skills. Additionally, environments that promote entrepreneurship including developing growth mindsets, enhancing attitude and self-efficacy, increasing interest, fostering entrepreneurial identity, and enhancing career awareness would contribute to twenty-first century skills development.

Among the most highly transferable skills that promote an individual's ability to succeed in school and beyond, across a wide range of disciplines, is the ability to use and understand STEM facts, principles, and techniques. Unfortunately, much of STEM education is "business as usual"; neither integrating these subject areas nor offering better, alternative pedagogies [38]. Achieving the aforementioned goals will necessitate teaching in ways that inspire all students and deepen their understanding of STEM content and practices. Moreover, the overarching challenge lies in the fact that many science and mathematics teachers need better preparation in their content knowledge and expertise in scientific practices in the classroom; thus, limiting the effectiveness of STEM education and further siloing the disciplines.

Currently, learning strategies in initial teacher education programs do not prepare teachers to develop and apply entrepreneurship and STEM skills [39, 40]. This lack of preparation is especially true with K-12 teachers as few are trained in STEM subjects and may not teach what they do not fully understand or feel comfortable teaching [41, 42]. Teacher education should be instrumental in imparting best pedagogical strategies and providing opportunities for teachers to develop integrated STEM and entrepreneurial knowledge and skills. To do so, in the following sections, the authors highlight two exemplar strategies: STEM PBL and DVG creation, focusing on entrepreneurial and STEM skill development and growth mindsets.

4 Curriculum and Pedagogy in STEM Education: STEM Projects and DVGs

"Curriculum and Pedagogy in STEM Education" is a course in a STEM specialty focus program emphasizing the learning needs of students in grades 7–12, developed by DeCoito in a teacher education program in Canada. Within the framework of this course, a STEM teacher education model was developed and implemented. As part of this model, TCs are provided with an opportunity to be involved in curriculum development through STEM PBL and DVG creation assignments.

The STEM teacher education model introduces TCs to attributes of STEM education. This is accomplished through an organic approach to curriculum development and accompanying pedagogy, and a unique focus on STEM concepts borne of the motivation to reinforce engineering, technology, mathematics, and science concepts, and reflecting entrepreneurial and STEM skills. In the STEM specialty focus, TCs are introduced to the nature of STEM education (e.g., nature of science, engineering, technology, mathematics; equity and diversity in STEM; engineering design process; computational thinking; history of STEM; etc.). TCs engage in curriculum development and are presented with opportunities to deepen their understanding of STEM concepts while developing STEM skills through projects [43], DVGs [44], interactive case studies [45] focusing on socioscientific issues, and educative STEM curricular materials. All assignments use a science, technology, society and the environment (STSE) framework that relates science and technology to society and the environment (STSE Expectations [46]).

In the Curriculum and Pedagogy in STEM Education course, the integration of STEM subjects and skills is both explicit and reflective, with a goal to engage students, promote problem-solving and critical thinking skills, and facilitate building real-world connections. Equipping students with twenty-first century skills to ensure successful careers in STEM fields will require new approaches, such as entrepreneurship, to teaching and learning STEM topics in K-12 classrooms. The assignments in the Curriculum and Pedagogy in STEM Education course emphasize social learning that advocates for "an interactive or participatory style of problem solving, whereby outside intervention takes the form of facilitation" [47, p. 47; 48]. Moreover, given that motivation is a driving force for student learning goals, the STEM course promotes TCs' self-regulated learning as an effective way to learn in and about STEM and entrepreneurship education [49]. In self-regulated learning "learners implement strategies by which they choose, use, monitor and adjust learning strategies and employ the strategies to control action in order to achieve specific learning goals" [50, p. 5]. According to Cheng, in the process of self-regulated learning, four components are involved: (1) learners' motivation for learning, (2) goal setting, (3) action control, and (4) learning strategies, and may be used to predict student performance. These components are embedded and demonstrated in STEM course assignments.

Eltanahy, Forawi and Mansour note that STEM learning alone does not result in entrepreneurs [51]. Enhancing long-term development of entrepreneurial competencies in STEM classrooms will require integrated practices that support designing STEM activities. For example, TCs were provided with opportunities to research and create STEM projects and DVGs in the Curriculum and Pedagogy in STEM Education course which resulted in prospects for TCs to (1) engage in the process of developing educative materials linked to curriculum, (2) use and model technology effectively in their future practices by enhancing and expanding their STEM and entrepreneurial skill sets such as creativity, innovation, leadership; and (3) engage in/with best practices associated with integrated STEM and entrepreneurship education.

4.1 Integrated STEM PBL and Entrepreneurial Skills

If we teach today's students as we taught yesterday's, we rob them of tomorrow.

John Dewey

PBL is not novel; it is prevalent in secondary, post-secondary and professional education contexts including medicine, engineering, education, economics and business. In the context of education, PBL refers to an instructional method that is inquiry based; one that engages learners in knowledge construction through completing meaningful projects, and developing real-world products [52, 53]. Research studies on PBL in teacher education and with in-service teachers have explored, for example, TCs' thoughts, feeling, and emotions related to the PBL process [54], successes and challenges inherent in teaching physics using PBL for elementary level TCs [55], teachers' project-based teaching core practices [56] and Israeli TCs' implementation of PBL in elementary schools during their practicum [57].

Integrated STEM PBL uses engineering design as the foundation upon which students bring their disparate and compartmentalized knowledges of science, technology, and mathematics to focus in order to solve meaningful real-world problems. Utilizing engineering design principles enhances real-world relevance and applicability, emphasizes making connections to STEM professionals and careers, and helps prepare students for post-secondary education. According to Slough and Milam, design principles in the design of PBL include (1) making content accessible, (2) making thinking visible, (3) helping students learn from others, and (4) promoting autonomy and lifelong learning [58, p. 15]. In the Curriculum and Pedagogy in STEM Education course, integrated PBL provides the contextualized, authentic experiences necessary for TCs to scaffold learning and build meaningful connections across science, technology, engineering, and mathematics concepts, while challenging and motivating them at the same time. Furthermore, TCs are presented with opportunities to develop and enhance twenty-first century skills by fostering critical and analytical thinking, amplifying higher-order thinking skills, promoting collaboration, peer communication, problem-solving, and self-directed learning. When implemented effectively, studies comparing learning outcomes for students taught via PBL versus traditional instruction show that PBL improves students' attitudes towards learning, increases long-term retention of content, enhances problem-solving and collaboration skills, and helps students perform as well as or better than traditional learners in high-stakes testing [59].

4.2 Examples of Integrated PBL in STEM

The STEM project assignment in the Curriculum and Pedagogy in STEM Education course reflects Capraro's definition of STEM PBL—an "ill-defined task within a well-defined outcome situated with a contextually rich task requiring students to solve several problems which when considered in their entirety showcase student mastery of several concepts of various STEM subjects" [60, p. 2]. In preparation for this assignment, a retired engineer was invited to conduct a workshop on modeling the engineering design process. TCs engaged in design principles, including blueprinting, and hands-on activities during the workshop. The goals of this assignment are to (1) engage TCs in using the engineering design process as the foundation for their STEM projects, (2) understand how their projects are situated in a STSE framework, and (3) enhance their twenty-first century skills such as creativity, problem-solving, collaboration, and critical thinking, to name a few. TCs were informed that they would be assuming dual roles—curriculum developers and co-constructors of knowledge—as they designed their STEM projects. They were required to develop a STEM project on a topic of their choosing, aligned with a curricular strand. TCs decided on which curriculum expectations their STEM project addressed; the curriculum focus, resources, pedagogical strategies; and the assessment criteria which reflected an adequate number of related "enabling tasks" that allow students to learn and practice the knowledge and skills they will need to successfully complete the STEM project. The STEM project rubric targeted TCs' knowledge and understanding of (1) PBL, (2) the engineering design process (inquiry, planning and testing), (3) STSE integration, (4) application, and (5) curriculum development and assessment focusing on PBL. TCs were free to choose a format for presenting their project, which included documentation of the research and development of the STEM project (e.g., models).

As part of the Curriculum and Pedagogy in STEM Education course, TCs developed, in groups of four, a STEM project over a five-week period. The STEM projects were more involved in terms of development than the single-concept based DVGs, as they were prepared as lesson arcs spanning 3–4 weeks of grade 7–12 classroom time. Three examples of topics chosen by TCs on which to build their STEM projects are waste management, global positioning systems, and drones. The projects are presented in the following sections and include: (1) *Waste management: A redesign* which focuses on waste production and environmentally friendly alternatives as the conduit for developing an integrated STEM project; (2) *Build and Use a Global Positioning System (GPS) Tracker*, which focuses on building a GPS tracker, programming a GPS receiver, as well as exploring uses of GPS systems, and the implications of these GPS systems on society; and (3) *Research Drones,* which focuses on climate change, specifically wind turbines, as wind energy provides clean renewable energy.

4.2.1 Project 1—Waste Management: A Redesign

The objectives of this project included developing a thorough understanding of negative anthropogenic effects on specific ecosystems, planning possible solutions, and utilizing research to create a product or campaign. Prior knowledge included a thorough understanding of the consequences of waste production, strategies for reducing the production of waste, recycling or removing materials for reuse, and waste processing or treatment and recovery of materials through thermal, chemical, or biological means. In the end, TCs focused on a coffee lid redesign, given that coffee cups are treated with polyacetylene thus rendering them leakproof but difficult to recycle, and the fact that fewer than 1 in 400 coffee cups (and lids) are being recycled because they are often considered too small.

TCs proposed a universal coffee lid designed to fit all cup sizes, and constructed with minimal amounts of recyclable plastic. They focused on a manageable component, that is, a lid that can be readily reused and recycled at the end of its life. The design used FreeCAD or other readily available AutoCAD software. As curriculum developers, in their instruction TCs encouraged end-users (secondary school teachers and students) of the curriculum to explore other means such as creating an advertising campaign, smart apps or promoting awareness to change habits. The idea behind the coffee cup lid design is similar to the design of a jar opener whereby a turn of the lid clamps it in place on a cup, and a locking mechanism keeps the lid in place on the cup. Illustrated below are the blueprint (Fig. 1a) and final product (Fig. 1b) for the universal coffee lid.

Below is an excerpt from a letter TCs designed as part of the assignment to raise awareness, requesting major coffee suppliers to utilize the universal lids, which highlights entrepreneurial skills learned during the assignment:

> Although we believe that our innovation can make a big impact on our environment today, we need your help in promoting our new product. It will be of great help just by dissuading consumers (customers) in using disposable coffee cup lids and letting them know about our new lids. Perhaps a small discount on coffee for consumers (customers) who bring their reusable lids will encourage them to start using our new lids and join our movement of reducing waste. We hope one day all coffee-producing companies will join our cause.

4.2.2 Project 2—Build and Use a Global Positioning System (GPS) Tracker

The objectives of this project included developing understandings of (1) basic logic processes of computer programs; (2) how to write and upload a simple Python script to a website; and (3) how satellite National Marine Electronics Association (NMEA) data is converted to geographic coordinates. In their curriculum development, TCs introduced students to investigating and examining different environments using the online game GeoGuessr (https://www.geoguessr.com/), a

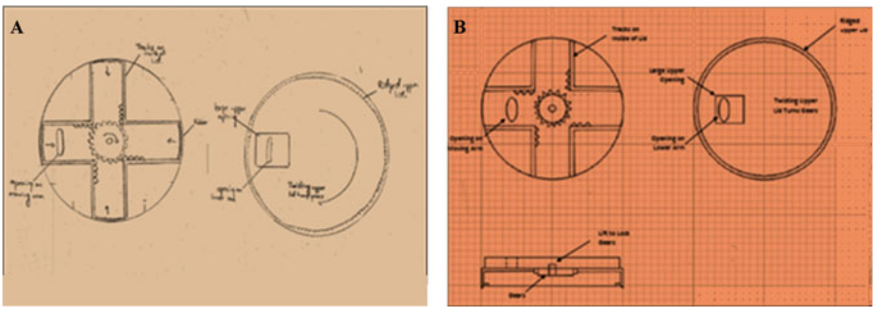


Fig. 1 Designing the universal coffee cup lid. **a** Initial blueprint. **b** Final design

geography game which uses Google Maps to take you on a journey around the world and challenges your ability to recognize your surroundings. Students researched different tracking devices used globally and within the community, as well as explored different careers associated with GPS (e.g., aviation technician, software engineer, digital designer, aircraft engineer, etc.), and economic benefits of commercial GPS use.

In this project, in their dual roles as curriculum developer and co-constructors of knowledge, TCs provided instructions on building a GPS tracker, as well as the other components (depending on purpose and usability); screen, antenna, internal maps, storage/memory, platform (e.g., Raspberry Pi), mount or grip, and power supply. TCs focused on teaching and learning associated with how GPS tracking operates, and demystifying the data GPS satellites send back. In addition, TCs explored programming in Python using the interactive freeware textbook *How to think like a computer scientist* [61], and engaged with actual coding. Once GPS trackers were built and programmed, students collected data over a two-week period with a goal of calculating corresponding carbon footprints. TCs suggested other applications for GPS trackers, including tracking animals (outdoor pets, strays, rabid animals, and migrating herds), similar to National Geographic's international 'Cat Tracker' study, which revealed the secret wanderings of 900 house cats across four countries (https://www.nationalgeographic.com/animals/article/cat-tracker-shows-where-pets-go), and tracking oneself to determine how much one exercises and where one spends most of their free time (see Fig. 2a for tracker-recorded movement). In the case where building a tracker was not an option, TCs provided modifications, including choice of programming an existing inexpensive pet tracker (see Fig. 2b for sample pet trackers available for purchase), or access to several free, web-based platforms supporting GPS tracking including Traccar (https://www.traccar.org) and OpenGTS™ (opengts.sourceforge.net). An extension to this project challenged learners to design and use a 3D printer to print a waterproof housing for the tracker.

4.2.3 Project 3—Research Drones

The objective of this integrated STEM project was to retrofit the classroom drone to attach an anemometer to measure wind speed and wind pressure. Prior knowledge included the fact that wind turbines play an important role in the sustainable generation of power. In order to determine the most efficient placement of wind turbines on particular coastal and higher altitude regions, researchers would have to measure wind speed at approximately 65 m high. Interestingly the classroom quadcopter drone has the ability to maneuver freely, ascending to heights in excess of 65 m. TCs then introduced drone technology to students, highlighting its advantages and disadvantages. TCs deduced that with the appropriate accessory device, the drone could record wind speed. In utilizing a 3D printer to equip a drone with an anemometer, TCs achieved a method for optimizing and determining the proper locations for wind turbine construction. The anemometer-equipped drone not only provided real time wind data at the exact location of the wind turbine, but its camera could also be used to assess the terrain and potential obstacles to

Fig. 2 Using a GPS tracker to track pet movement. **a** Sample exploration path. VectorStock image no. 17359201. **b** Sample cat/dog GPS collar available for purchase. Image from https://pickInn.com/pets-gps-tracker-activity-monitor

construction. If successful, this method could be adapted to identify optimal wind turbine placement in remote or more inaccessible locations.

The STEM project involved using the engineering design process to design and construct an attachment accessory that would secure the anemometer to the drone in order to gather data such as wind speed, height, and geographic coordinates that would permit more precise wind turbine placement for maximum wind speeds. The project planning included an introduction to TinkerCAD, a free, easy-to-use web app that equips the next generation of designers and engineers with the foundational skills for innovation (https://www.tinkercad.com/). TCs brainstormed several designs and selected the most appropriate design for an attachment accessory (Fig. 3a). Once the design was selected, TCs familiarized themselves with the class 3D printer by designing their own practice object and printing it. Once the design was approved, TCs printed the accessory prototype (Fig. 3b) and secured it to the drone.

TCs used the engineering design process through testing, evaluation, and re-design. The main component of TCs' research utilized an RC-PRO FPV Quadcopter Drone outfitted with a Yellow Jacket ABM-100 Smartphone Anemometer and accompanying iPhone. The anemometer and iPhone were attached to the drone using an accessory designed and developed in TinkerCAD by TCs and printed on a 3D printer. Data analysis was conducted in Excel™ and WRPLOT View which is a wind rose program for meteorological data. It provides visual wind rose plots, frequency analysis, and plots for several meteorological data formats. Wind roses are graphical charts that characterize the speed and direction of winds at a location. Figure 4a illustrates a wind rose diagram depicting a segment of data (Fig. 4b) collected by the anemometer.

Upon completion of this project, TCs concluded that they could see a drone equipped in this way being used to complete similar wind speed/direction surveys

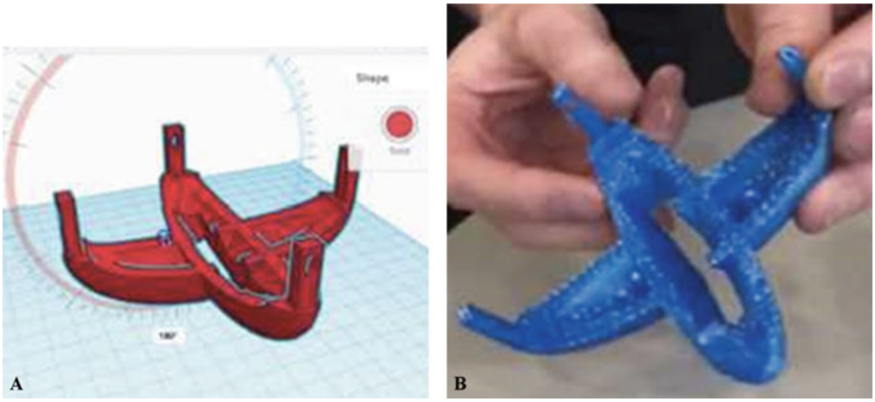


Fig. 3 Prototyping and printing a drone accessory mount. **a** Accessory design for anemometer. **b** 3D printed accessory prototype for anemometer

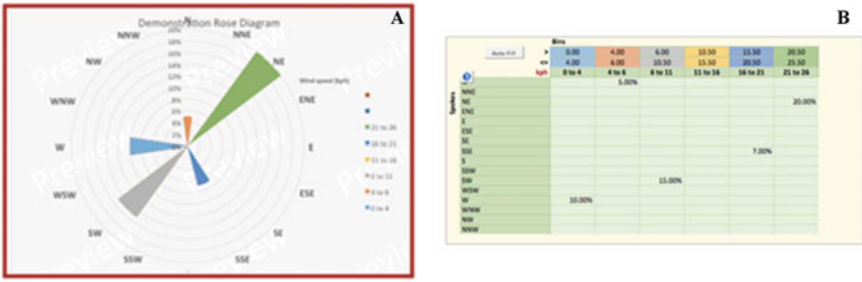


Fig. 4 Wind rose diagram (**a**) summarizing data collected from the anemometer mounted on the accessory attached to a drone (**b**). In the wind rose shown, the majority of the wind was northeasterly; minimal winds were detected originating out of the north

in a commercial capacity. TCs also identified value-added improvements, such as the addition of a laser that would monitor drone height, which would further increase the precision of measurement location.

4.3 STEM Learning, Entrepreneurial Skills and DVGs

> *Game developers know better than anyone else how to inspire extreme effort and reward hard work. They know how to facilitate cooperation and collaboration. Collaboration (teamwork) at previously unimaginable scales. And they are continuously innovating new methods to motivate players to stick with harder challenges, for longer, and in much bigger groups. These crucial 21st century skills can help all of us find new ways to make a deep and lasting impact on the world around us.*
>
> Jane McGonigal, Ph.D., Game Developer and Author

In recent years, digital technologies such as DVGs, interactive digital textbooks, virtual worlds, virtual labs, online simulations, YouTube videos, and television programs have been successfully employed to facilitate K-20 STEM learning objectives [62, 63]. Since the early 1950s television programming such as *Mr. Wizard, The Nature of Things, Bill Nye the Science Guy*, and *Space Cadets* have been used in the classroom to explore the concepts of probabilities, pH, food webs, magnetism, and gravity, to name a few [64]. Physics, chemistry, and biology experiments conducted in virtual laboratories such as *PhET* (https://phet.colorado.edu) and *ChemCollective* (https://chemcollective.org/vlabs) support immersive experiential learning for all students, including those in the remote settings necessitated by the COVID-19 pandemic [65, 66].

As part of a structured lesson plan, playing DVGs, such as the commercially successful *Minecraft* or *Angry Birds*, in the classroom facilitate the exploration of increasingly-complex STEM concepts such as geometry and projectile motion [67, 68]. Independent game developers such as *Spongelab Interactive* (https://spongelab.com) and *Gamified Learning Research & Development* (https://gamifiedlearningRD.com) create curriculum-driven resources to explore scientific concepts such as key milestones in the history of biology discovery, DNA replication, and climate change. These digital video games are researched to assess their impact on student learning and nature of science conceptions [15, 44]. In spite of the aforementioned, teachers report challenges in finding DVGs "in the wild" that intimately align with their course objectives [69, 70]. Adding the complexity of STEM resources that also integrate entrepreneurial skills makes finding ready-made assets a Herculean task. To quote Paul Simon, "the answer is easy if you take it logically" [71]. Create your own DVGs for use in the classroom, or better yet, have your students create their own DVGs that allow them to explore and validate the STEM concepts they are learning about, while embedding entrepreneurial skill development in the process.

While history is replete with successful "natural" entrepreneurs, as part of the twenty-first century skill set, entrepreneurship can also be learned through formal education [16, 20, 21, 51, 72]. Games based learning and gamified activities share similar goals, as the former uses a game as part of the learning process, while the latter turns the learning process as a whole into a game [73]. DVGs in the classroom can help with both STEM and entrepreneurial skill and knowledge acquisition. For example, Takemoto and Oe report that students perceive gamified activities in an entrepreneurial setting as good learning stimuli and that it promotes both strategic and critical thinking [74]. As well, game-based learning strategies and DVGs in the STEM classroom magnify student engagement and motivation to both learn and pursue STEM interests by utilizing literacies they are passionate about [68, 75, 76]. Furthermore, younger entrepreneurs (i.e., 12–17-year-olds, as opposed to 18–35 years old entrepreneurs) perceive entrepreneurial education to be an important driver in their efforts to become successful entrepreneurs [77]. DVGs "create the perfect environment for learning these [entrepreneurial and STEM] skills" [75, p. 186], as they can provide a venue that mimics real-world scenarios in which students can experiment, play, and learn.

5 Examples of TC-Created DVGs

In the Curriculum and Pedagogy in STEM Education course, TCs are also challenged to create DVGs encompassing at least three of the four STEM disciplines [44]. The overall goals of this assignment are to develop the TCs' twenty-first century skills set, to promote the TCs' digital self-efficacy, and to better prepare TCs to foster these skills in their future students. The development of entrepreneurship skills is implicitly embedded as an assignment objective, as entrepreneurial competencies such as creativity, critical thinking, innovation and perseverance are clear requirements for successful development of a DVG. Of special note is that the assignment utilizes principles of the engineering design process in game development, thus "engineering" is addressed in all games presented in this chapter [44, 78]. As part of the Curriculum and Pedagogy in STEM Education course TCs were required, either individually or in pairs, to develop within a three-week period a DVG to teach STEM concepts. After a single 75-min "introduction to coding" workshop in the STEM course, all DVGs were rapidly prototyped and developed, with most TCs requiring less than 40 hours to conceptualize, confirm alignment with curriculum, storyboard, develop, test and refine their game [44]. TCs also had access to additional support, beyond dedicated class time, through an online forum monitored by mentors and the authors. TCs were provided opportunities to develop a variety of STEM skills while creating their DVGs, including programming, math, creative thinking, logic, and using the engineering design process. One of the main goals of the assignment was to introduce TCs to the fundamentals of coding and computational thinking, which are critical skills for programmers and developers. Three examples of DVGs created by TC are presented in the following sections and include: (1) *Control*; (2) *Vector Planes*; and (3) *Corn Game*.

5.1 DVG 1—Control

One TC independently developed a DVG, *Control* (Fig. 5), to explore ecology concepts such as predator–prey relationships, food scarcity, and habitat stability. Utilizing a first-person shooter game motif, students assume the role of a hungry coyote named Control (Fig. 5a), intent on collecting as many tacos as possible to feed his mate and cubs. After each level, players are asked to reflect on their experience (Fig. 5b). In more advanced levels, Control needs to collect food while at the same time avoiding predators and hazards, such as bats and forest fires (Fig. 5c).

5.2 DVG 2—Vector Planes

Learning objectives associated with physics and mathematics can be more difficult to incorporate into a DVG. *Vector Planes* was created to teach and reinforce two-dimensional vector addition and subtraction. Players control a small plane by

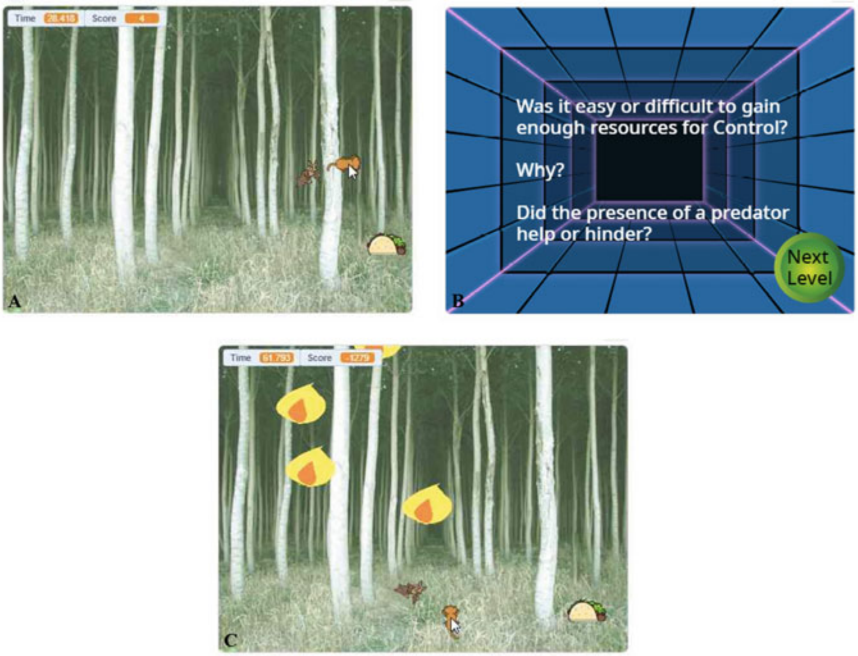


Fig. 5 Screenshots from the DVG *Control*. **a** Level one, where the coyote *Control* (mouse pointer) is trying to capture a food source (taco) while evading a predator (bat). **b** Score screen, prompting for discussion of ecology concepts before continuing. **c** Level two, where control is trying to collect food while avoiding both predator and hazard (fire)

varying lift, thrust, and drag forces, and must avoid obstacles such as buildings, spacecraft, and flying witches to score points. For new players, gameplay is simplified by initially disabling the added complication of wind (Fig. 6a); however, confident players can add wind mid-game by clicking the unobtrusive yet ever-present button in the lower-right corner (Fig. 6b).

5.3 DVG 3—Corn Game

Mendelian genetics and Punnett squares are introduced in grade 11 Canadian high-school Biology curricula (Ontario & Ministry of Education, 2008). For high school biology students, *Corn Game* was developed to address one of the more enjoyable aspects of high school biology education, Punnett squares which can be difficult for students to create and understand [61, 62]. In *Corn Game* players first select a farmer avatar (Fig. 7a), and then are assisted by a talking cow in learning how to create and interpret a Punnett square to maximize crop sales (Fig. 7b). While there are display issues with the DVG *Corn Game* (e.g., Fig. 7c and d), the learning experience is unhindered by faulty functionality.

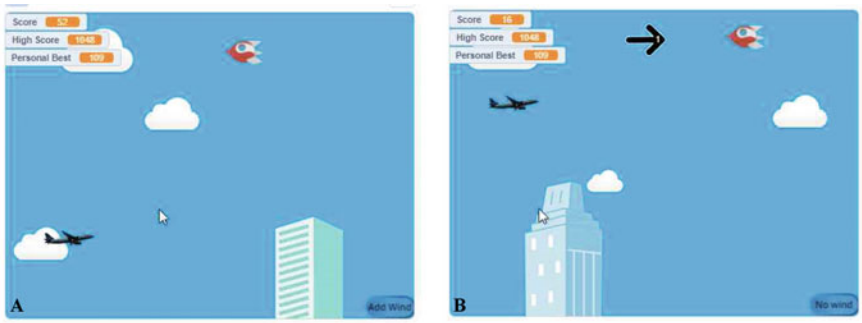


Fig. 6 Screenshots from the DVG *Vector Planes*. **a** Simple mode, where the player-controlled airplane must avoid obstacles. Gameplay is simplified due to the absence of wind (see button lower-right corner). **b** Advanced mode, where wind is an added vector (black arrow at top of screen). Arrow direction indicates whether a tailwind is in play (as shown), a headwind, updraft, or downdraft

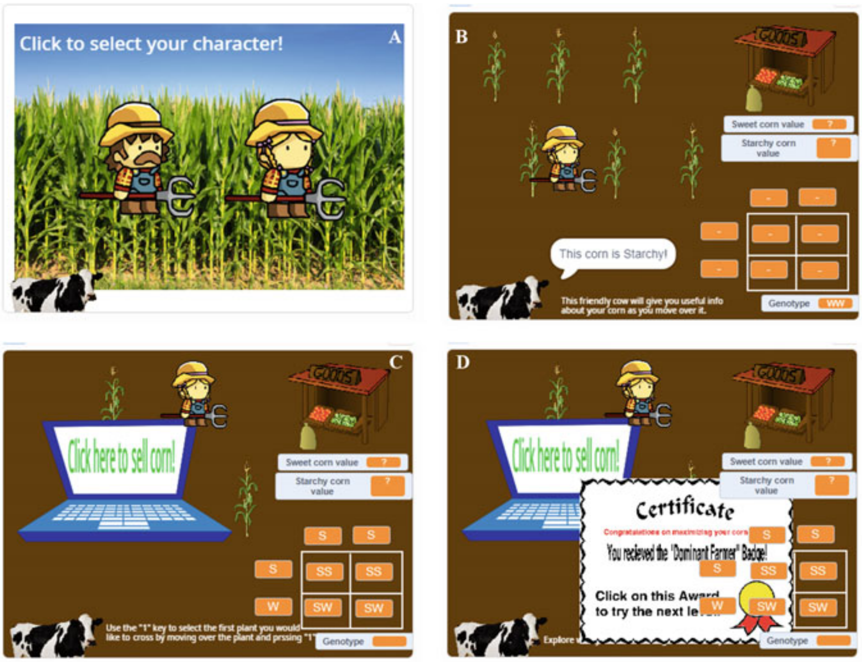


Fig. 7 Screenshots from *Corn Game*. **a** Avatar selection. **b** Avatar navigates the screen as prompted by the cow to obtain market and plant information. **c** Punnett square successfully completed. **d** "Dominant Farmer" award for successfully completing level one (monohybrid crosses)

6 Entrepreneurship and STEM Education

In the *Curriculum and Pedagogy in STEM Education* course, one of the authors was inspired by the DVG assignment to develop *Catch the Bus* (CtB, Fig. 8). CTB was developed to support the independence and community integration of people with intellectual and/or developmental disabilities [79].

The ability to navigate public transportation (PT) is one of the skills taught in the Personal Life Management elective course to students transitioning out of high school to independent living [46]. While other modalities to teach PT skills exist, they fall short of success in terms of long-term skill acquisition and real-time support [80–84]. Successfully piloted at a private high school in Canada to students aged 16–19, diagnosed with exceptionalities such as social anxiety, personality disorders, cognitive disorders, and obsessive–compulsive disorder, CtB was found to be beneficial in teaching PT skills to this group of students. Constructive feedback from participants identified areas for improvement and additional functionality [79].

Pursuing the entrepreneurial opportunity with CtB, the authors received support and endorsements from a university technology transfer office and regional transit commissions to further develop the application for commercial use. At the time of writing this chapter, funding was actively being pursued to create and distribute a mobile app version of CtB. The development and evolution of CtB represents the successful fruition of incorporating entrepreneurial and STEM concepts and skills into the STEM teacher education curriculum. Not all TCs will see, or even pursue commercialization of their self-developed resources. However, it is readily evident that opportunities exist for those with an entrepreneurial growth mindset.

Fig. 8 Landing page of the piloted *Catch the Bus* prototype

7 Discussion

Entrepreneurship promotes country-wide, and even global economic recovery and growth, and increases both the standard of living and perceived quality of life [4]. We posed the question: What is entrepreneurship, and how and when does an individual develop an entrepreneurial growth mindset? From the literature, we gleaned that entrepreneurial education is limited in K-12 education, yet research indicates that this is the optimal age group for teaching and learning such concepts, skills, and entrepreneurial intent, including learning inspiration, creative problem-solving, and teamwork, to name a few [35, 37].

There is a debate that entrepreneurial capacity can be an innate gift, similar to a talent in music or art [85–88]. However, like these two aptitudes, the authors and others contend that entrepreneurial knowledge and skills can be seamlessly embedded into existing school curricula to support development of entrepreneurial mindsets [51, 72]. For example, STEM and entrepreneurial education exhibit significant overlap in skill development, making STEM curricula a suitable conduit for explicitly embedding and leveraging entrepreneurial knowledge and skills. Research shows a gap in K-12 teacher comfort, self-confidence, and expertise in teaching both STEM and entrepreneurial content knowledge and skills. Teachers in this position are reluctant to teach outside of their comfort zone, and decline to include concepts that are inaccessible to themselves in their curriculum [41]. Due to this reluctance to embrace multidisciplinary and novel teaching methods, STEM disciplines tend to become siloed in K-12. For example, Blackely and Howell argue that "teachers have defaulted to the notion of S.T.E.M. rather than STEM," where the full stops "signif[y]... the silo-ing of the four distinct discipline areas, rather than their integration" [89, p. 104].

As illustrated in Table 1, the authors showcase integrated STEM projects and DVGs created by TCs in a Curriculum and Pedagogy Methods Course in STEM education. All STEM projects and DVGs were developed using existing course resources (i.e., a drone and a 3D printer) and freeware such as *Scratch* (https://scratch.mit.edu), a free visual programming language accessible to all developers, including kindergarten students [90, 91].

As a collective, these STEM projects and DVGs address numerous twenty-first century, STEM, and entrepreneurial skills. Over the course of DVG creation and STEM PBL development, TCs were engaged in several tasks that fostered an entrepreneurial awareness and encouraged entrepreneurial attitude and intention. At the same time, TCs were also engaged in developing and enhancing specific skill sets and competencies necessary to support future generations of learners. By utilizing principles of inquiry, design-based and experiential learning, as well as reflective practice [32], TCs were able to identify entrepreneurial growth within themselves by the end of the course.

In *Waste management: A redesign*, which involved the creation of a universal coffee cup lid, TCs were inspired to pursue a solution model for reducing the amount of single-use recyclable plastic winding up in a landfill. Brainstorming and

Table 1 Exemplar STEM projects and DVGs developed by TCs as part of a STEM course in teacher education

Exemplar	Main Topic	Entrepreneurship	Science	Technology	Engineering	Mathematics
Waste management: A redesign	Waste production and management	☑	☑	☑	☑	☑
Build and use a GPS tracker	Movement tracking via GPS	☑	☑	☑	☑	☑
Research Drones	Wind turbine design	☑	☑	☑	☑	☑
Control *https://scratch.mit.edu/projects/133299491*	Ecology	☑	☑	☑	☑	☑
Vector Planes *https://scratch.mit.edu/projects/130556924*	2D Vector Addition	☑	☑	☑	☑	☑
Corn Game *https://scratch.mit.edu/projects/138637984*	Punnett Square	☑	☑	☑	☑	☑

planning possible solutions is a creative process, while using research to create a product involves critical thinking and problem-solving. Members of the *Research Drones* project exhibited, through their STEM project presentation, similar enthusiasm and cultivation of an entrepreneurial growth mindset. This group went far above-and-beyond the scope of the initial assignment, reflecting an increase in entrepreneurial capacities, attitude, mindset, behavior and intention. These findings mirror those of Paco et al.'s study of entrepreneurial spirit, competence and behavior of STEM course students who had been exposed to entrepreneurial curriculum [22]. *Build and use a GPS tracker* perhaps represents a universal project, in that its application transcends traditional learning paradigms and creates a multidisciplinary arena whereby students can situate their own projects based on interest and opportunity. For example, a GPS tracker can be used to monitor pets, herds, children, military personnel, and objects such as keys and mobile devices. Additionally, GPS technology is a global phenomenon, thus a student who successfully acquires the knowledge and skills embedded in the project is better equipped to identify and pursue entrepreneurial opportunities on a global level.

Entrepreneurial growth is evident in each of the projects whereby TCs provided extensions, creating value-added content beyond the scope of the initial assignment. These projects were catalytic in developing an entrepreneurial growth mindset [14]. For example, TCs created marketing and campaign strategies to commercialize their products, solicited industry leaders for advice regarding further development, and embedded multiple modifications and accommodations to support student success and enthusiasm within and beyond the project.

TC-created DVGs incorporated STEM and entrepreneurial knowledge and skill acquisition, such as scientific-, digital-, and environmental-, and technological-literacies, as well as social/networking skills, learning agility, creativity, leadership, continuous innovation, problem-solving, self-esteem, persistence, proactive motivation, and perseverance [15, 20].

DVGs have the potential to promote entrepreneurial and STEM learning in student-players by working through completed games, be they commercially developed large-scale enterprises, or concept-specific resources created by in-service teachers for their own classrooms [92–94]. For example, the DVG *Control* illustrates "low hanging fruit" of entrepreneurship skill development such as opportunity recognition. Opportunity recognition is an entrepreneurial skill associated with the abilities to scan and search, evaluate, and make quick decisions [95, 96]. An advanced cognitive capacity, opportunity recognition requires the blending of information processing and creativity coupled with innovation and decisiveness to act quickly and effectively. Intriguingly, recent findings have shown that "shooter games" significantly enhance opportunity recognition development [97]. Despite game creation and DVG programming being a novel concept, the *Vector Planes* developer exhibited persistence and perseverance, in that he had no prior coding experience. Incorporating complex *if-then-else* statements to handle the effects of wind and player input necessitated significant troubleshooting, and experimentation was required to get the results "just right". Creativity is evident in this game as well, through seamless integration of physics and mathematics to develop a game that engages students while learning difficult and abstract concepts. *Corn Game* best illustrates risk-tolerance, proactive motivation, self-esteem, inner discipline and persistence [16, 21]. Furthermore, this DVG reinforces risk-tolerance and the notion that perfection is not required for success. Despite issues with visual presentation (e.g., Fig. 7d), the underpinning concepts and functionality are thoroughly vetted and illustrated: students can and do learn Punnett square knowledge and skill while playing this DVG. The game author encountered several challenges, also being new to programming, yet persevered and delivered an engaging, educational and functional product.

8 Conclusion

The express goal of teacher education is to prepare TCs to teach the next generation of learners. As entrepreneurial and STEM content knowledge and skills are imperative to the success of future generations of learners and innovators, teacher education is tasked with preparing future teachers to embrace the aforementioned as norms of teaching practice. To this end, in this chapter the authors outlined practices and curricula in STEM education that foster an entrepreneurial mindset and promote the development of entrepreneurial skills such as creativity, critical thinking, social skills and networking, innovation, leadership, and perseverance [16, 20, 21]. These competencies are imperative to support the development of twenty-first century skills, which are deemed essential to successful future careers in STEM fields.

STEM PBL resources and DVGs are shared in the hope that educators will be inspired to engage in similar exercises within their practice. In addition to improving their own entrepreneurial and STEM competencies, it is anticipated that they will also engage with and inspire the same competencies in their students. Furthermore, to better support TCs in their twenty-first century skill acquisition, which includes STEM and entrepreneurship competencies, teacher education programs need to incorporate in their design activities such as those outlined in this chapter. This will require that teacher educators become proficient in the areas of entrepreneurship education, as well as in digital-, technological-, environmental-, and scientific-literacies acquisition. Moreover, the ability to integrate these literacies with entrepreneurship skills is pivotal, given the global call for STEM education to include multidisciplinary curricula within a business and entrepreneurship context.

Given that 85% of the predicted career fields and positions available in 2030 do not yet exist [5], teachers will need to engage in professional development initiatives that integrate STEM knowledge with a broader set of business, entrepreneurship and commercialization skills. Curriculum will need to include design-based thinking, experiential learning, and inquiry opportunities if students are to engage explicitly and systematically in experiences that will empower them to develop entrepreneurial attitudes and mindset to better prepare them for the world of tomorrow. In addition, broader actions with key stakeholders such as ministries of education, curriculum developers, universities, parents, and policy makers must take place in order to leverage existing opportunities to develop talent advantage in students. In summary, promising benefits of entrepreneurship and STEM education require STEM curricula and pedagogy that increase entrepreneurship awareness and cultivate an entrepreneurial attitude, mindset, behavior, and intention among students.

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Back to School: An Examination of Teachers' Knowledge and Understanding of Entrepreneurship Education

10

Naomi Birdthistle, Therese Keane, Tanya Linden, and Bronwyn Eager

Education is the most powerful weapon which you can use to change the world (Nelson Mandela)

Abstract

Entrepreneurship education is renowned for its practical significance and its role in expediting the economic wellbeing of the global economy. Entrepreneurship education is principally an applied subject that links current business practices with academic theory. Entrepreneurial pedagogy and practices are increasingly being adopted in non-business subjects like science, technology, engineering, and mathematics (STEM). However, one must question whether teachers are equipped with the necessary skills and confidence to teach entrepreneurship education in the classroom, and thus whether they are able to prepare students to become enterprising leaders of the future. This chapter examines the perceived capabilities, knowledge, and understanding of entrepreneurship education in a

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sample of 30 high school teachers located in Victoria, Australia. Employing a participatory action research methodology, the reported study investigated teachers' attitudes towards incorporating the development of students' enterprise skills in their lessons and extracurricular activities. This involved testing entrepreneurship skills, capabilities, and mindset using online surveys. Two surveys were issued: one prior to a half-day workshop intervention and one post the workshop. Based on the results of this study, we propose several recommendations for STEM teacher training to enhance entrepreneurship education in the classroom. Advice is also provided to principals for adopting this approach school-wide.

Keywords

Enterprise · Entrepreneurship · Education · Twenty-first century skills · Teacher · High school · Resources · Knowledge · Principal · Student

1 Introduction

Employers in the twenty-first century are seeking employees who display twenty-first century skills and enterprise skills, such as flexibility, resilience, and creativity. More specifically, they are seeking new hires who display enterprise skills as often as technical skills, as found by The Foundation for Young Australians (FYA) [1], where in an average job advertisement for a young person in 2015, employers were 20% more likely to specify these skills than technical skills. What are the twenty-first century skills required of the workforce of today and why are they required? Twenty-first century skills include problem-solving, communication, presenting and pitching, digital literacy, teamwork, critical thinking, creativity, and financial literacy [2]. The workforce of the future needs to be able to manage social transformations on a global scale. Thus, graduates of the future need to know how to work in an ever changing, face paced world of work where innovations are constantly being introduced. Therefore, twenty-first century education requires a shift of what is taught in the classroom to help students grow in confidence to practise these skills, especially those in STEM disciplines where exposure to these soft skills may be lacking [3]. In this study, skill is defined as the ability to perform a task well, to have confidence to perform the task and to have expertise in the field [4]. Stauffer [5] identified 12 abilities that resonate with the twenty-first century skills and categorised the skills into three categories. The first category is called 'Learning skills' and includes critical thinking, creativity, collaboration, and communication. These skills, which Stauffer calls the '4 C's of twenty-first Century Skills' are about identifying solutions to problems; thinking outside the square, being able to work with others and being able to talk with others.

Next is 'Literacy skills' and these include information, media, and technology. Having information literacy means that students will be able to understand facts, figures, statistics, and data. Media literacy is understanding the methods and sources of information and technology literacy is about the hardware that enables technology to work. The last category is 'Life skills' and encompasses flexibility and adaptability, initiative, and self-direction, social and cross-cultural skills, accountability, leadership, and responsibility [6]. Each skill is unique in how it helps students, and they all have one quality in common: 'they are essential in the age of the Internet' [5, para. 4]. Enterprise skills and the skills associated with the twenty-first century skills overlap. Enterprise skills relate to having business knowledge and acumen, and commercial awareness and the skills range from critical thinking and problem solving, to creativity and innovation, communication, and collaboration, which resonate with Stauffer's 4 C's of twenty-first Century Skills and many of the 'Life skills'.

According to the Foundation Youth Australia [6] it is essential that students who will be graduating soon have the necessary skills for navigating the working landscape of the future. Australia however is not producing enough students with these essential skills when compared to other nations on a global basis. The Australian Government has called on educators to ensure that these skills are part of the skills set students have on completion of their studies [7]. There is an increasing trend towards overlaying teaching of enterprise skills onto educational subject matter [see for example: 8, 9]. One reason for this is that, for some students, educational content-matter might become more 'palatable' when experienced through an enterprise lens [10, 11]. Enterprise education affords students with short-term (i.e., immediate) and long-term benefits both in and out of the classroom. In the short term, enterprise education can positively influence students' motivation, attendance, retention, and connectedness. In the long term, entrepreneurship education at primary and secondary school levels is found to be an effective means of shaping enterprise-related abilities in later life. Furthermore, having enterprise skills in their 'skills toolbox' can enable them to be flexible and adaptive to changes that are occurring in the ever-changing work environment in which they will be employed in.

This chapter examines the perceived capabilities, knowledge, and understanding of entrepreneurship education in a sample of 30 high school teachers located in Victoria, Australia. The chapter commences with the exploration of the derived benefits of enterprise education and its perceived benefits to students and why they should be taught them during their formative years. The chapter then examines the entrepreneurship/enterprise education landscape in Australia. The methodological approach in gathering the data for this chapter is explained and the results of the pre-workshop survey are presented. A comparison between a cohort of teachers who completed both the pre- and post-workshop survey is given. The key findings of the study are discussed and several recommendations for teachers and high school principals are provided.

2 Enterprise Skills

Broadly conceived, enterprise education seeks to give participants skills and knowledge that will help them succeed in life. According to Ratten and Usmanij [12], when compared to other subjects, enterprise education is in a league of its own as one of the fastest-growing subject areas in the world. One of the distinctive features of enterprise education is its focus on participants' future potential in the workforce, and much of the literature relating to enterprise education emphasises its relevance to their future careers. The literature argues that students develop their ability to make positive and successful employees and employers because of the skills they learn in enterprise education [11, 13]. Another school of thought emphasises that enterprise education's relevance is as much about developing young people's 'life skills' as it is about enhancing their employability [14]. Table 1 highlights some of the skills associated with enterprise education.

A significant amount of literature acknowledges the positive contribution of entrepreneurship education on the development of people's know-how, skills as well as on the enhancement of entrepreneurial attitude and intention [15–19]. Higgins et al. [20, p. 135] state:

> There is a widespread consensus that traditional pedagogical methods of learning alone are insufficient to adequately develop entrepreneursEntrepreneurs to deal with the complexities of running and creating innovating businessBusiness opportunitiesOpportunities. There is a consensus that traditional pedagogical 'instructional methods' alone are insufficient to adequately develop entrepreneursEntrepreneurs to deal with the complexities of running and creating businessBusiness opportunitiesOpportunities. As a consequence, there is a growing need to cultivate innovative ways of thinking and new modes of pedagogyPed-agogy (teaching practices) to fully enhance and develop entrepreneurial approaches to education and learning.

Table 1 A sample of enterprise skills

Creativity—student's capacity to think creatively and develop new ideas	Innovation—student's ability to produce a value-added novelty	Leadership—student's capability of influencing others to attain goals
Confidence—student's feeling of self-assurance	Teamwork—students' confidence and effectiveness working as part of a team	Presenting—students' ability to present to others to share ideas
Critical thinking—student's ability to assess the value of a claim or information and come to a consultation about what to believe or to do about it	Financial literacy—student's ability to understand and properly apply financial management skills	Negotiation—student's ability to bargain to reach an agreement where some interests are shared, and some interests are opposed
Problem-solving—students' ability to approach challenges and situations where the answer is not immediately clear	Digital literacy—student's ability to find, evaluate and compose clear information through writing and other media on various digital platforms	Global citizenship—student's awareness of and understanding of the wider world and their place in it

Adapted from [1, 2, 5, 6]

Many academics take the perspective of 'learning for' as opposed to 'learning about' entrepreneurship [21] and see entrepreneurship and enterprise educational programmes as being useful to help students to learn how to consider an issue from different perspectives, how to explore possibilities in an effectual way, how to analyse situations and new information and to persuade others of the relevance and desirability of new solutions, and how to acquire and use the different forms of social capital that are likely to help this. These skills/attributes are suggested as key components in an 'enterprise for life' approach—because they should be useful in a wide range of situations [22] and can provide a foundation both for being more employable and for self-employment."

3 Benefits of Entrepreneurship Education to the Youth

Governments around the world recognise the value of enterprise skills in graduates and see the need to merge entrepreneurship with school education. Entrepreneurship education and entrepreneurial learning at secondary and even primary school level has been implemented in many countries around the globe. In members states of the European Union, discussions on implementation of entrepreneurship education at schools started in 1989 and a few years later relevant policies and frameworks were developed [23]. The policies that followed specified entrepreneurship as a competence that should be infused in teaching at all levels of education across the EU [24]. Similarly, Ministry of Education in New Zealand included entrepreneurship education into the school curricula from 2010 and results of this initiative showed improved students' engagement and improvement in academic performance [25].

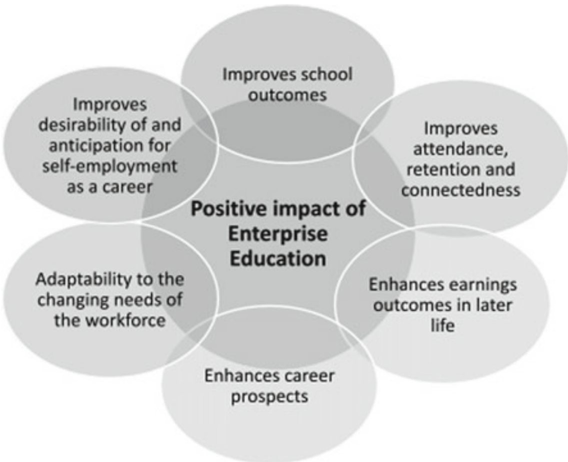
Some 12.8% (3,261,481) of all Australian residents are aged between 15 and 24 [26]. Australia does lags globally in equipping youth with enterprise skills (e.g., problem-solving, communication skills, digital literacy, teamwork, presentation skills, critical thinking, creativity, and financial literacy). This is evidenced in the research conducted by The Foundation for Young Australians [1] who found in 2015 that, despite staying longer in education, young people are not developing the enterprise skills increasingly demanded for work. It is not surprising then that in 2018, Programme for International Student Assessment (PISA) data, showed many Australian students were not proficient in enterprise skills [27]. Over a third of young people are also not proficient in science, mathematics, technology, financial literacy, and problem-solving. In many of these areas, Australia has moved down the international rankings. For example, in financial literacy, only 14% of Australian students made it into the high performers group, whereas the number of low performing students was 16%, an increase of 6% since 2012. Gender-wise, there was quite a small difference between proportions of overall high-performing male and female student numbers (16% and 13% respectively). The difference between overall low-performing male and female student numbers was even smaller (16% of males vs. 15% of females). The performance of female students in 2018 declined compared to the 2012 results. The proportion of low-performing female students increased by 7%. The data shows alignment between financial skills, mathematics and reading literacy, with at least half the high-performing Australian students also being high performers in mathematics and reading literacy (57% and 53% respectively). Many low-performing students demonstrated lack of mathematics literacy and reading skills (72% and 81% respectively) [27].

Engaging with programs of study or courses that have enterprise skills embedded in their learning outcomes can positively influence students' motivation, attendance, retention, and connectedness to peers and teachers and the broader community (see Fig. 1) [28]. In the long term, having enterprise skills is an effective means of preparing young people for challenges in work and in social contexts in later life [29]. Furthermore, enterprise skills are generic skills that are transferable across different careers and enables students to be adaptable to the changing needs of the workforce. Historically having technical knowledge was an indicator of success in your work [30] however, research has now found that successes in one's work can be attributed to having enterprise skills and are anticipated to be increasingly imperative in the future [31–33]. According to Foundation for Young Australians [1, p. 7] 'jobs of the future, or those jobs that are least likely to be automated, demand enterprise skills 70% more frequently than the jobs of the past'.

Engaging with enterprise skills also gives students the option of considering self-employment as a careerCareers (Occupations) option. These findings suggest that the growing importance of enterprise skills will continue.

Enterprise skills such as communication and digital skills already permeate diverse occupations and are constantly found as entry level requirements across industries. For example, according to Foundation for Young Australians [1, p. 7] 'digital skills are no longer just associated with technology-specific fields but are required in jobs as diverse as veterinarian, art director and dentist'. A few schools in Australia are starting to introduce the skills necessary to become successful entrepreneurs through start-up businesses or social enterprises. These are skills that

Fig. 1 Positive impacts of enterprise education [1]



educators are recognising as must-haves for young people (aged 15–24) entering the workforce in Australia and internationally, even if they do not choose an entrepreneurial path. However, we need to be teaching all members of the next generation of entrepreneurs, innovators, and enterprising employees the fundamentals of building new businesses from an early age today, to prepare them for action tomorrow and to help capitalise on the new ecosystem that the nation is building.

The pandemic has impacted global economies, leaving many people unable to cope physically, socially, emotionally, and economically [33]. In Australia, the situation is that youth unemployment has skyrocketed due to COVID-19. According to the Australian Institute of Health and Welfare [34], in 2021 16% of young people aged 15–24 were unemployed, an increase from 12% in 2019. Unemployment amongst young people in Australia has always been proportionally higher than other age groups [35]. This was particularly evident during the pandemic given many of them worked in the sectors that have been hit the hardest by COVID, i.e., retail, hospitality, and tourism industries. In addition to providing further work opportunities for young people, the pressing need is to ensure they are equipped with knowledge, skills, and capabilities to prosper in a world where they are faced with a high level of uncertainty. Embedding entrepreneurship and enterprise education into the school curriculum will provide young people with foundational, social, and cognitive skills to prepare them for the complexities of life and to provide them with the capability to anticipate and respond to societal changes [36]. We need to ensure that the youth of today are garnering the skills required for the future and one way of achieving that is to upskill the teachers in the twenty-first century skills, which forms the basis of this chapter.

4 Entrepreneurship Education in Australia

Featherstone [37, para. 12] quotes Prof. Per Davidsson, a world-renowned researcher in entrepreneurship, as saying that 'entrepreneurship education is still in its infancy in Australia'. This is very true and is further substantiated by the findings of Spike Innovations [38], authors of the report to the Chief Scientist, in that many Australian universities do not see entrepreneurship education as a priority and more specifically it states: '*Australian universities generally do not see producing entrepreneurs as a major part of their role*' [38, p. 17]. When compared to institutions in other countries who see themselves as having a central role in educating and cultivating future entrepreneurs, Australian Universities are not investing in programs to create and nurture the entrepreneurial mindset in their students to the same degree. Additionally, the report highlights that within Australian universities many academics have limited experience of entrepreneurship and thus '*…most academics teaching entrepreneurship courses do not have first-hand experience in a start-up and therefore deliver courses that are heavy on theory and light on applied content*' [38, p. 18]. Based on conversations with pre-service teachers in Australia they have informed the authors of this paper that many Australian universities do not teach entrepreneurship and/or education as part of the curriculum. In this paper, we aim to examine to what extent that is true and seek to propose recommendations to overcome this position.

5 Research Context

The project that forms the basis of this Chapter was funded by The Invergowrie Foundation, based in Melbourne. This organisation aims to encourage more girls into STEM since secondary school girls are less likely to choose STEM subjects than boys [39]. The goal of this project was to create resources and materials for high school teachers as well as provide training so that they can teach students about enterprise within their curriculum. Scholarly studies established that exposing schoolgirls to role models generates interest in STEM careers and encourages girls to follow similar paths [40]. However, there continues to be a lack of visibility of successful female STEM role models who hold senior positions. Because there are few women in STEM and subsequently fewer female role models that schoolgirls can relate to, the research team created educational resources showcasing five highly aspirational Australian female role models. These role models are accomplished and successful women in STEM, and included:

1. The founder of an educational robotics and coding training business
2. A founder of a social enterprise, established to teach girls how to code
3. A STEM entrepreneur who has patented her work and has several start-ups
4. A financial advisor and business growth strategist
5. A space lawyer, who is now training to be Australia's first female astronaut.

The educational resources that were created were five case studies based on the five STEM entrepreneurs interviewed, both in written and video format, which teachers can utilize in the classroom when teaching STEM subjects. Each case study had an accompanying lesson plan for students in Years 7–8 and Years 9–10 which was mapped to the STEM subjects in the national Australian Curriculum. Additional classroom activities were also collated for the high school teachers to use within their teaching. Part of the project entailed teaching the teachers how to use the educational resources created as an output of this project. Teachers were invited to participate in a workshop where the case studies formed the basis of the material and activities for the workshop (discussed in the methodology section).

6 Research Methodology

This study adopted the participatory action research methodology that seeks collaboration of teachers to empower them to generate knowledge. Within this context, this study investigates the understanding of the problem as well as offering a solution, i.e., supporting teachers in changing their attitudes towards incorporating teaching enterprise skills into their lessons and extracurricular activities [41]. After creating a set of teaching materials that included videos promoting successful female entrepreneurs, associated case studies with lesson plans, activities and additional lessons, the research team designed training workshops to support secondary school teachers in infusing entrepreneurship into their classes and/or as an extra curricula program. Principals of public and independent schools were contacted with the request to promote workshops to the relevant teachers and encourage their attendance. Subsequently, two workshops were organised—one in Melbourne for metro schools' participants and one in Ballarat for teachers from regional schools. Two surveys—pre- and post-workshop—were created to evaluate teachers' knowledge and skills in incorporate entrepreneurship concepts and enterprise skills development in their teaching as well as to evaluate the usefulness of the developed materials.

6.1 Teacher Profile

In total thirty teachers participated in both workshops, with 23 teachers coming from co-educational schools and seven (7) from single-gender schools. Four teachers identified their school as rural, with the remaining 26 teachers representing urban schools. All 30 teachers completed a pre-workshop questionnaire, however only 16 teachers completed the post-training questionnaire. What was garnered from the pre-workshop survey was an understanding of the teacher's confidence in teaching enterprise skills. The results indicated that there was a varied level of confidence in teaching enterprise skills, with eight teachers admitting to not being confident if had to teach in these areas (5—slightly uncomfortable and 3—very uncomfortable), whereas 10 teachers indicated "neither" and only 12 teachers selected slightly comfortable and very comfortable (7 and 5 respectively). This diverse background had to be considered when finalising workshop activities.

6.2 Intervention

Each workshop was organised at a venue located away from the school, to encourage more open discussion. The workshops were catered for and were held over four hours. Each teacher who attended the workshop received a welcome pack and in the pack was a guide to the activities they would be completing on the day. The guide explained how to deliver the activity, for what grade the activity was most appropriate for, the length of time it took to complete, and resources required. Each activity was initially completed by the teachers as if they were students. They were told what the activity was called, what they had to do and then asked to complete it. When the activity was completed, each group was asked to reflect on the activity. The teachers were then informed about the learning objectives of the activity, the connection that activity had to enterprise skills and an open discussion was had on any challenges they could foresee in delivering the activity.

At the beginning of the workshop, the project team provided a brief background to the research and the work they had done prior to the workshop, such as developing some teaching materials that were to be presented in the second part of the workshop. The first activity that the teachers experienced was a networking activity that enabled them to learn about the other teachers who were in attendance. This was in the form of a speed networking session where in 3 min they would talk to a teacher and converse with them. Two more '3-min blocks' were held and then each teacher had to introduce one of the teachers they met explaining who they were, what school they were from and an interesting thing that happened to them recently. The purpose of this activity was to help the teachers get to know who was in the room but also to experience a networking activity. A debriefing session was held after the activity to discuss how they might recreate this exercise in the classroom. Leading on from this the teachers were introduced to two enterprise exercises such as 'Marshmallow Challenge' and 'Bug's Report'. These exercises were then linked to the STEM curriculum and teachers were shown how they can be used to teach enterprising skills within their curriculum. These activities were used for two specific purposes; firstly, as icebreakers as teachers attending the workshops did not necessarily know each other, and secondly, to show how teachers can be creative and innovative and subsequently be comfortable in using these exercises within their classroom.

The first activity—Marshmallow Challenge—required teachers to work in teams of 4–5 to build a tall structure using pasta, string, tape with a marshmallow on top within a specified time. The structure had to be free-standing when the activity was completed. The objective of this activity was to develop:

- team building and collaboration skills,
- resilience in the face of challenges or frustrations, and
- design and testing skills.

Additionally, this activity let teachers experience the fundamental dynamics of teamwork. Once the activity was completed, the teachers were asked to reflect on who performed consistently well in this activity. The teachers reflected on how they could use this exercise within their classroom, and many said they could use it to teach about angles and weights (i.e., within mathematics), and engineering.

The second activity—Bug's Report—was an experiential enterprise exercise with the aim of developing the teacher's creative and innovative ability by identifying potential issues for product and service improvements. The aim of this activity was to encourage teachers to be more creative and innovative through examining the negative experiences in their daily life by evaluating products or services that 'bug' them. Each team member had to first individually highlight ten products or services that bothered or 'bugged' them and then in teams of 4–5, they whittled this down to one product or service. Next, the team had to explain how they could improve that product or service and turn it from a bug into an opportunity. This led to the teachers engaging in the opportunity recognition process by exploring various 'worst' case scenarios to develop potential avenues for new concepts. The enterprise skills that this activity specifically targeted were:

- Opportunity recognition
- Creativity
- Innovation
- Presenting
- Group work
- Time management
- Decision-making.

Teachers were then given a break and when they returned from the break, they were asked to reflect on the enterprise activities they had engaged with and to pose any questions they might have. Each enterprise exercise was wrapped up with a summary of what the exercise was about and what enterprise skills were associated with the exercise. Then, teachers were introduced to one of the case studies that was developed from the project and a snapshot of the remaining four cases was given (this was primarily due to time constraints). The teachers listened to the case study and then were brought through the lesson plan associated with the case study so that they got to experience the case as if they were students. Readers of this article can access the five case studies and the corresponding lesson plans at the following website: https://www.enterpriseandstem.online/about.

6.3 Data Collection

As stated earlier, teachers were invited to complete a pre-workshop survey before attending the workshop. This survey required respondents to develop a unique identifier so that the questionnaire could remain anonymous but so that it would enable the researchers to match the data in both the pre- and the post-workshop survey. The questionnaire included several Likert questions and dichotomous questions along with several open-ended questions. The pre-workshop survey with 18 questions in total had several questions related to the demographics of the teacher's high school, i.e., was it co-educational or single-gender, rural or urban and if the school currently offered enterprise education either formally or informally, through extracurricular activities. Teachers were then questioned as to their own entrepreneurial experience by asking whether they had started a business and if they had formally/informally studied entrepreneurship. The latter half of the questionnaire asked the teachers to identify how comfortable they were in teaching entrepreneurship and how comfortable they were in knowing where to get resources. The pre-workshop survey questioned the teachers on their entrepreneurial knowledge and understanding, and whether the principal of their school was open to entrepreneurship. They were then presented with several questions about where entrepreneurship should sit in the curriculum, how it should be taught and if they have the knowledge to teach entrepreneurship and/or enterprise within STEM.

The post-workshop survey had 13 questions in total, with some questions being like the pre-workshop survey but based on having completed the workshop. For example, the teachers were asked about their level of knowledge of entrepreneurship and where to get resources having completed the workshop. Both the pre-test and post-test questionnaire analysis involved the following predominant research themes:

- Where should entrepreneurship/enterprise education activities be situated in the curriculum?
- How should entrepreneurship/enterprise education be taught?
- Identifying the resources needed to teach entrepreneurship/enterprise concepts within STEM?

The post-test questionnaire had an additional research theme that centred on the teachers' views of the workshop and how it was delivered. Since this theme is beyond the scope of this chapter, the related teachers' responses will not be presented.

6.4 Data Analysis

Both pre- and post-questionnaires were analysed using descriptive statistical methods, however since teachers provided additional comments to explain why they selected a particular answer, open coding was applied to label themes identifying teachers views on the state of teaching enterprise skills in their school and in Victoria, the availability of teaching materials, workload issues, etc. To preserve teacher's anonymity when referring to their insights they are referred to as P1, P2, P3, and so on.

7 Research Findings: Pre-workshop Survey Results

Some 30 teachers attended the workshop and 22 completed the pre-workshop survey. Some 12 out of 22 respondents (54.6%) identified that the school currently teaches entrepreneurship and/or enterprise skills (10 from metropolitan schools and 2 from rural schools), however, the remaining 10 indicated the school did not teach entrepreneurship and/or enterprise skills. When asked if entrepreneurship/enterprise is a co-curricular activity, nine did not know, 13 indicated it was not a co-curricular activity and eight indicated it was. On further examination of those schools that teach entrepreneurship and/or enterprise skills, six had entrepreneurship/enterprise also as a co-curricular activity. The schools that did not teach entrepreneurship and/or enterprise skills did not offer this through extracurricular clubs or activities. Seven out of the 30 high school teachers indicated that they had started a business in the past and when asked if they had ever studied entrepreneurship formally, five indicated they had, with the remaining 25 having never studied it. Of these 25, four indicated they had studied it informally through MOOCs for example.

In the pre-workshop survey, teachers were asked where they think teaching and learning activities for entrepreneurship/enterprise should sit within the curriculum and Table 2 presents the 22 responses received.

The teachers discussed how the development of enterprise skills can and is being implemented in a range of subject areas from business and economics to humanities, in class and in extracurricular activities. The positive aspect is that teachers see opportunities to teach enterprise skills in a variety of subjects not in just business studies.

High school teachers were asked '*How do you think entrepreneurship/enterprise should be taught?*' and 13 teachers responded. The responses echo those of previous researchers who advocate for the 'teaching for entrepreneurship' (i.e., that will result in a student obtaining an entrepreneurial mindset) rather than the 'teaching about entrepreneurship' (i.e., that will give students knowledge of entrepreneurship), as shown by the thoughts that entrepreneurship should be practical, applied and 'hands on'.

> By doing than by theory. Get students to invent, market and promote their ideas. (P11)
> Project based. Authentic learning—see the value of it. (P12)
> By trial and error and by practicing those skills from a young age (bake sale, fundraiser etc.). (P13)
> Project or mock business. (P18)

When asked about the resources to teach entrepreneurship/enterprise concepts within STEM, three teachers did not know, and the others provided examples such as:

> Training, lesson plans and activities, examples, more space in the curriculum. (P12)
> A high-quality textbook with relevant Australian and international case studies. (P27)
> Ideas, protocols, information about permission, structures to follow. (P20)
> A dedicated cross-cultural team that could tie in different aspects of many subjects to support the same goal—and a PD supporting this. (P25)
> Access to examples, problem-solving type scenarios that often need to be overcome when looking at being an entrepreneur or using enterprise skills. Linking technology (perhaps case studies?) to these skills is also important and something which I feel I need more resources to support my teaching. (P21)
> Course outline, lesson plan outline, suggested tasks, assignments, videos. (P7)
> This is difficult to answer. My school is well-resourced, so I don't think we need any physical resources, but we do need a better network and a higher level of staff ability. (P3)

Table 2 Where in the teaching/learning activities should entrepreneurship/enterprise be taught?

Across all subject areas (P3)
Career development (P4)
It should be located within the Humanities and should be revisited several times between 7 and 10, if not at the primary level (P5)
Business Management. VCAL. Enterprise is part of the curriculum in these subject areas (P6)
It's in Victorian Curriculum—Humanities under the Business and Economics curriculum (P7)
We currently look at it in our Senior years (year 10 and beyond), which makes sense to me - they have the mathematical understanding to support what they are learning (P8)
The year 8s do run small business within the school (P9)
From primary up—entrepreneurship and creativity in primary through to particularly year 9 and 10 (P10)
In the STEAM curriculum (P11)
Maybe in humanities subject or in business class (P13)
We are currently teaching students STEM lessons and it could be incorporated into it. It could be included in Yr 10 or 11 commerce and business management (P15)
Traditionally they sit within the business studies domain, but they should be a part of a cross curricular subject offering (P16)
With subject areas—in context (P17)
Sprinkled throughout it (P18)
In every subject but especially in STEAM subjects. Setting up a successful business can happen in any subject area from Food Technology to Science to English. Once a person has created a product that people want, selling it and setting up a business to do this are vital skills. There is a reason why 20% of businesses fail in their first year and 50% fail by the fifth year (P20)
Brought in within the curriculum for middle school—e.g. year 7 as part of humanities (P21)
They are usually in Business Studies but could be included in other areas (P22)
Under Economics and Business—when you look at markets and how they operate, it is important that students understand the concept of enterprise and why it is encouraged within a community (P23)
In classes like Run Your Own Business, and maybe Business Management because those are subjects that the students can develop those skills in (P25)
Within the STEM framework (P26)
In each subject including the core subjects such as Maths, Sciences, STEM/STEAM and English (P27)
One area could be VCAL (P30)

What appears to be common amongst the teachers who responded to the resource question is the need for examples, case studies, and lesson plans to deliver entrepreneurship within the STEM curriculum.

Teachers were asked "why do you think entrepreneurial/enterprising skills are not explicitly taught to students". Teachers identified a range of issues that need to be addressed and they include

> Because it is still relatively new, or maybe because it is not in the curriculum. (P13)
> Because teachers don't have the skills or time to integrate it into their curriculum. (P14)
> Many subjects on offer at school, teachers not trained and no particular course material available. (P15)
> I think it is not taught since it is not part of the curriculum and because there is no easy formula. What works for a certain product or person may not work for someone else and there is the sense that there is so much competition out there that it is difficult. I think that teachers also either don't have the skills or if they do, they are not willing to share them. (P20)
> Some teachers may not be confident. Lack of knowledge or experience. (P21)

A common issue was teachers' lack of knowledge, skills and "first-hand experience". Teachers also pointed out that the curriculum is already "very crowded". Their comments demonstrate that they need help in adopting lesson plans and to modify tasks to include the development of enterprise skills without compromising the original intended learning outcomes.

Teachers were asked whether they have the knowledge to teach entrepreneurial/enterprising skills within STEM and to explain their answer. Twenty-two teachers responded to this question with 15 outwardly saying they did not have the knowledge to teach entrepreneurial/enterprising skills within STEM and some expanded by saying:

> Not currently but I am hoping by attending this PD I will gain some knowledge to apply to my STEM classes. (P3)
> I don't have the experience or contacts to effectively teach these skills within STEM, but it's certainly possible to develop these things in the near future. (P5)
> No. No experience teaching STEM through the lens of enterprising skills. (P6)
> No. I must confess I have not given this topic much thought before I was asked to attend this session, so I am curious to learn more. (P8)
> I haven't considered doing this before. I would have to spend time developing the course and becoming knowledgeable myself. (P9)

Some teachers indicated a level of knowledge relevant to teach entrepreneurial/enterprising skills with one teacher (P14) saying "I could touch on it, but not explicitly teach it", whilst others said:

> I have some skills in this area but need more skills to do this successfully. (P20)
> I run my own software development company, so I have some skills. (P24)
> I do have some idea as in the past I taught Industry and Enterprise and Business Management. That was a while ago so I would need either more PD on this or resources I can read and get ideas from. (P27)

The results from this question show the high school teachers' interest in self-development in the subject area, but it also shows a lack of consideration, thought, and/or experience within this area. This identifies a large gap in the knowledge of how high school teachers can adopt enterprising approaches to their teaching pedagogy within STEM.

8 Comparison of Results Between Pre- and Post-workshop Surveys

The following results are based on the responses of 16 teachers who completed both the pre- and post-workshop surveys and because of using a unique identifier, the researchers were able to match the data from both surveys with the teacher who answered. Teachers were asked how comfortable they were in teaching entrepreneurship and Fig. 2 indicates the results.

Teachers were asked how comfortable they were in identifying resources for the teaching of entrepreneurship before they completed the workshop and after the workshop. Nine teachers were very comfortable, five were somewhat comfortable and the remaining three teachers were 'on the fence' indicating neither comfortable nor uncomfortable in identifying resources for teaching entrepreneurship. Teachers were asked about whether the principal of the school was encouraging entrepreneurship and/or enterprise within the school and the school curriculum. Nine teachers did not know if the principal encouraged entrepreneurship and/or enterprise within the school, with the remaining seven indicating that the principal did encourage it. Two indicated that:

> The principal is very encouraging in the area of teaching entrepreneurship. (P28)
> Our principal is very encouraging of all programs that teachers propose. (P12)

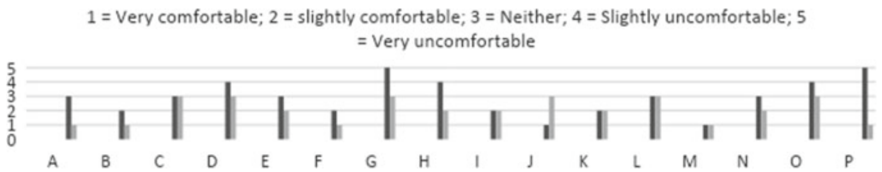


Fig. 2 Level of comfort in teaching entrepreneurship

8.1 Level of Knowledge of Entrepreneurship/Enterprise Principles, Theories, and Ability to Use Examples in Their Teaching

In both the pre- and post-workshop survey, a section of the survey asked teachers to consider their level of knowledge in several principles and theories within entrepreneurship and/or enterprise and to consider their ability to use examples. One of the principles and theories examined was teachers' level of knowledge in recognising and finding business opportunities. Figure 3 indicates the results of the 16 valid responses from teachers who completed both the pre- and post-workshop survey. Figure 3 shows that prior to the workshop half of the teachers had no knowledge or little knowledge of how to find business opportunities. Following the workshop, eight teachers identified that they are now more knowledgeable in principles, theories and/or examples of finding business opportunities. A further five teachers also indicated an improvement in their level of knowledge.

Following on with the business opportunity theme, teachers were questioned as to their knowledge in evaluating business opportunities. When the pre-workshop survey results were compared with the post-workshop survey results it was found that half the teachers had improved their knowledge in evaluating business opportunities on participating in the workshop. Two teachers indicated their level of knowledge remained the same because they already felt they were knowledgeable in evaluating business opportunities. The remaining teachers either still felt they were not knowledgeable or remained at being neither knowledgeable nor not knowledgeable. The results from the question which asked the teachers about their level of knowledge in evaluating the business environment did not change following the workshop.

The lean start-up and the business model canvas are two tools of entrepreneurship that have become quite popular in the twenty-first century. Both are methodologies by which to explain the potential operations of a business. The lean start-up enables the entrepreneur to develop his/her business with shortened product development cycles and rapidly discover if the business model is viable. The

Fig. 3 Recognise/find business opportunities

business model canvas is a strategic management tool that assists in defining and communicating a business idea or concept. Teachers were questioned as to their knowledge of both these tools. Thirteen teachers indicated prior to the workshop that they had no real knowledge or no knowledge of the lean start-up tool. Following the completion of the workshop, six teachers who had no knowledge of the lean start-up felt that they were now knowledgeable or very knowledgeable. This indicated a positive outcome from the workshop intervention on the lean start-up tool. Figure 4 highlights the pre- and post-workshop results of the teacher's knowledge of the business model canvas.

The findings from Fig. 4 indicate that all teachers knowledge increased post completion of the workshop about the business model canvas (BMC). In some cases, the teacher's acknowledged that they were 'not really knowledgeable' of the BMC however post the workshop their level of knowledge jumped to being 'very knowledgeable', which was a great outcome from the workshop. The workshop did not improve teacher's knowledge of conducting market research on customers. In some cases, the reverse occurred in that their knowledge worsened as some indicated that they were knowledgeable prior to the workshop but then on completion of the workshop they were not really knowledgeable. This is an area that warrants further investigation.

In business, it is fundamental that entrepreneurs understand their competition, and this was a question posed to the teachers who participated in the workshop. Teachers were asked if they knew how to evaluate competitors. A mixed and varied response was received to this question as illustrated by the findings presented in Fig. 5. Only four teachers indicated improvements in their knowledge of how to evaluate competitors. What is worrying is the level of negative change that occurred post the workshop. This could be due to the teacher's prior belief that they knew how to evaluate the competition but once they were exposed to methods and procedures from the workshop, they may have realised they did not truly understand how to evaluate the competition. This needs to be examined further to fully understand the outcome.

Understanding the terminologies associated with entrepreneurship is of crucial importance, so the teachers were asked about their knowledge of providing a

Fig. 4 Level of knowledge of the business model canvas

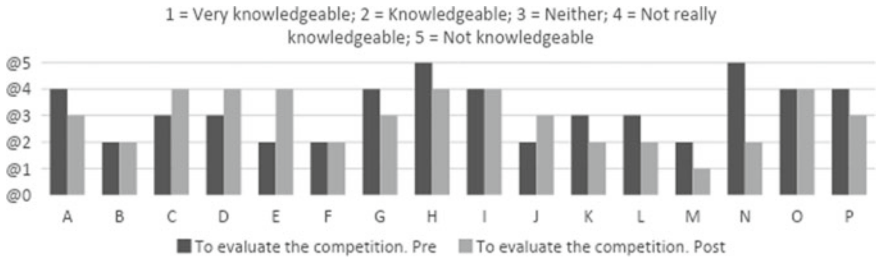


Fig. 5 Knowledge of how to evaluate the competition

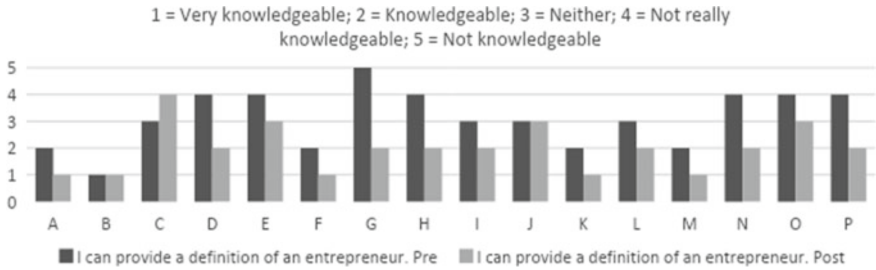


Fig. 6 Knowledge of how to define an entrepreneur

definition of what an entrepreneur is. Figure 6 highlights that prior to the workshop no teacher was very knowledgeable in this and in seven cases, teachers indicated that they had little knowledge on how to define an entrepreneur. Post the workshop this thinking changed. For example, the teacher who indicated that s/he had no knowledge at all then said post the workshop, s/he was knowledgeable.

A great way for anybody to learn about a subject or topic is to hear from someone who is immersed in it. Inviting entrepreneurs into the classroom can give students a wealth of information. Teachers were asked both pre and post the workshop if they knew how to find entrepreneurs to talk to their students. Ten teachers believed that their awareness improved and for the remainder their awareness remained the same. Teachers were questioned as to their knowledge of how to use case studies on entrepreneurs in the classroom. For 11 of the teachers the workshop had a significant improvement in their knowledge of how to use case studies in the classroom, as highlighted by Fig. 7.

9 Discussion and Recommendations

The need for twenty-first century skills is evident from a cursory glance in any 'Wanted ads' online or in newspapers. Enterprise education is often seen as a panacea for youth empowerment, by exposing the youth to the knowledge of

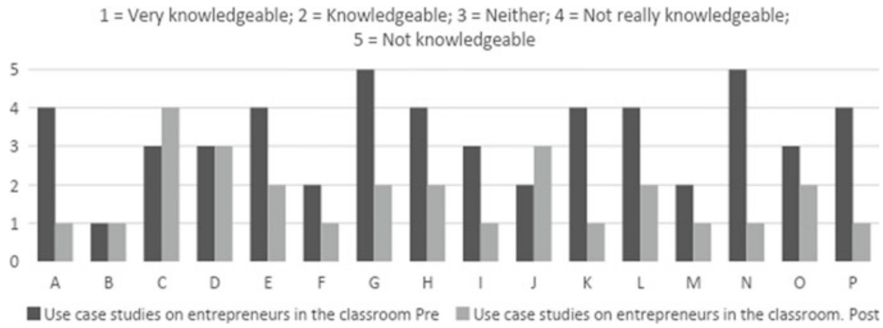


Fig. 7 Use of case studies on entrepreneurs in the classroom

various skills that will enable them to become self-employed rather than solely job seekers [42]. Many researchers observe that enterprise education provides students with lifelong skills that are demanded across industries [5, 6]. Australia's youth are finding it challenging to get employment. Unemployment figures prior to COVID were circa 12% of those aged 15–24 [32]. Due to COVID that figure has jumped by 4% to 16%. Once COVID is over, students currently in high school will have a challenging job market to deal with and it is imperative that they are given every chance possible to succeed—either as an entrepreneur or as a job seeker. This is where of course the teacher is important. Students need to be taught a curriculum that is current for the job market and as mentioned, that job market demands twenty-first century skills, of which enterprise skills are component.

Enterprise education is often embedded into subjects because of the hands-on and applied nature [8, 9]. However, studies have indicated that teachers in Australia are not skilled in teaching enterprise [38]. The reason being is that they either have never started and/or run a business themselves and thus would not understand the nuances behind it and/or they were not taught enterprise within their pre-service teaching. This study echoed these findings in that many teachers do not have prior entrepreneurial experience themselves. Many stated that they haven't the experience, or they haven't given the topic much thought. Some were open to learn these skills from participating in the workshop. Furthermore, many have not studied entrepreneurship formally nor informally, therefore they were going into the classroom with limited knowledge of how to teach these skills. The findings tell us that teachers are adept at taking on the challenges to teach entrepreneurial skills, however connections need to be made in terms of how they can incorporate these skills into the existing curriculum. They require guidance, resources and understanding of how to use the resources to give them the confidence to be able to teach these skills. It is recommended that the curriculum within pre-service teaching courses at university embed enterprise skills and twenty-first century skills explicitly. This will enable teachers across disciplines to embed the skills that are required for employability. Teacher professional development courses should focus on these skills explicitly so that teachers have the skills to embed them into their classroom activities.

Enterprise education is typically taught using a hand's on and/or applied approach and researchers have found that this approach often makes 'boring' and/or difficult subjects more palatable [9]. Our study found that teachers often related enterprise education to a business curriculum. A few, but not many, i.e., 3 out of 15 stated that enterprise should be taught within STEM. This echo demands by industry bodies such as the Institute of Public Works Engineering Australasia who stated that the most typical skills required by engineers are skills such as networking, empathy, interpersonal skills, critical thinking and collaboration. They are not typically the skills one is taught at school [43]. Additionally, the Australian Council of Engineering Deans said that technical skills, big picture and systems thinking, creative problem finding, definition and solving skills, collaboration, interaction and engagement skills, curiosity, adaptability, innovation, resilience and enterprise skills, digital intelligence, and emotional intelligence are skills that will be expected of engineers [44]. It is recommended that additional professional development programs be devised which focus on how enterprise skills can be embedded across the curriculum including STEM, because our study showed a change in teachers understanding of enterprise [to the positive end] post completion of the workshop. Teachers need to make concerted decisions to use their professional development time to incorporate some professional learning in understanding enterprise education and how to apply it to their teaching disciplines.

Teaching resources on any subject which have an enterprise focus tailored for high school students are often difficult to find [45]. Our study identified the need to support teachers by providing materials and resources as well as training in developing enterprise skills as part of regular lessons as well as through extracurricular activities. The study demonstrated that even a half-day workshop can be beneficial by providing teachers with knowledge of what resources could be helpful in raising students' interest in STEM fields, how to apply the resources to their teaching and how to improve their own confidence in teaching enterprise skills. It is recommended that annually teachers attend teacher professional development courses/workshops that are aligned with these skills to keep up to date with developments within the area. Additionally, it is recommended that case studies and lesson plans to deliver enterprise within the STEM curriculum are created and subsequently widely distributed. The Australian Government has announced several grants that can assist the teacher to work with industry and/or academics to create these case studies and lesson plans (details of which can be found in the Department of Industry, Science, Energy and Resources website under 'Australia's Tech Future/Government Initiatives' [46]). To assist in understanding what entrepreneurs do, it is recommended that teachers contact previous alumni that have started a business to return to the school and speak about their successes and failures.

High school principals are often the gate keeper to the school, and they have a major role to play in the management and guidance of enterprise education within the school [47]. In many of the schools i.e., 13, enterprise is not a co-curricular activity, and in 10 schools they did not have enterprise skills as part of the curriculum. Out of 16 responses, nine teachers indicated that they did not know if their principal encouraged enterprise within the school. It is recommended that the

Australian Secondary Principals' Association, a professional body that represents the interests of principals, deputy principals and assistant principals from government secondary schools across Australia, include enterprise skills as part of their agenda in forthcoming meetings. This would then enable principals to know more about the benefits of said skills to their school.

This study had a few limitations. The project was based on two workshops attended by 30 teachers in one state in Australia. Though 30 participated in the workshops, only 16 pre- and post-workshop survey responses could be used. Due to the sample size, statistical comparisons of skills pre- and post- workshops could not be made. It is recommended that more workshops be offered, and comparisons drawn from those results. Skills to teach entrepreneurship were self-reported and therefore some bias with teachers over or underestimating themselves could be present. A follow up study assessing the effectiveness of how they implement entrepreneurship education in their schools could address this limitation.

10 Conclusion

Enterprise and entrepreneurial education draw on and links to multiple curriculum areas. Its significance and practical applicability links current business practices with academic theory. twenty-first century skills such as problem-solving, communication, presenting and pitching, digital literacy, teamwork, critical thinking, creativity, and financial literacy are global capabilities that have been identified as important skills for students to develop for workplace preparation. Many of these skills are identified as important attributes that align with achieving future career success. Most teachers are not entrepreneurs and lack the understanding of the relevant concepts and skills to teach enterprise skills by embedding them into their lessons, therefore some scaffolding or training is needed to provide support in understanding the terminology and concepts.

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Naomi has entrepreneurship in her blood. She worked in her family business for over 20 years and ran her own consulting business. Naomi has studied in Scotland (Stirling University—BA Hons) Ireland (University of Limerick—Masters by Research and Ph.D.) and America (Babson College [1-year undergraduate program and an Executive Education program] and Harvard University [Summer school and an Executive Education program]). Her passion for entrepreneurship is evident by her research outputs. She has published 33 peer-reviewed papers, seven books with another five to be published in 2023; 26 book chapters, 64 conference papers and abundance of national and European reports. Naomi's research covers many areas within the entrepreneurship and family business discipline including the following: entrepreneurship education, minority groups and entrepreneurship; women owned and led businesses; succession planning in family businesses; divorce and family business and the role women play in family businesses. Naomi has recently been successful in securing two Department of Foreign Affairs and Trade (DFAT) both which have a focus on empowering women entrepreneurs in Vietnam and in Japan.

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Integrated and Innovative STEM Education: The Development of a STEM Education Minor

11

Helen Douglass

A culture of innovation embraces ambiguity, experimentation, and has some tolerance of failure.

Sina Mossayeb, Global System Design Lead

Abstract

Using design thinking as an enactment of entrepreneurial mindsets (EM), this chapter shares the creation process of a STEM education minor (or subsidiary course of study). Instead of one person or department crafting this course of study, the invitation was extended to a multi-disciplinary team, and entrepreneurial mindsets vis a vis a design thinking process were used to create a minor for undergraduate students interested in STEM education personally and professionally. Faculty, staff, students, and community members joined in a design thinking process to craft the minor for interested students across different majors (or principal subject of study) and colleges. Students from the colleges of business, engineering and natural science, health science, and arts and science can come together to cross disciplinary boundaries and integrate content, pedagogy, and innovation as they learn about formal[1] and informal[2] STEM education. This includes taking a course on design thinking. The author shares the design process and the resulting program of study for a STEM education minor as well as an example of undergraduate design-based research to solve a community problem.

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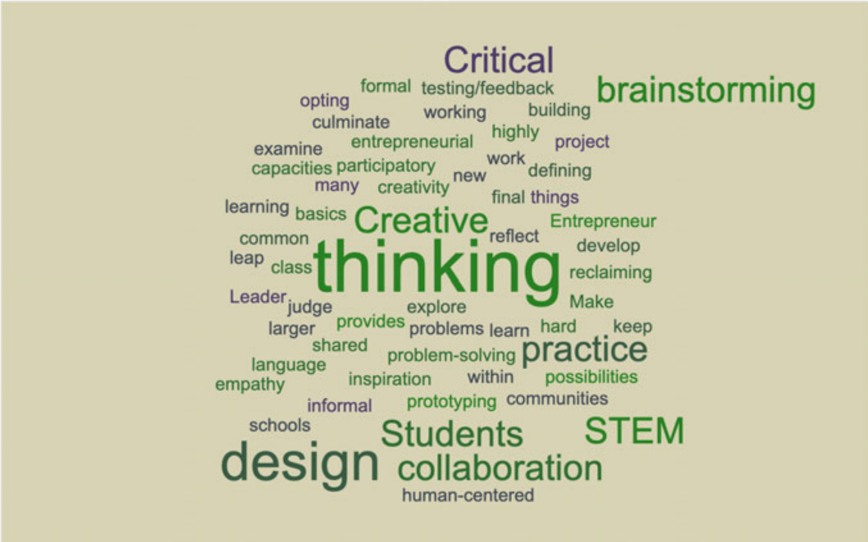
Graphical Abstract



Keywords

Design thinking · Undergraduate STEM education · Curriculum development · Collaboration

1 Introduction

“Entrepreneurial” is often exclusively associated with businesses and start-ups. The attributes one has related to growing or starting a business is one basic way to consider entrepreneurial mindsets (EM). However, EM has been defined in a number of ways [1–3]. A broad definition includes the set of cognitive behaviors that orient STEM professionals vis a vis engineers towards opportunity recognition and value creation in any context, not just that of an entrepreneurial venture [2]. In this context, EM has clear benefits for individuals, communities, industry/corporations, the United States and the world [4].

Aligning with this broad definition, the author and creators of a STEM education minor, (or supplementary course of study) in a department of education at a regional university in the United States enacted EM vis a vis a design thinking process. The design thinking process incorporates entrepreneurial mindsets, also known as innovator mindsets, in its approach to problem solving. It is a five phase iterative human centered process. By adopting a design thinking framework for the creation of the minor (supplemental) course of study, EM was embraced and enacted. In addition, two courses of the four required courses for the STEM education minor (supplemental course of study) for undergraduate students created by using the design thinking process include EM in course experiences.

Specifically using content from IDEO, CREATEDU and the Hasso Plattner Institute of Design at Stanford University (Stanford dSchool), all organizations that promote and teach design thinking, innovator mindsets and human centered problem solving were enacted in not only the process of creating the minor but in the products of one course, shared in further detail, that relies heavily on EM and the teaching, practice and assessment of the mindsets. Examples of mindsets discussed and used, among several, include creativity, collaboration, critical thinking, empathy, bias toward action and embracing failure. The chapter includes the process and products of the STEM education minor (supplemental course of study).

The development of a STEM education minor using a multi-disciplinary team shows innovation in how the program of study was developed and in the inclusive nature of allowing students from any discipline to pursue the minor. Our multi-disciplinary team, where members came together for the first time as a group with their own disciplinary perspectives, moved toward interdisciplinary work, where links between disciplines were harmonized into a coordinated and coherent whole as the development of the minor progressed [5]. Such interdisciplinary collaboration offers an opportunity of a supplementary course of study to any student with a professional or personal interest in STEM education. The creative and innovative design process that established the minor is also included in the minor in the form of a design thinking class all students are required to take. Design thinking processes were used by the interdisciplinary team to arrive at our prototype of the supplemental course of study, the STEM education minor as well as the inclusion of EM into STEM education [6].

This chapter introduces the aspects of STEM education minor, and then, provides specific examples of the STEM education minor and entrepreneurial mindset assessment as well as a student design project.

2 STEM Education Minor

The STEM education minor is a supplemental course of study developed and offered at The University of Tulsa. This section introduces the mission, nature, alignment, and the contribution of the STEM education minor. Undergraduate students may enroll in the STEM education minor for several reasons.

Numerous students from the college of engineering and natural science enroll in the STEM education courses due to their desire and interest in STEM education, but not in professional education. These students see themselves as future scientists and engineers, but also want to volunteer in schools, work in clubs and programs, and most likely will have release time from their work for voluntary service in the community. Likewise, several students from the college of business have enrolled in the STEM education courses due to the opportunity to pursue innovation and design thinking related to community programming, outreach and potential sponsorship or support of STEM education. In addition, several students from the college of arts and sciences (where the department of education is situated), including professional education students, have taken STEM education courses as they have a strong interest in STEM education as an additional area of teacher preparation. Additional students from arts and sciences take the class due to their interest in not only their major area of study but also to express their strong desire to volunteer or do outreach with STEM education endeavors. These students will not become professional scientists, engineers or educators but are still beneficiaries of the EM and experiences they have in the courses and the relation to their personal ambitions. The feedback on both the process of developing the minor, as well as the collaboration across disciplinary boundaries continues to be rich, and students have expressed a more integrated view of themselves and their STEM identities and future opportunities. Many students from various colleges are now participating in innovation events on campus and seeing areas of cooperation and synergy as opposed to isolated silos of content.

The process of developing the STEM education minor using design thinking and EM as well as including design thinking and EM in the course of study, continues to show promise for developing future formal and informal educators. In addition, with the interdisciplinary cooperation in the creation of the minor, a more diverse and inclusive group of students are crossing disciplinary boundaries and seeing the possibilities for their current and future lives.

2.1 Mission

The mission of the minor is to prepare undergraduate students for more equitable and inclusive STEM teaching. To achieve this mission, the purpose of the minor is to equip prospective teachers for filling underserved disciplines and to prepare those interested in STEM education for volunteer and/or informal STEM teaching. The minor allows students to be prepared for formal and informal STEM education across disciplines. It will impact not only students in the minor but those whom they teach in schools, after-school programs, and volunteer opportunities.

The minor contributes to objectives of the university related to all courses and degree programs for students. In an ongoing process of continuous improvement, the minor meets three university objectives as follows.

- *Reorient academic and co-curricular programs to catalyze a campus-wide culture of innovation and research*

The STEM education minor builds on the culture of undergraduate research in innovative ways by including each student in a research internship focused on STEM education. The minor itself is an innovation to meet the needs of education students and those from other disciplines, particularly engineering and natural sciences, to serve primary and secondary students approximately aged 5 years to 18 years (and written as Kindergarten through 12th grade, or K–12, in documents generated in the United Sates) in formal and informal contexts.

- *Provide our students access to an outstanding and diverse faculty and staff*

Students in the minor will have access to faculty in both the college of arts and sciences as well as engineering and natural sciences. In addition, they will be able to work with a variety of researchers across disciplines to complete a STEM education research internship.

- *Achieve recognition as the intellectual engine driving innovation, economic growth, entrepreneurship, and justice in the Tulsa region*

The minor's development has received national recognition for its design and interdisciplinary nature in providing an opportunity for education students and others to prepare for STEM teaching in formal and informal settings. Courses in the minor include design thinking, STEM standards and frameworks as well as pedagogy and content. Those who complete the minor will be well equipped to reach students in many settings and will have strategies and tools for creative problem solving due to their enactment and experiences with EM.

2.2 Unique Nature and Demonstrated Need

The emergence of STEM education in an integrated form creates a scenario for many teachers to be teaching in what is termed out-of-field [7]. In addition to the course of study in the department of education, students have the opportunity to minor in STEM education, which will help meet the growing demand for professional educators to extend their expertise into this integrated teaching and learning space which can be hard to fill.

The minor will provide for teaching and learning in formal educational spaces and contexts as well as informal education spaces, which is often where students experience STEM opportunities [8] and where many diverse students and those who have been marginalized access and experience STEM content. For students majoring in fields outside of education, such as engineering and computer science, the minor provides content and pedagogy for them to coordinate, volunteer and/or create informal experiences in STEM education. Students who do not major in education but complete the minor will also be better prepared to be advocates for education in whatever field they pursue and will understand the challenges and opportunities of integrated STEM education. In addition, all students will benefit from the alignment with EM and what has been termed power skills or 21st Century skills preparing students for the workplace [9].

STEM education in formal and informal contexts is also an opportunity to increase equitable and inclusive learning for all students, including those traditionally marginalized such as students from low socioeconomic backgrounds, students of color, and girls. By creating the minor in an interdisciplinary, collaborative manner, using a design thinking approach including EM, students have a unique opportunity to work across disciplines and be prepared for a variety of STEM education scenarios. The minor also allows for student choice, depending on their major, to tailor the experience to student needs, outlined further in the curricular section as well as problem solving via EM in the educational sector, something that is not always associated with EM [9].

2.3 Contribution

The STEM education minor will make a significant contribution to the intellectual community of the university and students' prospective career fields by taking an integrated disciplinary approach to prepare future educators, both formal and informal, for the needs of K–12 STEM students. In addition, the inclusion of methodologies and research related to students who have been traditionally marginalized allows students to be inclusive educators and advocates when they teach, mentor, or volunteer in STEM contexts. This minor also has potential to make a significant contribution to the broader community of educators by preparing professional educators and those who will work with STEM students in informal contexts, which is not typically addressed. EM and design thinking embraces many contexts and provides for students to tackle problems in human centered ways.

2.4 Alignment

The minor aligns with the university mission and institutional learning outcomes in several ways. Students in the minor will prepare and teach lessons, evaluate STEM programs using researched frameworks, and learn about authentic, relevant assessment. Each student will also participate in STEM education research, with a focus of their choice on formal or informal education. Students will examine their own STEM identities and the factors that influence them, and then translate these experiences into content and pedagogical choices to determine how to increase K–12 students' positive STEM identities. In addition, by including EM via design thinking, students will be able to approach problems differently, and have tools with which to solve them. Spaces of social and community needs would not be off limits to students who are equipped with EM via their STEM education experiences.

3 Needs Analysis

There is a growing emphasis on STEM in U.S. public schools, where over 90% of U.S. students are educated [10]. In terms of facilitating STEM classes, teachers may find themselves under prepared with little time devoted to integrated STEM. When informal science and STEM education programs are taught before or after school, or in special programs outside the day, volunteers, such as professionals from STEM industries, take on teaching roles. However, these volunteers have virtually no background knowledge in pedagogy, growth and development, or assessment. The informal programs can be engaging, but miss the mark on inclusion, content, and pedagogy relative to effective teaching and learning.

The minor seeks to meet the needs of the community by preparing for the STEM spaces. In addition, with the large numbers of students at the university majoring in subjects in the college of engineering and natural sciences, and the ethos of volunteering and outreach the campus community embraces, the minor provides for those students interested in teaching, but not pursuing professional education to be prepared to teach in informal STEM settings, where many people report they learn their STEM information and form their identities [11]. Rather than merely volunteering, which is important, the minor can provide these students with the opportunity to deliver quality, effective and inclusive informal STEM programming. EM via design thinking provides a way to address curricular challenges, as well as ways to address background knowledge and preparation. By adopting empathy techniques, creativity and ideation, to name a few mindsets, these challenges could be turned into a veritable playground of possibilities in problem solving.

3.1 Curriculum and Co-curricular Activities

The course of study outline for the minor includes both education and engineering and natural sciences courses, in addition to a research internship. The prototype of the plan and notes are included in their original format in Tables 1 and 2. In accordance with EM, in particular radical collaboration across boundaries, having multiple perspectives and ideas generated something new and useful for undergraduate students. Depending on the student's major course of study ("major") determines their choices they have in the STEM education minor (supplementary course of study). Tables 1 and 2 provide examples for students in different majors and how the STEM education minor can be obtained.

These plans of study were developed by an interdisciplinary group of faculty from seven departments (including mathematics, geoscience, biology, physics, electrical engineering, education, computer science, and gaming) and community partners representing professional engineering and informal STEM education. The group met over several months and followed a design thinking protocol for problem solving. The plans were then discussed and revised by the education faculty before voting unanimously to move forward with the minor being sent to college and university curriculum committees.

Table 1 Prototype of course requirements for education students

STEM Ed minor courses for education majors	
EDUC 2123 Introduction to STEM education	3 h
EDUC 2083 Design thinking in schools and communities	3 h
Content courses (as more become available, will add) • *CSG 1003 Game design* • *CSG 3613 Exploration of gaming technology* Additional STEM content courses may be taken, if not already required by major	6 h
*EDUC 3XX3 Research internship** Choose discipline of research interest Create a learning experience from researcher's expertise Students will work individually with an instructor to develop a research project, learning outcomes and summative assessment 45 h total or 3 h a week for one semester Exposition/share	3 h
Total hours	15 h

Table 2 Prototype of coursework for engineering and natural science students

STEM Ed minor courses for engineering/science/math majors	
EDUC 2123 Introduction to STEM education	3 h
EDUC 2083 Design thinking in schools and communities	3 h
EDUC 2023 Brain, learning and education <u>*OR*</u> *EDUC 3713 Child and adolescent development and learning*	Choose 1 3 h
EDUC 3733 Measurement and evaluation	3 h
*EDUC 3XX3 Research internship** Choose discipline of research interest Create a learning experience from researcher's expertise Students will work individually with an instructor to develop a research project, learning outcomes and summative assessment 45 h total or 3 h a week for one semester Exposition/Share	3 h
Total hours	15 h

3.2 Frameworks

Design thinking was used as a framework to develop the minor, and as such includes and enacts EM. The design thinking process has variations, but the author used the processes as outlined by Stanford's d.School and IDEO [12] as the primary framework. The process includes five iterative stages that include Empathy, Define, Ideate, Prototype, and Test/Feedback. The d.School has a specific educational focus and IDEO has both a community and business focus. Taken together, the framework and tools from these resources were the guides for developing the minor as well as for experiences offered in courses in the minor, especially the course Design Thinking in Schools and Communities, introduced in Table 2. Of note is the

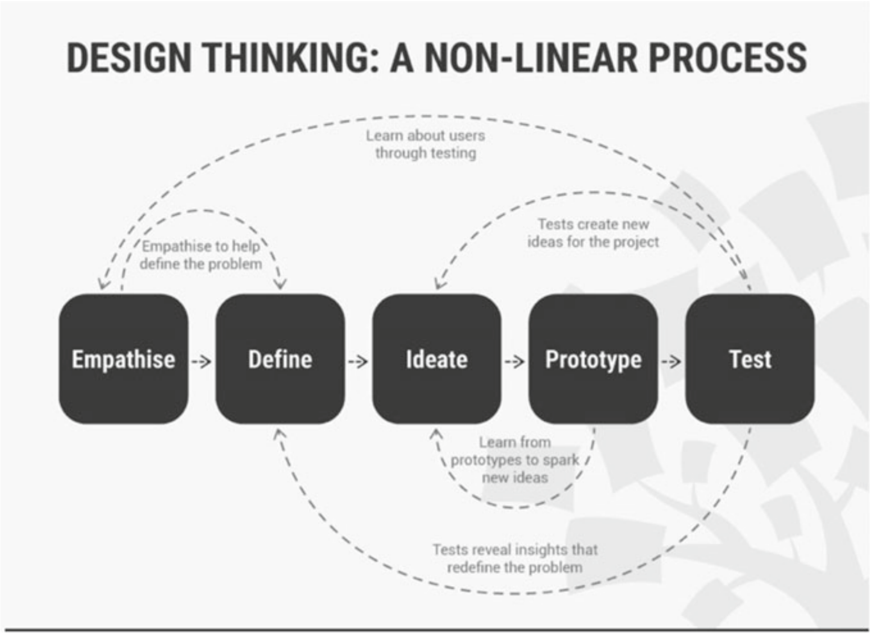


Fig. 1 Graphic of design thinking process [13]

iterative nature of the process, where each phase may be revisited according to the data collection and needs of the users. Figure 1 is a graphic representation of the process along with brief explanations of each phase.

Aligned with Fig. 1, designers at the Interactive Design Foundation [13, https://www.interaction-design.org/literature/article/what-is-design-thinking-and-why-is-it-so-popular] describe the process as:

… an iterative and non-linear process. This simply means that the design team continuously uses their results to review, question and improve their initial assumptions, understandings and results. Results from the final state of the initial work process inform our understand of the problem, help us determine the parameters of the problem, enable us to redefine the problem, and perhaps most importantly, provide us with new insights so we can see any alternative solutions that might not have been available with our previous level of understanding.

4 Examples of Entrepreneurial Mindset in a Design Thinking Project and Its Assessment

A challenge and opportunity related to entrepreneurial mindsets in STEM education is developing and assessing student's use of these mindsets. To elucidate on this issue, two examples are provided in the following sections.

4.1 Example of Entrepreneurial Mindsets in a Design Thinking Project

Students from the courses Introduction to STEM Education and/or Design Thinking in Schools and Communities (the two required courses in the minor, for all majors) were able to come together and participate in an entrepreneurial experience in the form of a design thinking challenge. Responding to a call for design proposals from a non-profit seeking to address problems specifically having an impact on African American communities, students were invited to participate. Seven students expressed interest and embarked upon a semester-long design thinking research project. Using the design thinking process, undergraduate students completed steps of the process including empathy, defining a problem, ideating possible solutions prototyping and testing/feedback.

Undergraduate students were able to see and apply entrepreneurial mindsets in the development of their solution to the problem they identified of racialized mathematics. By enacting the design thinking process, students embraced empathy, collaboration across boundaries, critical thinking and creativity, to name a few EM. Students operationalized racialized mathematics as the number of black middle school students who are qualified to be promoted to advanced mathematics courses, are not promoted as the same numbers of their white and Asian peers who are also qualified [14]. Their project titled "Just(ice) Math" consisted of a specialized, incentivized tutoring program, mobile math lab and community math center. Their work was featured in the inaugural Black Entrepreneurs and Inventors Hall of Fame gala sponsored by The Black Excellence Alliance. Students were also approached by a board member and founder of the National Society of Black Engineers wanting to support the program. Currently, students and the principal investigator are planning to take the project to the next iteration and pilot the prototype at a local high school and middle school.

Equally important, is that by participating in the weekly meetings, in person or virtually, students had the opportunity to not only reflect and practice design language and practices, they were able to interact with prototypes and provide feedback, thus improving the outcome. The project also provided time and space for students to dialogue about their own experiences and to challenge their own and others assumptions regarding racial inequality and education.

The project also brought together students from a variety of backgrounds and majors who wanted to continue in a real-life application what they had learned in either the Introduction to STEM Education or Design Thinking in Schools and Communities class. Although there were entrepreneurial experiences or those that required entrepreneurial mindsets in both classes, the foundation students experienced could be built upon in the real-life project. Students have reported that their own identities related to design thinking, an expression of entrepreneurial mindsets, have grown and improved. By having the opportunity to work on an entrepreneurial project, they were able to see their own contributions and creativity come to life with the birth of a project in response to a community need. The project was not framed as a for-profit business, which is what many of the students had previously thought about entrepreneurial mindsets. By offering classes that incorporate design thinking and projects based on this style of work, it is an inclusive way of providing experiences that students may not have had.

Entrepreneurial mindsets provided a framework for students to see themselves as creative and critical problem solvers. Engineering students in class identified with problem solving, but less so as creative or empathetic, part of the entrepreneurial mindsets included in design thinking. Conversely, students that did not have a strong problem solving or STEM identity, found their confidence and efficacy increased by completing design thinking projects. In addition, students saw themselves as contributing to the process and not side-lined in brainstorming solutions, creating prototypes, and defining the problems. With more students coming to the process, more voices and ideas are brought to the table, thus increasing the possibility of meaningful solutions to meet a wider variety of needs.

Including entrepreneurial mindsets in STEM curricula and classes, students saw the applications to more than businesses and for-profit scenarios. Applying the design thinking process allowed for robust engagement with social issues across a variety of contexts. For example, students had to reflect on their own experiences and biases regarding the proposed project and in particular the definition of the problem. Students determined that the problem was focused on the actual community and not circumstances. Using the tools and skills they were learning, students were able to correct the problem statement to align more with the empathy stage of the process.

Students continued to move through the process, which included investigating empathy by using a variety of tools. These tools included observation and interviews and analyzing data from the empathy phase to create problem statements and points of view to define the problem. From problem definition, students were able to move to the brainstorming phase followed by prototyping. Revisiting empathy data allowed for students to obtain feedback and test their brainstorm solutions and improve their prototype. In this instance, with the inclusion of a voluntary opportunity to enact entrepreneurial mindsets by using the design thinking process, students in STEM education were able to experience personal growth as well as present an innovative solution to racialized mathematics.

4.2 Example of Entrepreneurial Mindsets Assessments

Two assessments related to entrepreneurial mindsets that students complete in Design Thinking in Schools and Communities class are described in further detail. These include a Creative Confidence map and Mindset Reflection. In addition, the author describes an entire design research project students from the STEM education minor courses completed.

4.2.1 Creative Confidence Map

As an example of one way of assessing the mindset of creative confidence [15], students read a section of text on creative confidence, and watched a short TED talk

Fig. 2 Creative confidence map assessment [15]

given by IDEO founder David Kelley. After watching the video and reading the mindsets text, students craft an artifact of their choice, much like a concept map, displaying experiences in their life that are attributed to their creative confidence or lack thereof. As an important formative assessment strategy [16], the professor provides feedback in the form of notes and/or an individual meeting. The reading, video and assessment artifact act in concert to help inform the student of what experiences and messages may be influencing their perception of lack of creative confidence or creative confidence and how they may change their perceptions and actions in their design thinking approaches. An example of creative confidence maps is presented in Fig. 2.

4.2.2 Mindset Reflection

Another way entrepreneurial mindsets can be experienced and grown is with an assessment simply called mindset reflection. In this simple reflection, students in the Design Thinking in Schools and Communities class are given a list of mindsets adapted from the d.School, found as a resource from CREATEDU [17] and shown in Fig. 3. After a brief class discussion on each of the mindsets, students choose up to three mindsets they are curious about, want to grow in and/or see themselves as lacking. As a side note, the culture of the class is that of being asset based as opposed to deficit based, but students tend to see what is lacking in this assessment, as this is often the first time they have had exposure to the language and use of entrepreneurial mindsets. Students name the mindsets they choose and write a short reflection on why they chose the mindsets and how they see (or don't see) it manifest in their experiences.

At the end of the semester, students are given their initial self-reflection assessment back and are invited to revisit their assessment and reflect upon their class experiences related to their mindsets. Students are then able to see the growth they have experienced and comment on where they began and where they are at the end of the course. Overall, the students reflect that they have a deeper understanding or experience of entrepreneurial mindsets, see how they now have more capacity and use of the mindsets, and how they have learned more about each of the

Bias Toward Action	Get people out of their seats? (parents, teachers, administrators, students) Help people move forward when they feel stuck? Encourage student initiative? Do more, talk less? Embody quick turnarounds?
Focus on Human Values	Build empathy for others daily? Create a culture of interpersonal engagement? Incorporate empathy-building activities into the curriculum? Get people considering others?
Get Experimental and Experiential	Keep my ideas fresh and open to outside input? Get more experiential with curriculum? Get more experimental with curriculum? Create a "failure is good" culture? Encourage iteration? Decrease fear of failure? Engage people with ongoing projects and solicit feedback?
Collaborate Across Boundaries	Leverage outside experts? Create diverse working groups? Take advantage of different learning styles? Involve all community members in projects? Understand and leverage our own, and others', personal strengths?
Encourage Growth	Encourage reflection on and improvement of process? Encourage self reflection as a team member? Inspire creative growth?

Fig. 3 CREATEDU mindset list [17]

mindsets from what they originally reflected upon during the first half of the assessment. The professor provides formative feedback on the reflections. A student mindset included the following:

One of the weaknesses I had at the beginning was being afraid of failure. I did not like failing in classes, especially tests. I could not accept it. I always wanted an A on everything, but that never happens. I realized it is ok to fail, it happens to everyone, especially trying to come up with a solution in design thinking class. Everyone fails on at least one thing in their lifetime. Failing can be a good thing for you. You can learn from your mistakes, tasks and many more things.

Creative confidence maps and mindset reflections are two ways students assess themselves on entrepreneurial mindsets. They are two of the class experiences most commented on and provide a way for students and the professor to assess mindsets and the growth of using the mindsets in design thinking experiences. They also prepare students as they embark upon a design project of their choice as the culminating project of the course.

5 Conclusion

Using design thinking to enact entrepreneurial mindsets and practices, to create a STEM education minor allows for several growth and learning opportunities. It provides for the practices of collaboration and critical thinking to solve human centered problems. In addition, by using design thinking to create the minor, these mindsets are exemplified in the coursework within the minor, and act as an example of the mindsets in action. Students have opportunities to experience the results of design thinking as both a framework and process. The opportunities this provides for formal and informal educators continues to grow, and we look forward to the ongoing process of continuous improvement in making the minor more inclusive and accessible to many students of many majors. The design thinking framework and collaboration can be adopted by others who want to look at ways to solve problems in their institutions or contexts, that incorporate EM. The undergraduate students are then more prepared via the EM to face the challenges and opportunities they will encounter. They will embrace work in all forms with a cadre of skills necessary for the twenty-first century.

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Part III
Empirical Results of Enhancing an Entrepreneurial STEM Mindset

Fostering Integrated STEM and Entrepreneurial Mindsets Through Design Thinking

12

Aaron J. Sickel

To create, one must first question everything.

Eileen Gray (Architect and Designer)

Abstract

Design thinking refers to cognitive processes and design abilities that help designers develop solutions for human-centered problems. This chapter describes how design thinking can serve as an instructional driver to foster learners' integrated STEM learning outcomes and entrepreneurial mindsets. The author first defines the three constructs of design thinking, integrated STEM, and entrepreneurial mindsets. Next, he describes a design thinking project he facilitated for pre-service teachers enrolled in an elementary mathematics methods course as part of their university-based teacher education program. He unpacks how specific STEM learning goals and entrepreneurial mindsets were fostered and targeted during the project, with examples of pre-service teachers' learning from their design thinking journal entries. Drawing on research and his experience with design thinking education in the U.S. state of Hawai'i, the chapter concludes with the author's discussion of both challenges and opportunities for design thinking to play a prominent role across educational systems.

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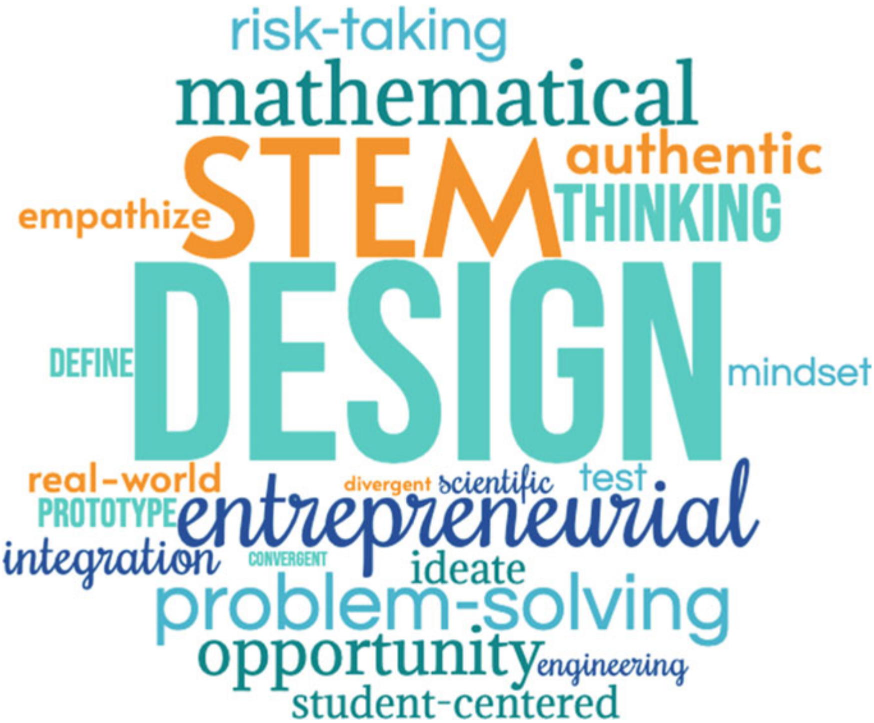
Graphical Abstract



Keywords

STEM · Entrepreneurial mindsets · Design thinking · Mathematics

1 Introduction

In the summer of 2017, I had just moved to Honolulu, Hawai'i, to take a new position with the Hawai'i State Department of Education's (DOE) Office of Curriculum and Instructional Design after spending nine years in the field of university teacher education. By taking the position of STEM educational specialist, I was exploring an opportunity to work more closely with school systems in the field of STEM education. One of the first conversations with my new administrator included the topic of design thinking; specifically, the state office wanted me to work with local organizations to begin offering design thinking workshops for teachers as part of a broader focus on supporting inquiry and innovation in Hawai‘i's public schools. At the time of the original conversation, I had read about design thinking and held only a cursory understanding of it from my prior work as a teacher educator. Yet, I was intrigued. One goal I had in this new position was to develop an openness to new ways of thinking about STEM—how students might become more engaged with learning the STEM subjects and how a range of pedagogical tools might help teachers deepen the learning experiences they create.

Over the two-year span I worked for the Hawai‘i DOE, design thinking became a priority within my portfolio of initiatives. I worked with local educational organizations who specialized in design thinking processes to offer professional development courses for teachers across the state. To upskill myself, I participated with the teachers in those professional development courses as a learner while they were led by design thinking educators. In the second year, I formed a design thinking collaborative so that educators across Hawai‘i who were using design thinking could work together to curate resources that would eventually be publicly shared with schools across the DOE. These resources offered specific ideas for lessons and units as well as strategies for scaling up the potential use and implementation of design thinking within individual schools and complex areas (a regional assemblage of schools, similar to school districts in U.S. mainland states). Design thinking had a considerable impact on my own way of thinking and my work as a STEM educator. I believe there is great potential for it to contribute to new ways of thinking about STEM education, and more specifically to the goals of this book, the fostering of learners' entrepreneurial mindsets through STEM learning experiences.

Following this introduction (Section "Introduction"), the chapter is organized into four ensuing sections. In Section "Defining the Constructs", I begin with a description of my views of design thinking, integrated STEM, and entrepreneurial mindsets based on literature and my work in Hawai‘i. In Section "The Paper Towel Project and Its Results", I provide a descriptive example of how I integrated a design thinking project with the aim of fostering integrated STEM learning goals and entrepreneurial mindsets for pre-service teachers in an elementary mathematics methods course as part of an undergraduate teacher education program. In Section "Challenges and Opportunities for Design Thinking", I discuss challenges and opportunities we have in the fields of integrated STEM education and entrepreneurial mindsets to make meaningful use of design thinking in the future. I conclude the chapter with Section "Conclusion" by summarizing the important concepts of the chapter.

2 Defining the Constructs

2.1 Design Thinking

Design thinking has become an increasingly popular construct in the field of business and commerce [1, 2]. Although it has no universal definition, Kimbell [3] explains that design thinking is described primarily from three different perspectives: (1) A general theory of design, (2) a cognitive style, and (3) an organizational resource.

Regarding the first perspective (design theory), design as a field is difficult to describe because "design has no special subject matter of its own apart from what a designer conceives it to be…design thinking may be applied to any area of human experience" [4, p. 16]. Whether it involves civil engineers designing a dam, a business manager designing a marketing plan, an artist designing a sculpture, or a teacher designing a lesson, design can play a role in the authentic work of any career and in the management of our everyday lives. What defines design thinking as a field is the negotiation of wicked or ill-defined problems. This kind of problem is open-ended, complex and has many possible solutions [5].

Regarding the second perspective (cognitive style), design thinking has evolved from a focus on specific descriptions of technological advances to also include a deeper look at the cognitive processes employed consistently by designers [6]. While not always linear in nature, design thinking is often associated with the nature of designers' active and creative thinking as they negotiate problems. In Razzouk and Shute's review of research on design thinking, they define it as "an analytic and creative process that engages a person in opportunities to experiment, create and prototype models, gather feedback, and redesign" [7, p. 330]. The five-phase process presented in Fig. 1 was developed by the Hasso Plattner Institute for Design [8] (colloquially called the d.school) and has been used extensively by a variety of organizations as well as elementary, middle school, secondary, and post-secondary learning contexts.

Regarding the third perspective (organizational resource), brothers David M. and Tom Kelley further popularized the term, design thinking, with the launch of IDEO in 1978, a global design and innovation company aimed at helping businesses design products and services [9]. They began thinking about the elements, mindsets, and abilities that allow designers to be successful and were the most learnable by organizations wishing to tackle ill-defined problems. These elements, mindsets, and abilities include both cognitive constructs (moving between concrete and

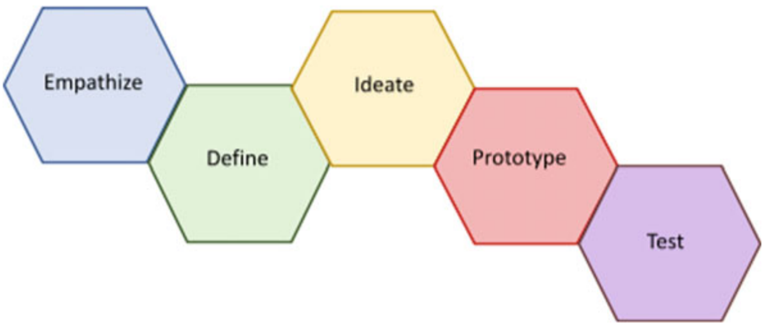


Fig. 1 Design thinking process developed at the d.school (reprinted with permission of [8])

abstract) and affective constructs (navigating ambiguity with an optimistic orientation). They discuss the importance of combining feelings, intuition, and inspiration along with rational and analytical mindsets to develop solutions that are both meaningful and functional [9].

2.2 Integrated STEM

It is important to articulate my views of integrated STEM teaching and learning. Below, I discuss my view of integrated STEM in alignment with essential features developed by a Hawai‘i DOE STEM Work Group, followed by reconsiderations of engineering design processes (EDPs) that often serve as the foundation for integrating STEM learning [10].

2.2.1 FAIR Features

As the STEM specialist for the Hawai‘i DOE, I came to understand there were many exciting examples of schools developing STEM programs or emphasizing STEM learning. At that time, the state had generally defined STEM education as encompassing three perspectives and goals [11]:

- Developing students’ learning and interest in the subjects of science, technology, engineering, and mathematics (silo view)
- Exposing students to integrated STEM learning experiences (integration view)
- Developing students’ “STEM skills”, e.g., problem-solving and creative thinking, which are helpful for both STEM and non-STEM careers (skills view).

In 2017–2018, I convened a work group of STEM teacher leaders with the task of further articulating goals for STEM education to public schools across the state. After examining the three existing goals, we were particularly interested in the notion of integrated STEM, which, on the one hand, has shown to produce positive student learning outcomes [12], yet on the other hand, has been difficult for teachers to operationalize [13]. We felt that further articulating this goal and view of STEM would help support the other two goals. After considering STEM literature and their own experiences as STEM educators, we asked the question, “What are the most fundamental or essential features of a high-quality STEM learning experience, regardless of grade level or guiding curriculum materials?” We felt that answering this question could provide clarity and coherence for future state-level STEM initiatives.

The resulting features were titled the FAIR Features of Integrated STEM, including: Student-Centered Instructional **Framework**, Authentic **Assessment**, Purposeful **Integration**, and **Real-World** Connections. Below, I describe each feature (the full explanation of each feature can be found in a document linked to the Hawaii DOE’s Learning Design website [11]).

Student-Centered Framework

To help teachers think about structuring STEM learning experiences, we articulated integrated STEM as being driven by an instructional framework that is student driven. We encouraged multiple frameworks depending on the specific experience being designed, which might include instructional approaches/sequences such as project-based learning [14] and/or design processes such as engineering design or design thinking.

Authentic Assessment

We encouraged teachers to conclude integrated STEM learning experiences with an authentic assessment, which we defined as being authentic to the STEM disciplines (e.g., developing a scientific presentation in similar ways that scientists would) and/or the goals of the specific task (e.g., if learners are being asked to develop a solution to a problem, they actually carry out that solution). We clarified that culminating assessments should be of varying types (e.g., physical models, written explanations, computer applications, etc.), and should assess skills and knowledge of particular STEM disciplines. While formative assessment is encouraged during integrated STEM experiences, we focused this feature on the critical role of authentic, culminating assessments.

Purposeful Integration

We viewed integrated STEM as involving the purposeful integration of at least two STEM subjects [15] and potentially non-STEM subjects [10]. Regarding standards, we felt a balance was needed between the state's adoption of standards-based learning and the open-ended nature of integrated learning. Specifically, there needed to be an anchoring standard of at least one STEM subject tied to the grade level according to the Next Generation Science Standards (NGSS) [16], Common Core Mathematics Standards [17], and/or International Society for Technology in Education (ISTE) Standards [18], but that the other subject connections may not be as explicitly tied to the targeted grade level, depending on the task. Essentially, we felt the problem, challenge, or task needed to authentically drive the learning as much as possible.

Real-World Connection

We encouraged teachers to help learners make explicit connections to the world around them throughout a STEM learning experience. This feature encourages a range of connections, from enacting or engineering solutions to addressing sustainability issues on the school campus to proposing solutions for teacher-presented scenarios, albeit scenarios related to a real-world problem.

2.2.2 Reconsidering Engineering Design Processes

It is helpful to compare design thinking practices with traditional views of engineering design processes in terms of human aspects of design and the role of contextual constraints. While I concur with other STEM educators' position [10] that EDPs can serve as important integrators or driving processes of STEM integration, I also believe there are ways in which traditional views of engineering design can be complemented by design thinking processes. Some scholars have discussed similar features between the two [19]. For example, the NGSS describes three important components of engineering design: defining problems, designing solutions, and optimizing solutions [16]. One might see some degree of alignment between these components and the d.school design thinking process, with the Define phase (defining problems), Ideate phase (designing solutions), and the Prototype and Test phases (optimizing solutions) addressing all components. However, such an explanation misses a few key elements from the perspective of design thinking: (1) highlighting the role of empathy and affect in design processes; and (2) ideating creatively before considering constraints. These two elements are discussed in turn.

Empathy and Affect

The Empathize phase can serve as a powerful means of connecting learners to the world around them, as they are required to consider how a particular real-world phenomenon is related to human issues and concerns. Design thinking educators have observed greater investment from students by beginning a design experience with empathy. For example, Cook and Bush described a STEM challenge using design thinking as the driving process in which fourth-grade students designed a prosthetic lower arm and hand to help a kindergarten student work on a computer [20]. They discussed the critical role of empathy because it "set the stage for students to care about the problem and as a result, they were personally invested and wanted to do everything in their power to design a solution for the kindergartner" (p. 99).

The Empathize phase supports learners' development and application of affective mindsets and characteristics throughout the experience. Brown describes a design thinker's personality profile, and extends the description beyond engineering design skills (e.g., thinking as part of a team, thinking and communicating in several languages of design) to move further into the world of affect [21]. Design thinking traits speak more to willingness, attitudes of persistence, and open mindedness. Not just tolerating ambiguity but a willingness to ask questions and take on new approaches; not just thinking as part of a team, but also adopting the perspective of someone else; not just handling uncertainty but adopting an optimistic attitude that a solution can be designed. In the same way that science education advocates for science as a human endeavor [16], design thinking offers a helpful nudge in the same direction for engineering and integrated STEM education.

Ideating Creatively Before Considerations of Constraints

A second way that design thinking offers a new perspective on traditional notions of engineering design is that it allows for a reconsideration of the role and placement of constraints during design processes. Many EDPs used in elementary, middle school, and secondary education highlight the critical role of constraints early on in the process. For example, a useful engineering model presented by the Teach Engineering website begins with the *Ask* phase before continuing on with *Research*, *Imagine*, *Plan*, *Create*, *Test*, and *Improve* [22]. One example prompt listed for the *Ask* phase includes: *What are the limitations?* However, during the early stages of design thinking, one does not need to initially consider constraints. Rather, the goal is to be open to the needs of end-users, define the problem in unique ways, and ideate creative solutions. This is not to say that reality and real-world constraints should not come into play. However, the advantage of this approach is that the designer does not need to prematurely take ideas off of the table, and it is always possible that part of a wild idea will become useful later on in the process. Moreover, creativity may be unnecessarily obstructed if learners focus intensely on constraints at the beginning of design processes. In essence, innovative design needs many ideas, with full acknowledgement that many of them will be adjusted or abandoned. This allows the design thinking process to make use of both divergent and convergent thinking during integrated STEM learning experiences. It facilitates divergent thinking early on while problems are being defined and solutions ideated, and then convergent thinking as solutions are fine-tuned through prototyping and testing [9].

I believe the advantages of design thinking might be a welcomed contribution within the field of engineering education, which in turn supports more of its use within integrated STEM education. Dym et al. discuss several concerns about the traditional engineering curriculum at universities. They call for engineering curricula to incorporate more attention to design, given that engineering programs have overly focused on knowledge of technical systems without attention to "the intellectual content of design," which is "consistently underestimated" [23, p. 104]. Due to concerns from industry about beginning engineers' preparedness with design, there has already been a shift toward more incorporation of design capstone courses at the conclusion of programs and cornerstone design courses at the beginning [23, 24]. This shift could potentially support a fuller set of desirable mindsets for engineering students, including a willingness to divergently identify new opportunities for innovative designs and a propensity for failing forward with confidence, both of which are discussed as important entrepreneurial mindsets in the next section.

2.3 Entrepreneurial Mindsets

After discussing the ways in which design thinking supports previously established goals of integrated STEM, I turn my attention to the desired outcome of developing students' entrepreneurial mindsets. The Network for Teaching Entrepreneurship [25], an international non-profit organization focused on entrepreneurial training and education, has articulated eight domains of the entrepreneurial mindset: (1) critical thinking; (2) flexibility and adaptability; (3) communication and collaboration; (4) comfort with risk; (5) initiative and self-reliance; (6) future orientation; (7) opportunity recognition; and (8) creativity and innovation. At a glance, STEM educators would be hard-pressed to view any of these domains as particularly incompatible with the goals of integrated STEM and could go as far as to say they are inherently situated within the design of most integrated STEM learning experiences. Therefore, the question becomes, what might be some ways in which the construct of entrepreneurial mindsets adds a new dimension to the goals of integrated STEM? I believe there are two distinguishing domains of entrepreneurial mindsets, which have great potential to add value to the design of STEM learning experiences: (1) opportunity recognition; and (2) comfort with risk.

2.3.1 Opportunity Recognition

The field of entrepreneurship is largely defined by the critical role of opportunities [26]—specifically "the process of discovery, evaluation and exploitation of opportunities" [27, p. 218]. In their book, *The Entrepreneurial Mindset*, McGrath and MacMillan present characteristics of habitual entrepreneurs, three out of five including notions of seeking and pursuing opportunities while avoiding exhaustion [28]. They go on to discuss different ways that entrepreneurs "stock the opportunity register" (p. 5) by constructing new ideas through opportunity recognition approaches, which include:

- *Redesign*—modify existing products/services
- *Differentiate*—highlight aspects of your products/services that distinguish you from competitors
- *Re-segment*—focus on better serving a segment of the target population with a product/service
- *Reconfigure*—change the current basis for segmentation and/or attract people to your product/services in a radically different way.

They present several specific strategies to aid entrepreneurs with these approaches, for example, creating attribute maps that help distinguish customer attitudes toward particular attributes of a product and sketching out fictitious super-products that would solve all problems under scrutiny. Entrepreneurs pursue opportunities that combine innovative thinking with practicality. As described earlier, one desired outcome of integrated STEM education is for learners to produce authentic products (FAIR Features) for human-centered problems (Empathy). To do this well, it will be helpful for learners to develop a mindset of opportunity recognition so that they identify key opportunities to innovate in ways that are helpful for their intended audience, user, client, or customer.

2.3.2 Risk-Taking

Due to the need to find new opportunities, entrepreneurship is not typically rooted in processes of optimization [27], a characteristic that distinguishes it from EDPs typically designed for elementary, middle school, and secondary education [16]. In part, this is based on an entrepreneur's need to act upon opportunities in tight timelines. A study by Busenitz and Barney revealed that entrepreneurs were more likely to exhibit biases toward "overconfidence (overestimating the probability of being right) and representativeness (the tendency to overgeneralize from a few characteristics or observations)" [29, p. 10]. In essence, entrepreneurs engage in risk-taking that privileges taking chances with new opportunities without becoming bogged down with counterfactual thinking, regret, or inaction [27]. Engaging in STEM learning experiences from a design thinking perspective inherently requires a willingness to try an idea and then adjust or abandon that idea as needed. A risk-taking mindset is essential for this aim.

3 The Paper Towel Project and Its Results

After defining the constructs of design thinking, integrated STEM, and entrepreneurial mindsets, I now describe an example of a design thinking project that attempts to foster integrated STEM outcomes and entrepreneurial mindsets.

3.1 Context

During my time as STEM specialist for the Hawai‘i DOE, I began experimenting with explicit integration of design thinking into STEM units. The following project has been incorporated into professional development initiatives for in-service teachers and mathematics methods courses for elementary pre-service teachers. The purpose of this project is to help develop teachers' understandings of integrated STEM, design thinking and entrepreneurial mindsets by engaging in an experience as learners that attempts to integrate all three constructs.

To describe the paper towel project, I will first explain the sequence of activities that occurs when I facilitate the project in the order of the five design thinking phases from the d.school [8]: Empathize, Define, Ideate, Prototype, and Test. The description below is based on the most recent project facilitation in a mathematics methods course for elementary pre-service teachers in a university-based undergraduate teacher education program offered in 2021. Descriptions of discussions that ensued during the project are based on my planning documents as instructor of the course. The course consisted of seventeen pre-service teachers, thirteen of whom provided consent for their course assignments to be shared in published outlets. The description below includes specific examples of journal excerpts from three groups of pre-service teachers. After describing the five design thinking phases, I will then unpack how integrated STEM and entrepreneurial mindsets were fostered throughout the project. I will conclude this section with a discussion of items from a pre- and post-course survey completed by the thirteen consenting participants.

3.2 Design Thinking Phases

Given that the pre-service teachers were adults who would benefit from experiencing the challenge and uncertainty associated with these constructs, it was explained that the project would ask them to engage with content and practices above the elementary level. The learning experience began with a question about a common household product—paper towels. Pre-service teachers were provided the following scenario.

Your consulting business has been hired by a non-profit company, Consumer Reports™, to provide advice to everyday consumers about what paper towel brands represent the best value. You will help Consumer Reports™ consider new ways of testing paper towels that could help lead to insights into user experience and make the most helpful recommendations. Your project will have the following parameters:

- *You will engage in the Design Thinking Process to develop your recommendations*
- *Your project will need to include some form of paper towel testing*
- *You will need to give consideration to the price of paper towels and the concept of value.*

Pre-service teachers then learned more about Consumer Reports™ and their mission to help consumers become informed about a wide range of products. They watched videos demonstrating how Consumer Reports™ employees develop and perform tests on those products to compare them based on performance (e.g., placing a specific amount of food on a dinner plate before running it through different brands of dishwashing machines). Pre-service teachers completed a journal aligned to the design thinking process as they engaged in the activities.

3.2.1 Empathize

In order to engage in more purposeful testing and to provide helpful recommendations, it is important to think about the end-user. For this phase, pre-service teachers interviewed a friend or family member and each other to develop different examples of user experience. The goal was not to collect a large amount of data to systematically look for the most common responses, but rather to look at a range of different experiences and seek out unexpected insights. I have found that it is important to discuss the concept of *value* with the whole class during this first phase, and how that concept may have different meanings for different individuals. For example, while one person may interpret value to be based primarily on the notion of best quality for the cost, others may interpret value to include notions of brand loyalty or environmental consciousness. It is helpful for pre-service teachers to have an open mind about the concept of value before proceeding with the interviews. Table 1 presents the characteristics of interview prompts important for the Empathize phase of design thinking, along with examples of groups' written prompts aligned to those characteristics.

3.2.2 Define

After gaining information from paper towel users, pre-service teachers engaged in a process of defining a problem they wanted to solve. In groups, they looked across

Table 1 Interview prompt characteristics and examples

Prompt characteristics	Example prompts discussed as a class	Fall 2021 pre-service teacher groups' prompts
Elicit specific experiences	You mentioned you use the paper towel to clean dirt off of your counter. Can you show me how?	How often do you use paper towels? Do you prefer using paper towels over other types of cleaning product (reusable cloths, etc.)? *(Group 1 Journal)*
Get at the *Why*	Why do you consider ____ characteristic when purchasing paper towels?	Why do you usually buy that brand? *(Group 2 Journal)*
Elicit feelings and emotions	How does it make you feel when a paper towel does not work in the way you want?	What would you use as a substitute for paper towels? *(Group 2 Journal)*
Engage users in unexpected perspectives	Think about your favorite activity or hobby. How might a paper towel be helpful or play a part in that activity?	What would your ideal paper towel company be like? Your ideal paper towel? *(Group 3 Journal)*

their interview responses and began developing a specific point of view. They typed individual excerpts of interview responses onto sticky notes using the google application, Jamboard™. They grouped their notes together, synthesizing information about their users and the specific needs they have, with the goal of constructing insights about their paper towel experiences. One design thinking strategy I encouraged pre-service teachers to incorporate was to focus on extreme users (e.g., those who use paper towels constantly or rarely). Additionally, pre-service teachers were encouraged to be aware of potential insights regarding users' preferences with particular brands or expectations of paper towel companies. Table 2 provides examples from three groups' journals of how identified needs can lead to insights for different types of users.

There are many helpful insights that arose from the Define phase, which we discussed as a whole class. For example, pre-service teachers developed insights that are common across extreme users (e.g., the notion that absorption and durability are the most important characteristics). Additionally, there were insights that can be viewed as complementary. Group 1 discussed how the constant user likes to use a paper towel more than once within a certain timeframe, and preferred to reuse paper towels more so than cloth rags. While this finding is not a direct insight from Group 2's rare user, if that person was able to use a single paper towel for cleaning more than one surface, this would likely be seen as beneficial. Affordable cost was highly valued by both the extreme and rare user in Table 2. However, we discussed the opportunity for companies to persuade their users that increased total price might be cheaper over time if customers get more money out of each towel used during cleaning due to durability or reusability.

Table 2 *Points of view* for users of paper towels

Users interviewed by pre-service Teacher groups	Needs	Insights
Constant user *(Group 1 Journal)*	• Weekly/daily cleaning • Drying hands • As a replacement for a plate • Does not care about the brand, only wants the cheapest single roll on the shelf	• Most important characteristics is that it is cheap and a single roll • Does not care about effects on environment • Uses it very often to dry/clean hands • Does not like the idea of having to wash a rag after using it once to clean. It's a waste of water
Rare user *(Group 2 Journal)*	• To wipe hands dry • Clean tables • Put snacks on top	• Cost is a factor, only buys when paper towels are on sale • Values durability
User interested in specific companies *(Group 3 Journal)*	• Cleaning and spills • Wiping hands post-washing • Eating	• Absorption and durability are important • Consumer would like information about companies to be more accessible

The Define phase concludes with the learners constructing *How Might We* questions that focus on insights from the *Point of View* activity. This allows the learners to narrow the focus on one or two problems with purpose rather than an open slate of potential problems. Two examples are presented below.

- How might we develop tests comparing the performance of different paper towel brands that are authentic to specific users' needs?
- How might we make a recommendation about the mathematical value of different paper towel brands?

3.2.3 Ideate

After defining a problem, the next phase was focused on brainstorming a wide range of possible solutions based on users' insights from the Define phase. Prior to brainstorming, pre-service teachers were reminded to follow the guidelines of ideation from the perspective of design thinking:

- Quantity over quality—record as many ideas as possible
- Encourage wild ideas
- Build off of each other's ideas.

They brainstormed ideas to test and compare the performance of different brands of paper towels individually, in groups, and then as a whole class. Several of the users expressed interest in durability, and therefore all three groups designed a

Strength Test to identify the weight that a towel from each Brand could withstand before breaking. In addition to this common *Strength Test*, the groups discussed more divergent views of tests that might help them assess a towel's other authentic functions, i.e. cleaning surfaces and absorbing liquids. The following list presents examples of tests considered as a class:

- *Shammy Test*: How quickly does the paper towel dry before it can be used again?
- *Dust Test:* How many counters or shelves can the same paper towel be used to clean before it's saturated?
- *Scrub Test*: How many hard scrubs can one get out of the paper towel on scratchy surfaces before it tears?
- *Spill test*: How many paper towels does it take to wipe up a common spill of liquid?
- *Mildew Test*: How long can a wet paper towel sit around before it smells or develops mildew?

3.2.4 Prototype

The purpose of the Prototype phase was for pre-service teachers to commit to at least two different testing ideas and try them out quickly and safely, so they could make any necessary adjustments or change course without spending a substantial amount of time in a formal Test phase. Groups were encouraged to perform just one trial of each test and then discuss what worked or what might need to be changed. For example, Group 3 prototyped a *Spill Test*. Their initial procedure involved spilling ½ cup of water on a surface and recording the number of towels needed to absorb water from the spill area. According to their report, the test seemed to be helpful but they also found some elements of the procedure that needed clarity. They provided the following notes:

- *Tests give good information*
- *To implement consistently we need to wipe the spill and not remove the dripping towels from the spill area until spill is dry (affects number of towels used)*
- *Use less water; ¼ measuring cup*

(Group 3 Journal).

Figure 2 provides images submitted by Group 3 to show how the test changed to laying paper towels and leaving them in the spill area after the first iteration. They made this change for two reasons: (1) to avoid transferring water away from the spill area inconsistently, and (2) to more authentically engage in a clean-up process.

3.2.5 Test

After the groups' paper towel tests were prototyped and adjusted, they engaged in the final Test Phase. Pre-service teachers were directed to perform their paper towel tests with different brands using clear, consistent procedures, considering what is

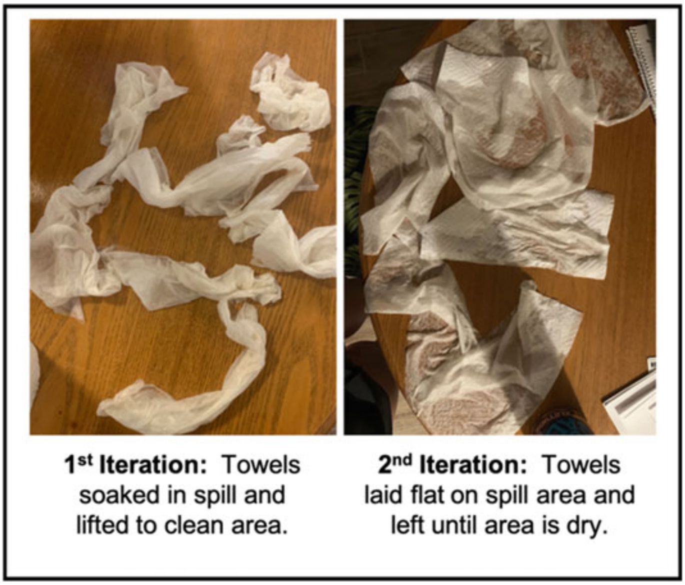


Fig. 2 Group 3's images of the spill test for two iterations of the prototype

being manipulated (independent variable), measured (dependent variable), and what variables are serving as the controls. They were directed to consider the question of mathematical value, recording information related to cost, number of rolls, and number of sheets per roll.

Pre-service teachers analyzed their data from the Test phase and developed recommendations both for their testing procedures but also regarding which paper towel brand is the best value considering performance and cost. This led to an explicit focus on mathematical reasoning. They realized that to make claims of comparison, units needed to be precise, manipulated, and used consistently in the analysis. They were encouraged to frame a mathematical question to answer. For example, Group 3 sought to answer the question, *What is the user's cost per spill of ¼ cup of water?* Table 3 presents the mathematical calculations used by Group 3 to determine the customer's cost per spill of water. This table provides their calculations for one brand of paper towels.

Group 3 completed the same steps of analysis for another brand that performed the *Spill Test*. Table 4 shows a comparison of calculations comparing two different brands.

Group 3 found that the mathematical calculations provide nuanced insights into the performance of the two brands. For example, based only on the cost of one roll and the performance of the brands, one might conclude that Brand B is the best value. One roll of Brand B cost $1.49 with an average performance of 8 sheets per spill, whereas one roll of Brand A cost $1.92 with an average performance of 8.5 sheets per spill. With Brand A being more expensive per roll and requiring half of one sheet more than Brand B to clean up each spill, the conclusion could be in favor

Table 3 Group 3's calculations for one brand of paper towels (Group 3 Journal)

Step	Equation	Calculations for Brand A
1. Establish cost per sheet	[Package cost/(#Rolls × #Sheets per roll)] = **Cost per sheet**	Cost per sheet = [$30.72/(16 × 250)] = **$0.0077 per sheet**
2. Determine number of spills cleaned per roll	Sheets per roll/Average #sheets required to clean spill = **#Spills per roll**	250/8.5 = **29.4 spills per roll**
3. Determine cost per spill	Cost per sheet × Average #sheets required to clean spill = **Cost per spill**	$0.0077 × 8.5 = **$0.0655 per spill**

Table 4 Spill test calculations comparing two brands of paper towels (Group 3 Journal)

Calculations	Brand A 8.5 sheets per spill (Recommended)	Brand B 8 sheets per spill
Cost per roll	$1.92	$1.49
Cost per sheet	$0.0077	$0.0155
Spills cleaned per roll	29.4	12
Cost per spill	$0.0655	$0.124

of Brand B. However, with further numerical analysis, Group 3 found that the cost per sheet was actually lower for Brand A because the roll had so many more sheets than Brand B (250 vs. 96 sheets per roll). This explains why one roll of Brand A can clean up more than twice as many spills than Brand B, with the cost per spill being almost half (6.5 cents vs. 12.4 cents). Therefore, Group 3 determined the cost value to be in favor of Brand A, and recommended it from the perspective of cost analysis.

In addition to analysis of economic value, pre-service teachers researched information on people's practices and preferences with paper towels as well as companies' approaches to ethical issues. They drew on this information to present their final recommendations to the class and the users they interviewed during the Empathize phase. A whole-class discussion ensued, focusing on questions about the mathematics and science they grappled with during the project, as well as the following questions that remained uncertain:

- How might a paper towel be designed differently for particular goals?
- How could a redesign lead to different marketing strategies, appealing to different types of users?
- Is there a way to completely change the paper towel market?

This discussion was rich with endless complexities for a seemingly simple product. For example, a topic explored in depth was the detrimental environmental impacts of paper towels. Pre-service teachers found examples of paper towels made of biodegradable, non-GMO grasses such as bamboo and sugarcane as well as reusable, compostable towels made of cellulose and cotton that are also highly absorbent, thereby also meeting the need of several of the constant users [30]. This presents an opportunity to market the product simultaneously to the environmentally conscious user, the constant user who wants ease of use, and the rare user who can spend less money by purchasing efficient, reusable towels.

Group 1 found that paper towels could present some health hazards for people. They reported the following notes from their research:

- *To create paper towels, they go through a chemical (chlorine) bleaching process*
- *This process may leave harmful, potentially toxic, dioxins in the paper towels*
- *Dioxins have been found to be carcinogenic to humans and animals*

(Group 1 Journal).

Group 1 reported that one of their users might change their daily practices with paper towels based on the test data and research information presented to the user, including information about the potential to be more environmentally conscious by using reusable antimicrobial towels:

Based on the absorption test and durability tests, she [user] might reconsider using a different brand when cleaning because she sees that cheap isn't always the best. For now, she will continue to use paper towels one time because of the germs. She will no longer be using them to dry her face due to the fact that paper towels may contain chemicals that are carcinogenic. She is wary about the antimicrobial towels but may consider them for in the bathroom or if she uses them for one specific purpose in the kitchen. (Group 1 Journal).

Based on a user's interest in the companies that manufacture the paper towels, Group 3 researched the ethical practices of their selected paper towel brands. They reported that one user was "glad to know that [the recommended brand] is managed by a more ethical company [than other brands]" and wished that "information like company ties, values, and Human Rights information policies were more accessible to consumers" (Group 3 Journal).

Ultimately, pre-service teachers reflected on their experience as design thinkers, realizing that they integrated a wide range of knowledge and skills during the project, and arrived at insightful solutions.

3.3 Facilitating Integrated STEM

Below, I discuss how this design thinking project supported the FAIR Features of STEM and empathy while avoiding a premature consideration of constraints.

3.3.1 Design Thinking Supported the FAIR Features and Developing Empathy

The design thinking sequence met the criterion of a Student-Centered Instructional **Framework**; it provided an overarching structure but allowed pre-service teachers to engage in exploratory experiences and make their own decisions about what questions to ask, testing ideas to prototype, information to research, and how to pursue their final recommendations.

The final presentation of the paper towel project served as an Authentic **Assessment** in that learners were required to develop tests authentic to how a real company engages in the same practice.

There were many opportunities to engage the pre-service teachers in Purposeful **Integration**. The anchoring common core mathematics standard asked pre-service teachers to "use units as a way to understand problems and to guide the solution of multi-step problems" [17, para 1]. The mathematical analysis to assess a paper towel brand's value required multi-step thinking, leading to a tabular mathematical model (See Tables 3 and 4) with a precise selection of units. This project had the added benefit of helping pre-service teachers view the mathematics component as creative and necessary to arrive at a final solution. The project also required learners to engage in the scientific practices of planning and carrying out investigations [16], as they had to develop fair tests, and engineering practices of defining problems and solutions. Last, pre-service teachers engaged in internet research and met ISTE standard 3.a. by employing "effective research strategies to locate information and other resources for their intellectual or creative pursuits" [18, para 4].

Linking the paper towel performance to cost provided an opportunity for an explicit **Real-World** Connection, because the pre-service teachers are all consumers who purchase paper towels. This Real-World Connection supported the broader goal of integrating **empathy and affect** into the STEM learning experience. The pre-service teachers become invested in developing a final recommendation that would inform their users from the Empathize phase, who were their own friends and family. The groups' research on the potential hazards of paper towels and companies' ethical practices provided information that was helpful to their users, which supported pre-service teachers with considering the information needs of a wide range of customers.

3.3.2 Design Thinking Supported Divergent Thinking by Avoiding a Premature Focus on Constraints

It is intuitive for pre-service teachers to consider tests focused on durability and absorption based on their own experience of using paper towels. However, the design thinking sequence pushed pre-service teachers to ideate a range of test ideas that initially seemed unusual or impractical due to the focus on users' needs. This led to creative test ideas often excluded from earlier iterations of the unit grounded solely on scientific experimentation, for example the *Shammy Test* and *Mildew Test*, which focused on users' needs related to reusability. Group 3 decided to engage in a *Spill Test* in a way that mirrors how a user might clean up a spill with a desire for authentic results. Constraints were eventually examined during the Prototype phase, but by avoiding a discussion of constraints early in the process, pre-service teachers were free to ideate as many test ideas as they could. This ideation step helped facilitate my broader goal of supporting divergent and creative thinking during integrated STEM learning experiences.

3.4 Facilitating Entrepreneurial Mindsets Through Design Thinking

The design thinking sequence supported the entrepreneurial mindsets of opportunity recognition and risk-taking, as discussed in turn.

3.4.1 Problem-Framing Supported Opportunity Recognition

Design thinking engages learners in perspective-taking and problem-framing [9]. The Define phase of the d.school's design thinking process is a critical component that requires more time than what learners might originally anticipate. In the paper towel project, pre-service teachers invest time in thinking about the problem flexibly. They asked questions like, "Does a typical strength test of placing pennies on a towel until it breaks solve anyone's problem?" Without dedicated time to think about problems in relation to insights from user experience, a proposed solution may be innovative in design but not of much use to end-users. The problem-framing component inherently imbedded into design thinking processes allows for learners to brainstorm and discuss new opportunities. This occurred during the paper towel project during the Define and Ideate phases when pre-service teachers looked for opportunities to redesign a typical paper towel test to be more authentic to their users' needs, and after the Test phase, where the conversation naturally veered toward ongoing opportunities to re-segment paper towel products for users who care about health, environmental and ethical issues.

3.4.2 Prototyping Supported Risk Taking

Design thinking has great potential to help learners become more comfortable with taking risks with its focus on recognizing new and potentially surprising opportunities from the Empathize and Define phases. Risk taking is particularly supported by the Prototype phase. Engaging in iterative prototyping can increase learners' creative confidence in trying new ideas [31] with less pressure for any one idea to immediately succeed. This failing forward perspective makes it less likely for a learner to invest too much time and resources in a solution idea that does not work, a natural challenge when working with ill-structured problems. A typical scientific experiment would require a methodical and careful set of procedures to ensure fair testing (considering independent and dependent variables) and safety. This type of testing is employed in the final Test phase. However, in the design thinking process, pre-service teachers were first encouraged to do a shorter, simplified version of their ideas (as prototypes). The pre-service teachers developed an idea with paper towels in hand, and then, had dedicated time to make any adjustments without feeling rushed. During our class discussions, several pre-service teachers noted that the Prototype phase was helpful with maintaining a low-stakes atmosphere while also allowing for improved procedures during the final Test Phase.

3.5 Pre-service Teachers' Self-reported Course Outcomes

Design thinking projects that foster integrated STEM and entrepreneurial mindsets may need to be integrated into courses or timeframes that are traditionally dedicated for individual STEM subjects within elementary, secondary, middle school, and postsecondary learning contexts. The paper towel project was an extensive unit lasting multiple weeks within a one-semester mathematics methods course for elementary pre-service teachers. The paper towel project was designed to be in support of broader course goals; specifically, developing pre-service teachers' confidence as learners and teachers of elementary mathematics. The project provided a context for pre-service teachers to engage in a student-centered, mathematics-centric STEM unit as learners while also observing and discussing how I designed and facilitated the experience as their teacher. Thirteen pre-service teachers from the course responded to survey items aligned to the desired course outcomes pre- and post-course. The results are presented in Table 5.

Across the three survey items, the majority of pre-service teachers reported a positive change on each of the three items (e.g. Disagree to Agree). All pre-service teachers who recorded no change for any of the items provided the same responses of neutral, agree, or strongly agree on both the pre- and post-course survey. Additionally, there were no pre-service teachers who reported a negative change from the pre- to post-survey for any of the items (e.g. Agree to Disagree). While I cannot make claims about how the design thinking project is specifically associated with particular changes on the survey items (in relation to other course components), it is encouraging to note that the course embedded a significant, time-consuming design thinking project and also yielded positive outcomes related to preparing pre-service teachers to be elementary mathematics educators.

Table 5 Pre-service teachers' change in responses to the mathematics course Likert-type survey items (5-point scale including strongly disagree, disagree, neutral, agree, and strongly agree)

Survey items	Same response of neutral, agree, or strongly agree from pre to post	Positive change in response from pre to post (e.g. Disagree to agree)
I feel confident as a learner of mathematics	4	9
I feel confident as a teacher of mathematics	2	11
I know how to plan a student-centered mathematics lesson	4	9

4 Challenges and Opportunities for Design Thinking

While design thinking offers opportunities to foster entrepreneurial mindsets during integrated STEM learning experiences, it is pertinent to discuss existing challenges for future implementation across elementary, middle school, secondary, and post-secondary learning contexts. For each challenge listed below, I offer opportunities to move forward.

4.1 Avoiding Rote Design Processes

As discussed previously, both designers and entrepreneurs engage in creative and divergent thinking, which is not always suited to a step-by-step process that must be followed with fidelity. It is interesting to note that the d.school is in the process of moving away from a heavy reliance on the five-phase sequence described in this chapter and moving toward a greater focus on core design abilities. These design abilities, e.g., moving between concrete and abstract, experimenting rapidly, and building and crafting intentionally [32], can be employed flexibly and support designers who wish to tackle ill-structured problems with a wide range of purposes (be it solving problems related to customers' needs and/or global issues related to sustainability and the environment). To this aim, there is an opportunity for design thinking educators to share examples with the wider STEM education community of how design thinking processes naturally include flexibility as they unfold. For example, prototyping and testing may lead learners back to the Ideate phase to brainstorm new solutions or even the Define Phase if they realize the problem might need to be reconsidered. A useful example of flexibility can be found in a study by McCurdy et al. [33]. They studied nineteen 7th grade students as they developed their own problem-based design thinking tasks and found that students engaged in more than one type of solution pathway, concluding: "there were no apparent dead ends or complete roadblocks as long as students were considering the overarching authentic problem" (p. 45). Educators may feel more comfortable with flexible pathways if they engage in design thinking experiences as learners, through formal professional development programs or from other educators who have implemented design thinking in their classrooms. The more educators see articulations of this phenomenon in practice, the more opportunities exist for them to develop a value for flexible paths and a willingness to support adaptive implementation with their learners.

4.2 Time

Similar to any student-centered learning experience, time is needed to allow for an entire design thinking process to be completed. In my own experience of working with teachers in Hawai'i professional development workshops, teachers often find time to integrate the first four phases of the d.school process by concluding with a low-resolution prototype and some feedback but without an authentic cycle of testing and redesign due to time constraints. A challenge of student-centered projects is teachers' concerns about whether they have time to devote to a lengthy learning experience within the curriculum, both from the perspective of implementation and assessment. There are opportunities for researchers to explore the factors that increase teachers' willingness to engage students in a full design thinking process within the realities of school structures. For example, educators might be best served to initially find low-risk spaces to try out a design thinking experience. This might include an end-of-the year project, during science fairs, as part of extracurricular activities like school clubs, or within other timeframes that allow for flexible learning (study hall, genius hour, or library time). The science education community has learned that it is important for teachers' beginning experiences with inquiry-based teaching to be positive and low-risk [34, 35]. I suspect that engaging in a positive, full experience with implementing design thinking in the classroom has potential to increase teachers' confidence and willingness to pursue additional learning experiences driven by design thinking processes. This proposition, however, needs further investigation.

4.3 STEM and Entrepreneurial Mindset Outcomes

Most formal learning contexts, particularly elementary, middle, and secondary schools, are responsible for aligning lessons, units and projects to state or national learning standards divided by specific subject areas. Regardless of the pedagogical approach, integrated STEM educators have called for a focus on aligning STEM learning outcomes to both conceptual and skill-based learning standards across the STEM disciplines [10]. There are a few helpful examples in the STEM educational literature that highlight the implementation of design thinking with explicit alignment to STEM learning outcomes. Cook and Bush describe how a teacher integrated design thinking into an existing unit that also focused on students' learning about structure and function [20]. Simeon et al. found that secondary-level students in Nigeria developed conceptual understandings of Newtonian physics concepts after completing STEM learning modules that incorporated elements of design thinking [36]. I offered another example of university students learning mathematics content and developing science and engineering practices within this chapter. Yet, the research and practical examples for STEM learning within design thinking experiences are limited. Across both practitioner and research journals, there are endless opportunities to articulate more examples of supporting STEM learning with design thinking as the driver and to investigate the factors that shape successful learning experience designs. Moreover, there are opportunities to further establish design thinking practices and entrepreneurial mindsets as important STEM outcomes in and of themselves. Just as Marks and Chase found that elementary students gained knowledge of iterative prototyping (as an intended learning outcome) after a design thinking intervention, it will be important to examine the potential benefits of developing outcomes associated with creative confidence, problem-framing and opportunity recognition [37].

4.4 Scaling Across Systems

Most studies and illustrations of design thinking in the STEM, engineering, and design literature highlight examples of individual educators or small collaborative teams engaged in the process of creating new learning experiences that utilize design thinking. Similarly, my experiences as a STEM educator in Hawaiʻi have revealed that design thinking is being both explored and employed in isolated pockets across the state. Some schools have fully embraced the process, such as Waipahu High School, which has dedicated space for design thinking initiatives within their career academies [38]. Some schools have teachers who have designed and implemented design thinking learning experiences within their own courses, and I suspect there are other schools with less access to design thinking professional development. A key question that arose during my work on the DOE Design Thinking Collaborative was, how can it scale across a school or complex area/district? Table 6 lists common perceived barriers I have encountered for any educational institution or system about scaling design thinking efforts, as well as strategies that have held the most promise with gaining traction. The strategies focus on negotiating the realities of school systems, encouraging a *start anywhere you can* approach, and relying on positive experiences and invitations rather than top-down policies and mandates.

Table 6 Perceived barriers and strategies to support forward movement of design thinking initiatives in educational systems

Perceived barriers	Potential strategies to move forward in educational systems
Lack of leadership support	Align design thinking proposals to existing initiatives, priorities, or already identified challenges related to student learning
Lack of collaboration	Consider starting collaborative efforts to develop design thinking projects with a wide range of stakeholders e.g., students, teachers (your school or another school), parents, local organizations and/or community members
Incompatibility of educators' mindsets with design thinking	Invite teachers to try a design thinking mini-activity as learners or with their students in a low-risk environment to build confidence and reflect on the experience
The 'One more thing on my plate' perspective	Provide examples of how design thinking can be incorporated into multiple grade levels and subject areas

5 Conclusion

In this chapter, I have attempted to describe how design thinking can drive a STEM learning experience, and the benefits this construct offers to the goal of fostering entrepreneurial mindsets through STEM education. Design thinking engages learners in the human aspects of design and adds value to STEM learning experiences by complementing traditional views of engineering design and inherently supporting entrepreneurial mindsets such as opportunity recognition and risk taking through problem-framing and rapid prototyping. It is important to note that I do not argue for design thinking to be the sole driving or integrating process of STEM learning experiences. Far from it, there are multiple research-supported instructional approaches that educators can use depending on their teaching goals and the nature of the STEM task. However, design thinking has untapped potential in a wide range of learning contexts. The literature on design thinking specific to STEM education and entrepreneurial mindsets is developing but still in its infancy. More research in this area has great potential to shed light on helpful strategies to confront challenges I proposed, while also revealing new opportunities to enhance STEM and entrepreneurial mindset outcomes not yet conceived. It is my hope that this chapter serves as one stepping stone toward a fuller understanding of the potential pedagogical value and instructional applications of design thinking to STEM learning experiences that foster entrepreneurial mindsets.

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Inspiring the Next Generation of Innovators Through a Multidisciplinary Entrepreneurship and STEM Educational Outreach Programme

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Maeve Liston, Gillian Barry, and Patricia O'Sullivan

Our kids now need an education that is far more connected and real than in the past—an education system that gives them not only knowledge, but also provides them with empowerment and agency. They need an education whose ends are not just to improve themselves, but rather to improve the world they live in.

[Prensky 1, p. 1]

Abstract

Education systems and industries right across the world are calling for students to acquire key transferrable skills for the twenty-first century workplace. We need people to develop a set of beliefs that shape how they make sense of the world by questioning and looking for problems from the world around them, i.e. we need people that can solve problems creatively with an entrepreneurial mindset. Therefore, a highly capable STEM and Entrepreneurial population with critical thinking skills are essential to ensure not only economic, but also social

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and cultural prosperity, making the world a better place in which to live, work, and play. In order for this goal to be achieved, it is necessary that future populations can apply skills within and across disciplines and in real-life situations i.e., knowledge, skills, and abilities associated with STEM and entrepreneurial thinking. This chapter will describe an interdisciplinary educational outreach program for students between the ages of 14–17 years old. The 'EMPOWER' Programme allowed participants to experience, practice and reflect on a wide variety of innovative and creative inquiry-based, student-centered, teaching and learning pedagogies, focusing on scientific thinking, entrepreneurial thinking, generating new ideas and translating ideas into actions. The aim of the EMPOWER Programme was to design an approach that moved beyond traditional science and business programs, to an approach that involved the development of 'growth mindsets' that enable and empower students to approach problems, to experiment, and to meet the needs of individuals and communities that will benefit from their solutions.

Keywords

Entrepreneurial STEM education · Multidisciplinary · STEM · Educational outreach · Entrepreneurship

1 Introduction

The world of work is ever evolving and therefore there is a need to adapt and change our education system, so that it is relevant and future focused to prepare for our changing future. It is predicted that only 40% of the jobs that exist today will exist in the future [2]. The future jobs that will be available, and the skills that they demand, have not been fully imagined, and are difficult to predict and so a greater focus is now being placed on developing flexible and adaptable graduates with key transferrable skills, such as metacognition, synthesis and critical reflection, creativity, and innovation, that can be applied across all life paths and careers central to employability in the future [3]. It is of critical importance that all forms of educational experiences at all levels are innovative, relevant and prepare students with real world skills to face any challenges that are transferrable to the workplace [4, 5].

This chapter describes an interdisciplinary educational outreach programme for students between the ages of 14–17 years old. The aim of the 'EMPOWER' Programme is to design an approach that moves beyond traditional science and business programmes, to an approach that involves the development of 'growth mindsets' that enables and empowers students to approach problems, to experiment, and to meet the needs of those that will benefit from their solutions. First, innovative education is presented. Next, the Empower Programme and its activities using Engineering Design Process (EDP) are introduced. The results of the programme are addressed and discussed.

2 Innovative Education

Conversations across education circles are now focusing on the need for innovation and models of innovative education that foster future 'Innovators' [6]. There have been many books written on the 'Art of Innovation' and strategies employed by innovative companies by well-known innovators such as Tom Kelley, general manager of the Silicon Valley based design firm IDEO [7, 8]. Many books of this kind on Innovation outline how to be innovative within a company or during one's career. However, we must ask how do we educate students to become innovators?

The majority of the time, innovations in education focus solely on new technologies in supporting teaching and learning in the classroom. However, an innovation can just be a different way of doing something that also happens to be a better way of doing it [9]. Innovative learning environments empower students to move away from learning subjects in silos, towards creating solutions to real-world problems through multiple disciplines, so that they go on to create solutions to problems for the rest of their lives, becoming 'Solutionaries' [1, 10]. Learning environments that are innovative support students in building twenty-first century skills, to become flexible, self-directed, social, productive, and responsible citizens [11–13]. For this to be achieved:

- The boundaries between different subject areas need to be overcome, where students can experience the big picture from multiple perspectives [14, 15]. From our experience as educators, learning needs to shift away from learning specific subject areas in silos to more of an integrated approach to teaching. This approach will involve students learning and applying key competencies and skills across all subject areas, showing the inter-connectedness between subject areas and links across all twenty-firstcentury career paths.
- From our discussions with students, they need to be surrounded by adults and education systems that will provide such experiences where they are provided the opportunity to develop their creativity and imaginations. Wagner concluded that from interviewing well-known innovators in successful companies, one common thread appeared across their life experiences, that they were surrounded by adults that nurtured their creativity and sparked their imaginations [16]. Therefore, it is important that not only educators, but students are provided with the opportunities to explore the life experiences of great innovators that lead them down the path of innovation.
- From our experience, students would like to and need to meet role models that overcame a problem or problems encountered in their everyday life by using their knowledge, understanding and skills in an area (for example Science, Technology, Engineering and Mathematics, STEM). Many innovative entrepreneurs apply STEM skills and knowledge within their business models, but this is not recognised or addressed within our education systems and curricula.

We believe entrepreneurial STEM education is the answer to addressing innovation in education, as it ticks so many boxes i.e., it is relevant, creative and involves problem solving and active citizenship. Entrepreneurial STEM education answers the calls of education systems and industry across the world in developing populations that can tackle challenges in society and act on their ideas. We describe entrepreneurial STEM education as a transdisciplinary approach to education where knowledge, attitudes and skills associated with STEM and entrepreneurship are applied in developing solutions to life's problems. Currently, the concept of ideation and addressing problems within society is lacking from education systems internationally where we are not preparing our students to think creatively and innovatively [16].

2.1 STEM, Entrepreneurship and Active Citizenship

The European Commission emphasizes the need to ensure that young people acquire social, civic, and intercultural competencies, by promoting democratic values and fundamental rights, social inclusion, and active citizenship throughout the education system [5, 17]. Many of these skills are developed within subject areas such as civics and social studies and to a lesser extent in geography. We need to look at innovative ways of ensuring that students become actively engaged and responsible citizens across all subject areas. Marshall states that "To educate our children as STEM knowledge creators, innovators, entrepreneurs, and global change-makers with the capacities to understand complex issues, creatively invent solutions, and ethically catalyze change requires their immersion in mind and practice fields rooted in meaning, not memory; engagement, not transmission; inquiry, not compliance; exploration, not acquisition; personalization, not uniformity; interdependence, not independence; collaboration, not competition; challenge, not threat; questions, not answers; and joy, not fear" [18, p. 49].

We are strong advocates for an education system that prepares students to face challenges in the world that they participate and live in and how they can lead change as adults. STEM knowledge is fundamental to developing actively engaged students and responsible citizens. STEM education that focuses on 'Science with and for Society' can develop social awareness and responsibility in our students by making them aware of difficulties that we face in our everyday lives. This could help to better understand the world as well as guide technological development and innovation [19]. Therefore, understanding STEM is not only important for those interested in STEM and pursuing a career in STEM but for everyone so that we can make decisions about challenges that affect our lives [20].

STEM lessons and educational experiences can significantly contribute to developing a sense of ethics and social conscience among students [21]. The question is, how can this be achieved in the classroom? In these times in a world facing severe global challenges such as climate change, food security, rising migration, social justice, or the current coronavirus crisis, developing *Science Capital* and citizenship education is more important than ever. *Science Capital* is the measure of people's knowledge, attitudes, skills, and experiences with science [22]. People with *Science Capital* engage with science as part of their normal, everyday life. They see the relevance and value of science in everyday life and have an awareness of where and how science skills, knowledge and understanding are useful for all careers and walks of life. To summarize, *Science Capital* looks at what and how people know, what and how they think and who they know.

Exposing young people to real social and environmental challenges and ideas locally, regionally, nationally, or internationally develops their critical and creative thinking, problem solving and problem identification and inquiry skills [21, 23–25]. Positioning the problems in context and increasing relevance of a topic in STEM encourage students to find solutions to such problems and develop their capacity to make informed decisions about political and civic issues as well as their own lives [26, 27]. The above mentioned skills are not only STEM skills, but these too are also entrepreneurial skills. Scientists, engineers, mathematicians, and entrepreneurs are continuously innovating, identifying problems, creating, and inventing new solutions (prototypes and services). The importance of the skills associated with Entrepreneurship Education and STEM education are becoming more relevant not only in STEM occupations but in nearly all sectors of the economy and society [28–30]. STEM projects and activities can encourage exploration of new ideas and resourceful problem solving and risk-taking through lessons that are linked to relevant environmental, societal, and industrial issues [31]. It is important to note that STEM education can greatly complement and support entrepreneurship, while entrepreneurial education can support the teaching of STEM skills and competencies. The following STEM skills and entrepreneurial skills and competencies go hand in hand:

- Critical and creative thinking
- Problem solving and problem identification
- Flexibility
- Managing risk, failure, and uncertainty
- Decision-making
- Willingness to experiment
- Being open-minded.

The STEM and entrepreneurial skills that are used to solve complex problems "are required of almost everyone in order to successfully negotiate the complexities of contemporary life" [32, p. 4].

STEM skills can therefore support the development of creativity and imagination within business programs and can significantly contribute to developing an entrepreneurial mindset among our younger generations. STEM activities inspire creativity, experimentation, problem identification and solving, innovation, inquisitive thinking, and teamwork [21, 33]. STEM and entrepreneurship also involve collaboration and communication, troubleshooting and decision making in order to design and test a prototype of a product or service. However, from our knowledge and experience of STEM education nationally and internationally, we believe that STEM education has not yet achieved these goals and needs a stronger focus on idea generation, brainstorming and design thinking, for the development of innovative projects.

Marshall [18] argues that STEM education must be overhauled to include four specific outcomes:

1. stimulate imagination, creativity, and breakthrough innovation in STEM learning.
2. encourage multigenerational, cross-sector collaboration, and problem-solving by diverse multidisciplinary, multi-stakeholder, and multinational teams of students, faculty, and partners.
3. nurture social entrepreneurship and moral change leadership "for" the world.
4. serve as catalysts for the transformation of STEM teaching and learning and the development of a new generation of collaborative and innovative STEM educators [18, p. 49].

To conclude, converging STEM and entrepreneurial practices can be the answer to achieving innovation in education. STEM education is now considered a very important teaching strategy in refocusing education on critical thinking, and a willingness to explore and engage with the real world [34]. Pedagogies associated with STEM act as a vehicle for engaging students with the real world, allowing participants to learn and apply content, practices, and skills of the STEM disciplines to situations they encounter in their everyday lives. This approach to education is achieved by delivering STEM through interdisciplinary and transdisciplinary approaches to teaching and learning, removing the traditional barriers that separate the four disciplines of science, technology, engineering, and mathematics and integrates them into real-world, rigorous, and relevant learning experiences for students [35]. This approach asks students to make additional connections, not only between the STEM subjects but also with other subject areas, concepts, and ideas [35, 36].

As can be seen from the above paragraphs, on the one hand STEM education can greatly complement and support entrepreneurship, while on the other hand entrepreneurial education can support the teaching of STEM skills and competencies. We propose that STEM needs to be integrated into entrepreneurial education and entrepreneurship needs to be integrated into STEM education i.e., STEEM (i.e., science, technology, engineering, entrepreneurship, and mathematics) education. A complete reimagining of STEM and entrepreneurship education is needed in order to address the ever-changing world and complex world we live in.

3 The EMPOWER Programme

This chapter will describe an interdisciplinary educational outreach programme in Ireland for students between the ages of 14–17 years old. The 'EMPOWER' Programme allows participants to experience, practice and reflect on a wide variety of innovative and creative inquiry-based, student-centered, teaching and learning pedagogies, focusing on scientific thinking, entrepreneurial thinking, generating new ideas and translating ideas into actions. The aim of the week-long Empower Programme is to design an approach that moves beyond traditional science and business programmes, to an approach that involves the development of 'growth mindsets' that enables and empowers students to approach problems, to experiment, and to meet the needs of those that will benefit from their solutions.

In Ireland, the National Skills Strategy 2025 included as one of its objectives to pilot innovative summer camps to promote entrepreneurial thinking, STEM, and design skills among students [30]. The Action Plan for Education 2017 (Goal 4: "Build stronger bridges between education and the wider community") also set out as one of its main objectives to "Create a stronger focus on Entrepreneurship, Creativity and Innovation" [29]. Therefore, the EMPOWER programme is designed to include both STEM and Entrepreneurship activities in order to raise awareness around the links between these disciplines.

The EMPOWER programme is funded by the Higher Education Authority in Ireland to design an approach that supports the development of 'growth mindsets' enabling and empowering students (14–17 year-olds) to identify problems, experiment, and meet the needs of those that will benefit from their solutions. This approach was taken so that students would develop a belief system that their abilities can be developed over time through effort and persistence.

3.1 The EMPOWER Programme Framework

The overall objective of the EMPOWER Programme is to develop skills in young people that will embrace innovation, enhance, and develop creative and critical thinking skills, recognize opportunities, solve problems, develop solutions, test opportunities, and develop effective communication skills.

The EMPOWER programme was designed to include both STEM and Entrepreneurship activities in order to raise awareness around the links between these disciplines (Fig. 1).

Activities during the programme focus on problem solving allowing the participants to recognize the interconnection between scientific process skills, engineering habits of mind, and entrepreneurial skills (Fig. 1).

3.2 Programme Design

EMPOWER provides the participants with the space and time to practice and reflect on the student's own talents, how problem/need seeing, problem solving, creativity, scientific thinking and design thinking are versatile and transferable skills locally, regionally, nationally, and internationally across all life-situations, career paths and walks of life.

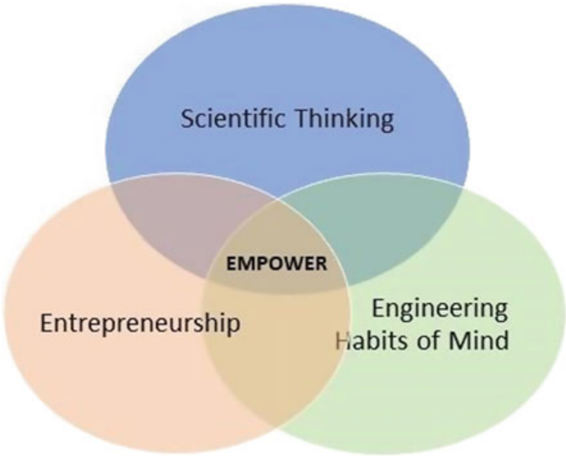

Fig. 1 The EMPOWER programme framework: STEM innovation and Entrepreneurship. *Source* All images are from the EMPOWER programme from Mary Immaculate College Limerick

EMPOWER is designed and delivered by a multidisciplinary researcher-practitioner partnership among a STEM educator, project managers, team members from an Innovation and Enterprise Centre, entrepreneurs, scientists, and engineers. This approach ensured that the programme integrated and converged, novel and up to date STEM and entrepreneurial practices and competences in an effective and relevant way.

The EMPOWER Programme involved 5 main design principles:

- **Principle 1**: Enhance and develop a culture of creativity, innovation, adaptive leadership, and enterprise among young people with a diverse range of life-experiences and from different socioeconomic backgrounds.
- **Principle 2**: Practice problem solving and critical thinking skills in developing creative and proactive students who can manage the uncertainty and continuous change typical of today's world.
- **Principle 3**: Inspire and develop skill sets that allows and helps students to use their knowledge and abilities to accomplish their goals.
- **Principle 4**: Developing the mind-set and believe in oneself as a creative innovative thinker and leader.
- **Principle 5**: Develop and provide a platform where the students can continue this engagement, networking, creating links with enterprise, business and industry and cultural and artistic communities through a network of mentors.

Activities during the programme focus on the design thinking approach to problem solving allowing the participants to recognize the interconnection between scientific process skills, including engineering habits of mind, and entrepreneurial skills, through a wide variety of novel, creative and innovative activities [37] (Fig. 1). The term "Design Thinking" refers to thinking skills or practices designers use to create new ideas and to solve problems [38]. It is an innovative, creative, and human-centered process that employs collaboration in order to generate user-focused products, services or experiences. Activities during the EMPOWER programme included key STEM and Entrepreneurial Competencies such as problem seeing, empathy, idea generation and communication (Fig. 2).

The EMPOWER activities included workshops on 5 main themes:

1. The Engineering Design Process (EDP)
2. Observations And Opening Their Eyes to The World Around Them (Problem Seeing)
3. New Ideas and Novel Solutions: Inventions
4. Storytelling, Listening and Empathy
5. Design Thinking: Making it Better.

These activities will be described in greater detail in the proceeding sections.

These workshops included inquiry based open-ended design, STEM and engineering challenges and explorations, right throughout the week focusing on key inquiry-based pedagogies, ideas, and skills (Table 1).

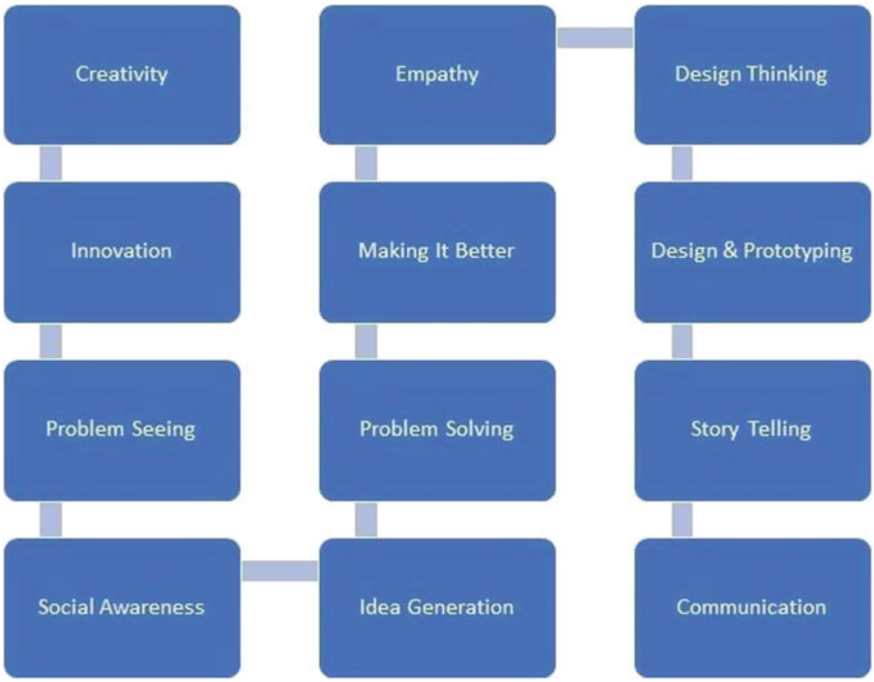

Fig. 2 Key STEM and entrepreneurial competencies and skills developed during the EMPOWER activities. *Source* All images are from the EMPOWER programme from Mary Immaculate College Limerick

Table 1 Underpinning theories informing the approach to EMPOWER

STEM education	**Problem-solving** by engaging with and changing the world [39] **Collaboration and teamwork** [40] STEM education is not just one thing—it's a range of strategies that help students apply concepts and skills from different disciplines to solve meaningful problems [35] Developing a capacity to: • Remove any boundaries between the subjects [36, 41] • Integrate and apply a deeper level knowledge and understanding of mathematics and science to create technologies and solutions for real-world problems using engineering design approach [21]
Engineering challenges	• Ritter and Webber stated that in order to design rich design tasks, a design task should involve a 'wicked' problem [42]. For example, a task that does not fully specify the problem, no one single 'best' solution, no guidelines and no set list of exact permissible actions and rules. An engineering challenge given to the students 'The marble madness run' began with them exhausting possibilities and ideas that they initially thought would work, then to begin to 'ideating', further discussions, drawing diagrams and 'thinkering' and 'iterating' after failures [43]. This activity allowed the students to value others' ideas and value communication, facilitating useful discursive design discursive practices in the students [44] • Connecting the designer's problem solving and user considerations [45] • 'Discourse-in-practice' [44] • D*esign model—System image* [45]
Design thinking	**Design Thinking = a Kaleidoscope** • 'A mixture of materials and elements that may not shine on their own, but that dazzle when combined or set in motion in a particular configuration. The point is to connect students to a structure for learning that acts as a multiplier, mobiliser, and magnifier, by creating reflective and crystallized views of the many facets of any concept under design. Like the elements in a kaleidoscope, students shine when put into action in creative problem solving' [46, p. 10] • Design thinking teaches youth to solve complex problems with the aim of developing their creativity and critical thinking skills for the twenty-first century workforce [38]
Empathy and story telling	• The entire design process was conducted through an empathetic lens [47] • Empathy is incorporated into engineering, STEM and entrepreneurship [48]
Mixing ideas concept	Each team member brainstorms ideas on how they could solve the problem or design responses to the design challenge [49]
Growth mindset	Encouraging the constant deconstruction and rebuilding of their ideas [50]

4 The Engineering Design Process (EDP)

The Engineering Design Process (EDP) was used during the EMPOWER programme to provide a model that guides the participants from identifying a problem or a design challenge to creating and developing a solution. The EDP, presented in Fig. 3, involves the following steps:

1. Defining the problem: introducing criteria and constraints.
2. Conducting research: look up videos, images, architecture etc.
3. Imagining: brainstorming informed ideas on how to solve the problem posed and come up with a number of possible solutions and ideas.
4. Planning: Choose the idea that the group predicts will work best and design their prototype. This involves sketching out their design.
5. Creating: designing and developing the prototype they have all selected.
6. Testing and evaluating the prototype.
7. Redesigning based on the testing and evaluation stage if required.
8. Communicating and presenting their results and conclusions.

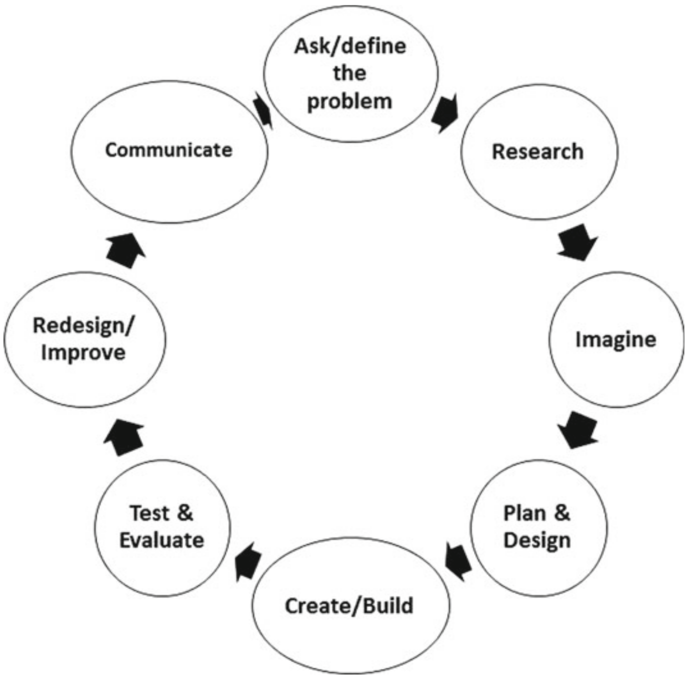

Fig. 3 The engineering design process (EDP) used during EMPOWER. *Source* All images are from the EMPOWER programme from Mary Immaculate College Limerick

The eight steps of EDP are utilised in the activities by adopting a spiral approach during the five-day EMPOWER programme, where each activity builds on previous experiences and activities.

A strong focus is placed on creativity and innovation therefore right throughout the week, the participants work in teams to solve a variety of engineering design challenges. The imagining, designing, and creating elements of the EDP unleash the participants' creativity through ideating, prototyping, and piloting new ideas. During the engineering challenges the participants were made aware how the design of a prototype undergoes multiple cycles of innovation [51]. Some of these activities included designing and building and summarised in the following.

An Extendable Arm

Tom and Lucy are astronauts and have just landed on the Moon. They need to collect samples of moon rock, however their astronaut suits make it difficult to pick up smaller items. Can you design and make an extendable arm that can pick up the moon rock for Tom and Lucy? Figure 4 shows students designing an extendable arm.

Fig. 4 Engineering design challenges: an extendable arm. *Source* All images are from the EMPOWER programme from Mary Immaculate College Limerick

The Longest Trickiest Tracks
You and your team have been selected to make the longest trickiest marble run using cardboard and toilet/kitchen roll inserts. You will design the longest, trickiest course in which to deliver a marble to its final destination. The longer and trickier the better. The marble must do the following at least once as it is moving through its track: Go up, Come down, Fly through the air and Change direction/turn. Figure 5 demonstrates students trying to build the longest trickiest track.

A Catapult
Create a Marshmallow Catapult that will launch a mini marshmallow? Can you build a Catapult that will launch a Marshmallow that can: Hit a specific target (Accuracy), Travel as far as they can (Power), and be powerful enough to knock a wall of small cardboard matchboxes/kitchen rolls (Power and Tower)? The Catapult must be free-standing and cannot be supported or propped up against anything. Figure 6 shows students working on their Catapults.

Fig. 5 Engineering design challenges: the longest trickiest tracks. *Source* All images are from the EMPOWER programme from Mary Immaculate College Limerick

Fig. 6 Engineering design challenges: a catapult. *Source* All images are from the EMPOWER programme from Mary Immaculate College Limerick

Design and Make a Bridge
Design a 3D bridge which is strong enough to hold a weight above the ground. Your bridge can only be made with drinking straws and paper sticky tape. You do not have to use all the straws in your pack. You cannot use any more straws than what is given to you. The tape is just for connecting your straws together—not for strengthening your structure. The bridge should be at least 20 cm high, 20 cm wide and be at least 50 cm long (2.5 straws long). Figure 7 illustrates students' designing a bridge that can hold a weight above.

4.1 Observations and Opening Their Eyes to the World Around Them (Problem Seeing)

Throughout the week, the participants were given time to just stop and develop their observation skills, to encourage them to explore how things work, and to seek problems in the world around them whether it be a product or service. We explore the concept of knowing how to see and the difference between observations (people perceive things differently) and inferences (have different observations and expectations). These activities allow the participants to explore scientific thinking and its correlation to support judgment and key entrepreneurial development.

Fig. 7 Engineering design challenges: design and make a bridge. *Source* All images are from the EMPOWER programme from Mary Immaculate College Limerick

Examples of these activities include:

- Find 5 things you didn't notice before anywhere when you go at lunchtime.
- The Monkey Business Illusion by Daniel Simons (https://www.youtube.com/watch?v=IGQmdoK_ZfY).

4.2 New Ideas and Novel Solutions: Inventions

Many of the workshops are based around how we are moving from an era of invention to an era of innovation [52], exploring the difference between invention and innovation. The participants further develop their scientific thinking and engineering habits of mind by exploring inventions i.e., new ideas and solutions to problems. They explore how products have adapted or improved over time. They also explore how many products may just be an improvement of what is already out there and how inspiration for a new idea can often originate from an improvement of an existing idea or an improvement of a process, service, or product. For example, looking at the first mobile phone and how it has evolved over time to the smartphone. It began as an invention, but engineering innovations have changed its functionality over time based on the developments in STEM and the needs of its users.

Fig. 8 Participants carrying out SCAMPER activities during EMPOWER. *Source* All images are from the EMPOWER programme from Mary Immaculate College Limerick

Example of activities targeting inventions and innovations include:

- List 15 alternative uses for a paper clip
- Exploring 11 products invented for something else or an alternative use discovered/invented by mistake (for example post-it notes, bubble wrap, Microwave ovens).
- SCAMPER Activity: The idea of this activity is to show that innovation and putting a new idea into practice finds its roots in creativity, which involves coming up with new ideas and novel solutions. The activity is a tool to support creative and divergent thinking, demonstrating how creative ideas frequently develop from seemingly unrelated facts and ideas put together in new ways [53]. The participants watch the following video: https://www.youtube.com/watch?v=G8w0rJhztJ4. They then take two items per group from the box of random items. They then work down through SCAMPER Activity generating new or alternative ideas/uses for the two items. Exploring ideas on how to substitute, combine, adapt, modify, put to other uses, eliminate, and reverse/rearrange the two items. They presented back their ideas to the rest of the group, sharing their ideas and new products they designed (Fig. 8).

4.3 Storytelling, Listening and Empathy

Empathy is now identified as an important characteristic for acquiring twenty-first century design and engineering skills [54, 55]. Empathy can engage young people with controversial situations, where scientific knowledge is needed to make informed decisions. Therefore, empathy can help children to better understand how STEM-related issues can affect people and society [56]. Zeyer and Dillon explain that it is the personal and social character of socio-scientific issues, their human factor, so to speak, as well as the intrinsic inclusion of care and empathy in reasoning, that make socio-scientific issues particularly apposite for empathising—much more so than classical physics' laws, chemical reactions or biological concepts [57].

During the EMPOWER programme participants explore the concept of active listening and develop empathy skills by engaging with a variety of different individuals, organisations, and businesses where their product or service were designed based on empathy and concern for the well-being of others guide decisions [58]. The students begin with a workshop on active listening and understanding the difference between empathy and sympathy with representatives from Narrative4 (https://narrative4.com/). These activities include Story Exchange 'If I hear you clearly' and active listening exercises. Once participants develop an understanding of the importance of active listening, they engage with empathy at a deeper level, whereby they explore entrepreneur's' stories and learn how they developed a solution to a problem that was affecting their lives or the lives of others.

Examples of the stories included:

- **The Duffily Bag** is a sleeping bag designed to alleviate the problems faced by homeless people sleeping on the streets. It is lightweight, waterproof, heat-retaining, non-flammable, highly reflective, and made of metallic bubble wrap. Emily Duffy developed the Duffily Bag to solve some of the problems with existing cloth bags. Emily developed the prototype Homeless Wrap when she was 14 and showcased it at the National BT Young Scientist Competition in Ireland in 2015. The Mendicity Institute reached out and formed a partnership where service users were employed to manufacture the sleeping bags and distributed them around the greater Dublin area as well as to refugees in Calais and Dunkirk.
- **Izzy Wheels** (https://www.izzywheels.com/our-story) was founded by Irish sisters Ailbhe and Izzy Keane. The idea was inspired by Izzy who was born with Spina Bifida and is paralyzed from her waist down. Izzy has always seen her wheelchair as a symbol of freedom but never felt it expressed her personality. They now make bespoke colorful wheelchair covers. Their mission is to challenge negative associations with wheelchairs and let users celebrate their individuality by personalizing their source of independence. They want to show the world that wheelchairs can be so much more than a medical device, they can be a piece of artistic self-expression.

These presentations allow the participants of the EMPOWER programme to seek an understanding of another person's perspective and how developing products and services are much more than just making money. Through these activities they begin to develop an appreciation that products and services can make life better for people. It also shows that empathy is a very important feature of STEM and entrepreneurship.

Throughout the week participants also hear from a variety of Social Enterprises about their mission, what they want to achieve and how they are achieving this (product or service).

4.4 Design Thinking: Making It Better

Design thinking is an innovative, creative, and human-centered process that employs collaboration in order to generate user-focused products, services or experiences. The pedagogical framework for design thinking designed at Stanford involves five stages; Define, Empathy, Ideation, Prototype, and Test. The participants are introduced to the design thinking process by carrying out a fast design challenge that is relevant to their lives, for example redesigning the school bag or redesigning the canteen lunchtime experience. During these fast challenges, students work in pairs, working down through a template that is provided to them, focusing on empathy, developing a needs statement and ideation (Fig. 9). Figure 6 describes an introductory design thinking activity on redesigning a school bag.

Each student takes turns in interviewing the other and both must work down through the different stages. This activity helps students in gaining a further understanding of empathy and developing their empathic skills. They, then, design a prototype of a school bag for each other based on the needs of their partner (Fig. 9). As the participants are working through the process, the similarities between the engineering design process and design thinking model are highlighted (Table 2). By doing so, their awareness of how STEM can make products better is increased. They also explore that even though empathy is more explicitly addressed in the process of design thinking, empathy plays an important role during the initial research phase and testing and re-designing phases of the EDP.

5 Design Thinking Challenge/Engineering Design Process

The next phase of the programme involves the participants carrying out a project in groups. Each group is allocated a mentor for the week from local STEM industries and enterprises to support the students in developing their projects. The mentors were a mixture of male and female young and enthusiastic entrepreneurs from a variety of backgrounds and from the region. The mentors were chosen so that the participants could relate to them and engage with the mentor in a meaningful way. The mentors provide insights into their experiences and expertise, that can help the participants to develop their ideas and solutions. The mentors are there for the participants right throughout the week and support them in their EMPOWER journey.

Challenge: Redesign the school bag

1. What do you like/dislike about your school bag?
2. What was the most frustrating/annoying thing that ever happened when you were using your bag?
3. What do you hold in your bag?
4. How do you like to organize things in your bag?
5. What did you find out about your partners' experiences? What stood out to you? What are you curious about?

Stage of Engineering Design Process	Stage of the Design Thinking Process
Ask/define the problem: Introducing criteria and constraints	Defining the design challenge
Conducting research: Observing, understanding and synthesizing	Empathize Collecting information: Empathizing with the users, listening and observing and understanding their users, finding new ideas and further defining the design challenge
Imagine: Brainstorming	Ideate: Brainstorming
Plan & Design	Prototype
Create/build	Prototype
Test and Evaluate	Test
Redesign/ Improve	Iteration: what has been learned?
Communicate	Iteration: what has been learned?

EMPATHY & RESEARCH:

- Think about your partner's **NEEDS**.
- What does he/she like about his/her bag?
- What problems does he/she face?
- What stories stood out for you?

DEFINE your partners need by writing a NEEDS STATEMENT

____

- Name
- **NEEDS A WAY TO**
- ______________________________

user need
- **because he or she**
- ______________________________

insight

Stage of Engineering Design Process	Stage of the Design Thinking Process
Ask/define the problem: Introducing criteria and constraints	Defining the design challenge
Conducting research: Observing, understanding and synthesizing	Empathize Collecting information: Empathizing with the users, listening and observing and understanding their users, finding new ideas and further defining the design challenge
Imagine: Brainstorming	Ideate: Brainstorming
Plan & Design	Prototype
Create/build	Prototype
Test and Evaluate	Test
Redesign/ Improve	Iteration: what has been learned?
Communicate	Iteration: what has been learned?

IDEATE & IMAGINE

Brainstorm 10 or more ideas ***for different*** ways to meet your user's needs. No idea is too wild! Sketch or write them in the space below

PLAN & DESIGN, CREATE & BUILD: PROTOTYPE

BUILD your solution

Make something your partner can interact with. Use the prototyping materials.

TEST & EVALUATE

SHARE your solution with your partner and **CAPTURE** feedback. Remember it is just a first prototype so listen and learn.

ITERATION: REDESIGN & IMRPOVE

- What worked?
- What could be improved?
- Redesign/improve the school bag for your partner.
- Was your initial design the same or different than your final design?

Stage of Engineering Design Process	Stage of the Design Thinking Process
Ask/define the problem: Introducing criteria and constraints	Defining the design challenge
Conducting research: Observing, understanding and synthesizing	Empathize Collecting information: Empathizing with the users, listening and observing and understanding their users, finding new ideas and further defining the design challenge
Imagine: Brainstorming	Ideate: Brainstorming
Plan & Design	Prototype
Create/build	Prototype
Test and Evaluate	Test
Redesign/ Improve	Iteration: what has been learned?
Communicate	Iteration: what has been learned?

Fig. 9 Introductory design thinking/EDP activity during EMPOWER. *Source* All images are from the EMPOWER programme from Mary Immaculate College Limerick

Table 2 Similarities and differences between the stages in the engineering design and design thinking processes

Stage of engineering design process	Stage of the design thinking process
Ask/define the problem (Introducing criteria and constraints)	Defining the design challenge
Conducting research (Observing, understanding, and synthesizing)	Empathize collecting information while empathizing with the users, listening, and observing and understanding their users, finding new ideas and further defining the design challenge
Imagine (Brainstorming)	Ideate (Brainstorming)
Plan and design	Prototype
Create/build	Prototype
Test and evaluate	Test
Redesign/improve	Iteration: what has been learned?
Communicate	Iteration: what has been learned?

The projects focus on developing solutions to problems. Every year we change the scenario, situation or the challenge. One year we invited elderly people to speak to the participants around specific problems and scenarios they encounter in their lives. In this particular year, we decided to look at this cohort in society across the world as the percentage of people that are over the age of 60 is growing exponentially, resulting in a “Gray Tsunami” a term coined by the United Nations. There is a storytelling element (active listening and empathy aspect) to this activity, where the students develop an understanding of the world of the elderly person. We, then, challenged the students to make the lives of these elderly people better. We asked them to identify a problem (one of many) that had been highlighted through their stories and work through a combined design thinking/EDP process to create solutions to the problem identified. The aim is to develop problem solvers and problem generators, attempting to solve the problem in front of them and seek novel challenges [32]. Five categories of questions asked to each project team throughout the project work are as follows:

1. The Problem—what need(s) are you addressing and for whom

   - Describe the problem—What scenarios exist now or in the future for your focus area?
   - What need are you addressing?
   - It is important, and why?
   - Who are your stakeholders?
   - What research can you do? How will you validate/prove that there is a problem here to solve?

2. The Solution/Vision

   - What are the key benefits of your product or service?
   - What are the key challenges you face as a team to develop this product or service?

3. The Innovation

   - The uniqueness/originality of the idea/vision/concept (this can be reinvention/evolution, revolution, or disruption of a product/process/service/market or perhaps the market doesn't yet exist)

4. Viability/Feasibility

   - How feasible is the solution—what do they think needs to happen for their innovation to be realized—have they considered the barriers (competition, costs, regulation, negative influences, user adoption etc.)

5. Teamwork

   - How has the idea evolved during the brainstorming session?
   - How has the team worked together?

6 Results

Feedback and reflections from the participants are gathered through surveys at the end of the EMPOWER week. The survey explores their experiences and what they learned from participating in the programme. The questions are kept broad and general so as not to guide their answers in any way. The two questions that are asked are as follows:

- What have you learned over the five days?
- What were the main benefits for you personally?

Results from two years of data collection will be presented and discussed in the proceeding sections ($N = 115$, Male = 64, Female = 51). The participants were from a variety of socio-economic backgrounds and from many different types of schools (Female only, male only and disadvantaged schools).

The qualitative data from the open-ended questions were audio-recorded and all ethical considerations were addressed. The data were analyzed using data-driven thematic analysis [59]. Answers were coded manually. Two rounds of coding were completed prior to identifying dominant and distinct themes.

One aim of the programme is to provide opportunities for participants from a variety of different backgrounds to experience innovative and creative inquiry-based activities that explore scientific thinking, entrepreneurial thinking, generating new ideas, and translating ideas into actions. Comments from the participants implied that the programme was successful in its aim. One student stated that "I learned to have a different outlook when approaching any problems I may face", another found out that "it is okay if your first idea fails". Many of their comments on what they learned highlighted that the programme contributed to the development of important twenty-first century transferrable skills. These comments are categorised and presented in the following sections.

6.1 STEM and Entrepreneurship Skills

New skills in science and engineering and entrepreneurship and how to develop a project.
I have learned more about the process of designing products.
All about innovation.
The different skills needed for entrepreneurship.

6.2 Generating New Ideas, and How to Translate Ideas into Actions

How to brainstorm ideas.
How to turn my idea into products.
Learning new ideas, making new ideas.
Innovation and creativity.

Figure 10 shows students brainstorming ideas and coming up with new ones.

The programme wanted to move beyond traditional science and business programmes, to an approach that involved the development of 'mindsets' that enabled and empowered the participants to approach problems and to meet the needs of those that will benefit from their solutions. One student commented that "I found that the different way of approaching the problem had opened my mind to new ideas". Comments from the participants highlighted how they developed their empathy skills, through the EDP and Design Thinking.

6.3 Design Thinking and Empathy Skills

Design thinking and empathy.
Teamwork and empathy is important. It is important to listen to other people.
The listening workshop was a fun way to think more about the empathy.
How to be an active listener.

Fig. 10 Brainstorming and generating new ideas during EMPOWER. *Source* All images are from the EMPOWER programme from Mary Immaculate College Limerick

Fig. 11 Developing creativity through STEM Engineering challenges and prototyping. *Source* All images are from the EMPOWER programme from Mary Immaculate College Limerick

The EMPOWER programme aimed to develop life-long skills in young people, embracing innovation and creativity (Fig. 11). The participants listed many life-long skills they developed throughout the week; for example, 'I started to think differently and communicate better' and to 'never give up when you are on a project and always look outside of the box' and 'I learned to be innovative'.

6.4 Life-Long Learning

Lots about innovation, entrepreneurship, and teamwork.
How to show my skills in innovation.

I've learned a lot about innovation.
How to be a leader.
Listening skills.

Students also realized they had talents that they had not realized they possessed; for example, "I found out I was creative".

6.5 Life and Careers Paths

The participants also recognized that the skills they developed throughout the week, they can "implement in life elsewhere". They mentioned the relevance of the programme to their future: "Future work (ing)life", providing them with "an insight into future opportunities". Some specific ideas included "how A.I. can affect the workforce in later years". Overall, they felt that they had "a greater understanding of the world of business". One also mentioned that "I can use these skills in business class and running my own mini student enterprise into the future".

6.6 Personal Development

There was a strong focus on 'empowerment' during the week-long camps i.e., the personal and social development of the learners (Fig. 12). When the participants were asked about the benefits of the programme for them personally, as previously presented, many mentioned the scientific, engineering, creative and business skills that they developed but they also mentioned important social skills. In general, many mentioned that they "got to talk to new people, and develop my social skills", with one mentioning that "I think that besides learning a lot I have also become more comfortable talking to people I don't know. New communication skills". All participants highlighted through the STEAM and Design Thinking challenges that they developed their communication and teamwork skills, where they learned "how

Fig. 12 Teamwork during EMPOWER. *Source* All images are from the EMPOWER programme from Mary Immaculate College Limerick

to be an active listener, how to work in a team" and "to be more outspoken and to work as a group". The participants also acknowledged that they "learned how to work better with people whose personalities are different to mine" acknowledging that they developed an "ability to work with difficult people". Many also mentioned that as a result they were "more confident" as they "met new people", "made friends" and were provided with the opportunity to develop their "public speaking" skills. All participants stated that they made new friends, and this was a very important aspect of the programme as many students attended the programme not knowing anyone at the beginning of the week.

6.7 Collaborative and Inclusive

The participants presented their projects at the end of the week to a panel of entrepreneurs (social entrepreneurs, engineers, and scientists) and intrapreneurs from STEM industries (Fig. 13). An intrapreneur is an employee who is tasked with developing an innovative idea within a company. In short, the employee acts like an entrepreneur within an organization. The 5-min presentations were assessed based on the following criteria: Creativity; clarity of the need/problem; what the solution was; why it was innovative; how feasible was the idea? and how the team has worked together.

The informal, collaborative, and inclusive atmosphere that we aimed to achieve was highlighted by many students, who mentioned that they "enjoyed the atmosphere of working in a group".

Feedback from the participants highlighted the unique nature of the EMPOWER summer programme in providing students with opportunities not available to them during the school year. They mentioned that the programme allowed them "to learn things that I wouldn't be able to learn about anywhere else. I learned teamwork and empathy".

Fig. 13 Students presenting their work during EMPOWER. *Source* All images are from the EMPOWER programme from Mary Immaculate College Limerick

7 Discussion and Conclusion

Many researchers are now questioning how we develop twenty-first century skills in students [60]. STEM and entrepreneurial education can play a significant role in the holistic development of learners, facilitating the development of problem solving, critical-thinking, creativity, innovation, and communication skills, to name but a few. During the EMPOWER programme, designing, inventing, and prototyping allowed the students to practice and develop not only scientific process skills, and engineering habits of mind but also entrepreneurial skills such as systems thinking, adapting, problem-finding, creative problem-solving, visualizing, and improving. These activities allowed the participants to find a “different way of approaching the problem”, opening their “mind to new ideas”.

The programme placed an emphasis on innovation, providing a range of alternative solutions to a problem or creating a novel solution to meet needs of an individual, group, or organization [61]. This approach was achieved by integrating the concepts of Making it Better, Active Listening and Empathizing into the EMPOWER activities and project work. The participants then were able to see the importance of listening to others and that “teamwork and empathy are important”. They also developed their empathy skills by engaging with a variety of different individuals, organisations, and businesses where their products or services were designed based on empathy and concern for the well-being of others. Feedback from students showed that they had developed an awareness about the importance of “listening to other people”. The integrated Design Thinking/ EDP approach to solving programmes also helped them to understand how STEM-related issues can affect people and society [56].

The programme focused on transdisciplinary approaches, placing an emphasis on developing transversal skills, addressing relevant issues in our world through questioning, challenging, and problem solving [62]. However, this approach has not yet been adopted throughout the education system in Ireland. A lot of focus has been placed on STEM and Entrepreneurship in developing twenty-first century skills and contributing to society through national strategies and action plans, but educational practices in the subject areas remain isolated and are disconnected from one another. For effective change to occur educational systems need to build an altogether new structure in which to spur new thinking [63]. The EMPOWER programme was designed and delivered by a multidisciplinary partnership with a STEM educator, and individuals from an Innovation and Enterprise Centre, entrepreneurs, scientists, and engineers. We therefore not only got participants to think outside the box we also thought “outside the system” when developing this educational outreach programme, a concept mentioned by McNulty [63]. It is also important to note that the programme has also opened the eyes of the design teams from STEM and enterprises as to how these two disciplines can be combined as this remains a relatively new concept within education circles [16, 64].

Fullan stated that there are too many "disconnected, piecemeal, superficially adorned projects" within our education system [65, p. 109]. Wagner also argues that innovative education needs to focus on five key elements: collaboration versus individual achievement, multidisciplinary learning versus specialization, trial, and error versus risk avoidance, creating versus consuming, and intrinsic versus extrinsic motivation [6]. The EMPOWER programmes focused on all these multidisciplinary approaches showing that solutions to real problems can be developed and achieved by students in the classroom. The integrated STEM/Entrepreneurship approach adopted, allowed the participants to focus on creativity, imagination, curiosity, collaboration, integrative thinking, and a bias toward action and experimentation [16, 66]. One participant commented, "I learned to have a different outlook when approaching any problems I may face".

We initially designed the EMPOWER programme to develop 'mindsets' that enable and empower students to approach problems, to experiment, and to meet the needs of those that will benefit from their solutions;, however, the feedback has shown that the programme has a major influence on the participants' personal and social development. Many participants mentioned the social aspect of the programme i.e., making new friends, teamwork, and working together. One student commented that "I think that besides learning a lot I have also become more comfortable talking to people I don't know. New communication skills".

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Pitching STEM: A Communicative Approach to Entrepreneurship in STEM Classrooms

14

Alandeom W. Oliveira and Adam O. Brown

When we are selling our ideas, the audience must first buy us.

Peter Coughter

Abstract

This chapter examines a group of undergraduate science students' oral performances and perceptions of a STEM pitching activity designed to enhance their entrepreneurial mindset. Drawing on scholarly literature from the fields of STEM education and business communication, it is argued that that communication can serve as a source of synergy that educators can strategically capitalize upon as part of their interdisciplinary efforts to teach entrepreneurship in STEM classrooms. In practice, such an approach entails providing STEM students with an opportunity to engage in instructional activities such as making a STEM pitch to a hypothetical funder about an innovative technology. In theory, integration of this form of business communication into the STEM curriculum is hypothesized as a source of entrepreneurial cognition for STEM learners (i.e., it can give rise to entrepreneurial thinking and mindset). Moreover, its reliance on communicative action is consistent with approaches to entrepreneurial education wherein the STEM entrepreneur seeks to actively create entrepreneurial opportunities. To illustrate how this interdisciplinary approach may look in practice, we examine and analyze the classroom

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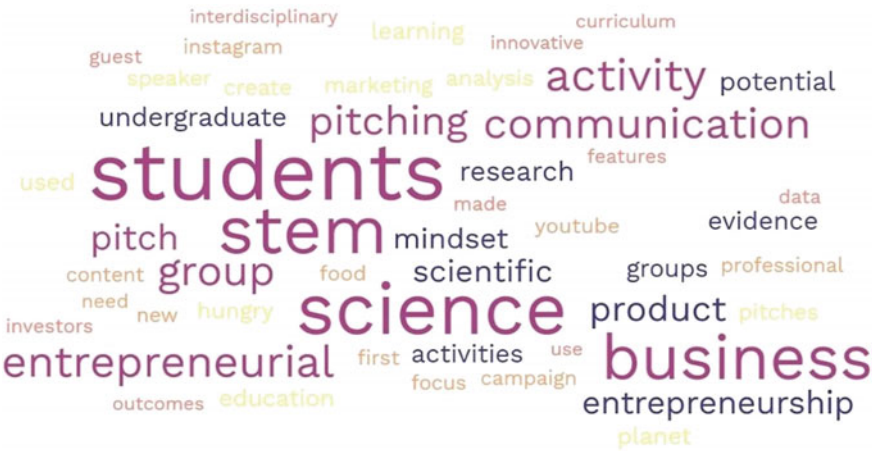
implementation of a STEM entrepreneurship activity at a Canadian university. In this activity, a group of undergraduate science students were given a seminar on the interface between science and business marketing, followed by a group activity in which they had to create and perform a promotional pitch for a plant-based meat substitute product. This chapter analytically scrutinizes an interdisciplinary curriculum designed to create entrepreneurial mindset, students' oral performance when pitching STEM, and their perceived learning outcomes.

Graphical Abstract



Keywords

STEM entrepreneurship · Entrepreneurial mindset · STEM pitching · Undergraduate science education

1 Introduction

At the higher education level, there is growing interest in preparing the next generation of STEM entrepreneurs. Such an interest is evident in the widespread proliferation of educational efforts aimed at providing university students in the STEM fields with opportunities to learn about technology commercialization and develop business and entrepreneurial skills [1]. As part of these efforts to prepare future STEM entrepreneurs, university educators have resorted to a variety of instructional pedagogies [2], including business simulation programs, actual startup activities, entrepreneurial tasks that are infused into a STEM content course, and free-standing courses (e.g., e-commerce course for science majors). Emphasis is placed in creating authentic learning environments for students to explore the nature of technology commercialization, to practice entrepreneurship, to experience the creation of a STEM business (from ideation to implementation), to acquire entrepreneurial skills such as being able to identify an entrepreneurial opportunity, and to gain knowledge about the process used by entrepreneurs to transform an innovative product idea into a successful and commercially viable business.

Educational programs in STEM entrepreneurship vary not only in terms of format but also in their conceptualization of entrepreneurship itself. While some programs emphasize new business creation (producing start-up founders), others prioritize development of entrepreneurial mindset. Among the latter programs are those that aim to produce STEM professionals who have entrepreneurial ways of thinking and working that can be applied to existing organizations [3]. This distinction is particularly evident in the mission statement of the Kern Entrepreneurship Education Network: "our vision is not just to teach students how to start their own businesses, but to prepare them to think entrepreneurially, particularly more broadly and deeply about how their ideas fit into their environments" [4, p. 13.265.9]. Originally coined by McGrath and MacMillan [5] and further elaborated by others, the term *entrepreneurial mindset* has been defined in varied ways. Haynie et al. define entrepreneurial mindset as "cognitive adaptability… the ability to be dynamic, flexible, and self-regulating in one's cognitions given dynamic and uncertain task environments" [6, p. 218]. More than just acquiring a set of soft skills, developing an entrepreneurial mindset also entails learning dispositions and attitudes. Hill [7] breaks down entrepreneurial mindset into eleven salient elements that students must learn: (1) action orientation; (2) creativity; (3) independence; (4) internal locus of control; (5) leadership; (6) need for achievement; (7) opportunity recognition; (8) perseverance; (9) risk taking propensity; (10) self-efficacy; and, (11) tolerance to ambiguity. From this perspective, being a STEM entrepreneur is more than just learning how to start an entrepreneurial venture or commercialize a technological innovation, it also entails becoming a type of person who generally thinks and behaves entrepreneurially. As elaborated below, we believe that such a mindset can be effectively fostered through interdisciplinary pedagogies wherein business and science communication are infused together such as STEM pitching classroom activities.

Teaching science through entrepreneurial classroom activities remains an unknown educational phenomenon in the field of science education. While some studies have recently examined science teacher development of educational entrepreneurship in the context of professional preparation [8, 9], the pedagogical use of entrepreneurial activities for science instruction is yet to receive analytical scrutiny. To address this gap in the science education literature, this chapter examines and analyzes the classroom implementation of a STEM entrepreneurship activity at a Canadian university. In this activity, a group of undergraduate science students had to create and perform a promotional pitch for a plant-based meat substitute product. Throughout the chapter we use the term *entrepreneurship* in reference to a subfield of academic business concerned with opportunity, strategy, and innovation. Our specific research questions (RQs) are:

1. What were the main design features (i.e., curricular attributes) of the STEM entrepreneurship activity?
2. What were the main communicative features of science students' oral performance when pitching a STEM business for the first time?
3. What did students perceive to be the learning outcomes of such activity?

2 Communication in Science and Business

Professional success in both science and business is contingent upon communicative ability. In both academic fields, recent scholarship has consistently identified communication training as a vital component of professional growth and an area of undergraduate education in need of improvement. Below, we first review educational scholarship centered on science communication and business communication, separately. An argument is then made that such shared concern with communication development across the two academic fields can serve as a source of synergy that can be strategically capitalized upon to enhance entrepreneurial mindsets through STEM education.

2.1 Science Communication

Science communication has been traditionally considered a secondary aspect or non-integral component to the STEM disciplines. However, recent years have seen increased recognition of the importance of public science communications to benefit society as well as the endeavors of science itself. This recognition is described rather emphatically by Gregory and Miller, who point out that "in the last decade or so, scientists have been delivered a new commandment from on high: *thou shalt communicate*" [10, p. 1]. As communication has been increasingly seen as an essential part of a scientist's professional responsibilities, infusing it into undergraduate science education has become a priority among university educators [11, 12]. The ability to effectively communicate scientific information in society at large is critical for political decision-making, regulation of science, and funding. For example, to secure funding for their research, scientists must be able to produce compelling proposals that clearly convey the value and applicability of the ideas being proposed as well as the potential broader impact that the proposed discoveries may have on society [13, 14]. Therefore, development of effective science communication skills in undergraduate classrooms is crucial for preparing the next generation of scientists for successful public engagement, education, and influence.

However, at an undergraduate level, this important "soft" skill is not sufficiently taught to students. Brownell et al. [11] indicates that generalized science communication is a valuable skill that not many scientists or aspiring scientists have been taught sufficiently. Gray et al. [15] surveyed 50 employers of graduates from Massey University, New Zealand, and found a significant trend of students only "occasionally" or "sometimes" being up to par with the written communication skills required for their employment. Likewise, Chan [16] emphasizes that the level of communication education offered to students during their undergraduate degrees is not adequate for the expectations of employers. Such research findings highlight the urgency of teaching science communication in tandem with science learning to increase undergraduate students' employability and ensure that they can achieve the highest level of success possible.

In an effort to address the above issue, university educators have resorted to a wide variety of activities for teaching science communication to undergraduate science students [16]. In addition, more specialized scientific communication activities offered to undergraduate students include oral presentations, written reports, lab reports, written responses on tests/exams, and group discussions. Across these latter activities, emphasis is placed on communicating science to scientific audiences (i.e., academic communication). However, such a narrow focus is inconsistent with the fact that professional scientists also have to communicate with nonscientific audiences in the workplace [17], including investors, funders, and commercial partners. To increase their chances of professional success, students also need to develop a strong foundation in informal science communication during their undergraduate degree. This can be accomplished, we argue, through integration of business communication activities such as pitching into the undergraduate science curriculum.

2.2 Business Communication

Communication is also of central importance to the world of business, where it is the focus of an entire field of scholarship, namely business communication. Emphasized in this field is the centrality and near omnipresence of the *entrepreneurial pitch*, a communicative practice in which entrepreneurs attempt to sell their innovative ideas to collaborators, investors, or clients [18]. Epitomized by the TV show *Shark Tank*, the act of making a pitch is aimed at securing investment for an innovative product in a competitive business context [19]. This act is often conceived in terms of a baseball metaphor [20] wherein the entrepreneur (pitcher) is viewed as throwing (pitching) an idea to a potential stakeholder (catcher) in a very short period of time loosely equivalent to an elevator ride from the first to the tenth floor [21]. Pitching, as theorized in the field of business communication, is a professional genre centered on a value proposition [22]. At its core is a proposition or claim about the commercial value of a new product to investors and customers. This claim can be either accepted or dismissed depending on the pitcher's rhetorical performance.

Entrepreneurial pitches are characterized by specific discursive structures and linguistic features. For Smith and Viceiza [19], a pitch consists of three basic parts:

introduction of concept/idea followed by an *initial ask* (amount and percent of investment being requested) and then *negotiation* (e.g., questions and answers about the enterprise). Moreau [23] identifies two additional parts, namely to *establish a niche* (the entrepreneur creates a market space by criticizing an existing industry or specific product), and to *occupy the niche* (the entrepreneur presents a new product as a "better" option in comparison to pre-existing ones). Nelson [24] adds that an entrepreneurial pitch may include a business plan; a description of potential markets, competitors, and obstacles; company qualifications, characteristics, and milestones; and/or an account of current funding sources.

Particularly relevant to this chapter is the body of research focused specifically on pitching innovative technologies. This research emphasizes that, to become successful entrepreneurs, STEM innovators need to learn to effectively pitch their technological innovations to appropriate audiences [25]. Considered as part of the rhetorical dimension of technological entrepreneurship [26], the business pitch is seen as an attempt to persuade a stakeholder of the value of an *innovative product,* often with the support of a slide deck (e.g., PowerPoint slideshow). To this end, the pitcher has to be able to present the new product in a manner that is compelling and engaging (i.e., promote it), and that can create interest in the audience. Moreover, the pitcher has to be able to effectively speak to the needs of catchers and persuasively make claims that can convince them of the business value of the new product (i.e., help the audience envision how the technological innovation could meet the needs of potential buyers and be profitably adopted by the market).

Despite their technical expertise in the STEM domains, novice innovators often need training in professional communication, particularly in how to effectively pitch their ideas/products [27]. To attend to such a need, education programs in entrepreneurship that offer training in effective pitch communication have become increasingly available [28, 29]. In these programs, technology innovators are provided with instruction and guidance on topics such as rhetorical strategies (e.g., making presentations more compelling by including evidence), engagement tactics (e.g., performing demonstrations, telling stories, asking questions, etc.). Participants hone their pitching skills as they take part in educational activities such as *Shark-Tank* style pitching competitions and pitch redesign based on feedback from a trainer or mentor.

2.3 Pitching STEM

As emphasized throughout the above literature review, persuasive argumentation and rhetorical influence are an important part of professional communication in both STEM and business fields. Whether through writing research proposals or orally presenting business propositions, professionals in both fields need to be able to make a compelling case and convince an audience of the value of their work in order to secure the funds required to advance one's research agenda or start a new entrepreneurial business. In other words, the ability to persuade or influence others (e.g., peers, other professionals, and/or the lay public) is an essential feature of professional communication in both STEM and business. Such a trend points to the pedagogical value of *STEM pitching competitions*—classroom activities in which students are challenged to convincingly communicate technological innovations to potential investors (real or simulated) as they compete for funding. Such activities, we believe, can serve as powerful interdisciplinary springboards for enhancing entrepreneurial mindsets through STEM education. This belief is subjected to empirical scrutiny in this study, which examines a STEM entrepreneurship activity in which a group of undergraduate biology students had to create a promotional pitch for a plant-based meat substitute product. Our methodology is described next.

3 Methodology

Exploratory in nature, the present study adopts a flexible and emergent methodology partially aligned with the tradition of grounded theory [30]. As part of this ethics-board-approved study, descriptive data were systematically collected through open-ended research methods (survey and video-recorded classroom observations). Data was analyzed inductively to build a naturalistic account [31] of the pedagogical nature and perceived learning outcomes of an interdisciplinary classroom activity (STEM pitching) designed to foster entrepreneurial mindset in science students at the undergraduate level.

3.1 Participants and Intervention

Participants in this study consisted of a group of science undergraduate students taking a third-year course called *The Public Communication of Science*, aimed at developing science communication skills among undergraduate science students. Enrollment consisted of a total of 40 students.

Designed to prepare future scientists to communicate science to various non-specialist audiences, the class met twice a week for 1.5-h sessions. The course was structured as a series of seminars with guest speakers—specialists in communicating science to the public from various sectors of society, followed by a student activity based on the learnings from the specific expertise of each guest speaker. Over the course of the single semester (15 weeks) it covered topics such as public speaking, talking to the media, and government policy reports and briefings. The focus of this study is limited to the third week of the course. During this week, the focus was *Pitching Science to Business*. Spanning two entire lectures and a recitation session (total of 4.5 h), the set of classroom activities implemented during this particular week were subjected to analytical scrutiny and used to articulate a communication-based approach to enhancing entrepreneurial mindsets through STEM education that holds promise. The STEM Entrepreneurship Activity was structured as follows:

Day 1 (Lecture): 30-min presentation by guest speaker + Group Work (1 h).
Day 2 (Recitation): Group Work (1.5 h).
Day 3 (Lecture): Student Pitches (1.5 h).

On the first day, the guest speaker for the week was the owner of a local marketing company who worked with small- to medium-sized brands in the food industry (e.g., bars and restaurants) providing communication advisement. With a background in environmental science, he had experience working with non-profit groups, science research and policy communication, and marketing in both the public and private sectors. As a former science student now in the marketing field, he was knowledgeable about science as well as social media and digital advertising. The first day began with a talk, in which the guest speaker used a PowerPoint slideshow to present three exemplars of highly successful STEM business pitches currently in the market. These exemplars dealt with the following commercial products: (1) *Reefertilizer*, (2) *Instant Pot*, and (3) *Macdonald's fish and chips*. During the presentation, he introduced students to the inventors behind these technological innovations, discussed features that made their STEM business pitches successful (e.g., use of digital and social media strategies), identified many platforms and methods used to sell the products (e.g., YouTube, Instagram, fast food chains, home meal care services, etc.), showed videos developed to market the products (e.g., the award-winning Reefertilizer jingle at https://vimeo.com/374944262), and introduced basic principles of pitching a STEM business idea (Table 1).

During his presentation, the speaker emphasized how the creators of Reefertilizer used their jingle video (a catchy, creative, and simple pitch unlike other fertilizer ads) as a YouTube ad targeted at gamers (a key demographic), hence making

Table 1 Guest speaker's examples of successful STEM business pitches

Product and ad description	Key takeaway points
Reefertilizer—Grow Good Weed Cannabis needs 3 things to grow: Light, Air, and Nutrients. The first two are easy, nutrients should be too. This is what Reefertilizer was made for	• Adapt message to popular platform • Target specific demographic • Push the envelope creatively
Instant Pot—Dinner. Done The product was developed with an advanced microprocessor and incorporated the functions of five cooking appliances into one: pressure cooker, slow cooker, rice cooker, steamer, and warmer	• Leverage already existing popular communities online • Empower people to empower yourself • Find a strong strategic partner (Amazon)
MacDonald's—Fish and Chips With the Fish and Chips Meal, we've brought something unique to the table—not just made for Atlantic Canadians, but made by Atlantic Canadians. The new meal is described as a two-piece serving made with 100 percent wild-caught Atlantic haddock	• Partner with "industry expert" • Pilot project (use the scientific method) • Clear and concise message

Source SCI 3101 The Public Communication of Science [32] headlines, producing a substantial boost of sales, and even winning marketing awards. He also emphasized the unique nature of the "grassroot approach" used by the Instant Pot creator where he sought to empower chefs by sending them free Instant Pots and encouraging them to publish new books and recipes using it, ultimately making Instant Pot a huge success, particularly with Amazon. The speaker also described how the creators of Macdonald's Fish and Chips took a scientific approach by first piloting their product in Atlantic Canada prior to launching it nationally (described as an experiment). He, then, summed up his presentation as follows:

So, I've given examples of different ways to create an engaging type of campaign to launch in Canada. One way is leveraging an existing platform, one way is empowering a community, the third way that we looked at was kind of using the scientific method with an industry expert, the McDonald's one.

These three business strategies are discussed at length in marketing books such as 33 Million People in the Room: How to Create, Influence, and Run a Successful Business with Social Networking [33].

At the end of his presentation, the speaker introduced students to their pitching assignment. Working in small groups (four members each), students were to create an engaging campaign to launch an innovative product called *Hungry Planet®* in Canada. Developed by Todd and Jody Boyman, this plant-based meat was designed to serve as an analog and potential substitute for conventional animal meat (see official website at https://www.hungryplanetfoods.com/about/). Proteins from plants such as soy and pea were used to create a product that shares the aesthetic qualities (e.g., texture, flavor, appearance) and approximated the nutritional profile of conventional animal food items such as beef and burgers. Such a product is consistent with recent calls for more *sustainable diets*, that is, food whose production strives to reduce its ecological footprint, and that can hence help mitigate human impact on the environment (e.g., off-setting global warming, minimizing losses of habitat and biodiversity). Other benefits include higher nutritional content (healthier compared to animal products) and an ethical treatment of animals.

The specific aim of this assignment was for each group to prepare to make a 5-min STEM business pitch that addressed the following questions:

1. Who is your audience?
2. What is the best platform that you can launch on?
3. What format should pitch use (video, press release, a FAQ (Frequently Asked Questions), social media campaign, influencer survey, etc.)?
4. What's the key message for the product?
5. How do you excite, engage, and empower your audience?

For the remainder of the lecture (Day 1) and the entire recitation session (Day 2), students worked in small groups. This group work time was devoted to background research and pitch preparation. Using notebooks, students were instructed to research the Hungry Planet® product, find scientific research related to the product (evidence that could be used to sell their product and/or justify aspects of their campaign), explore potential platforms/commercial partners, and research a target audience. Then, on Day 3, a spokesperson from each group made a business pitch (10 pitches were made overall) and received feedback from classmates as well as the professor and guest speaker.

3.2 Data Collection

Our main data sources were the curriculum developed by the instructor, video-recordings and the survey data. First, curricular materials (assigned readings, handouts, PowerPoint slideshows, course syllabus, student work) were systematically collected and used to determine the main curricular design features (e.g., structure, sequence of activity, and content) of the interdisciplinary intervention (Responding to RQ 1), Secondly, video-recordings were made of the entire STEM Entrepreneurship Activity implemented in the third week. These data were used to identify engagement tactics and rhetorical strategies deployed by students, and communicative features of their pitching presentations (Responding to RQ 2).

Lastly, a written survey served as the main source of data used to determine students' perceived learning outcomes of the STEM Entrepreneurship Activity (Responding to RQ 3). Designed originally for the purpose of providing the students with an opportunity for targeted reflection on the activity, the survey comprised of the following open-ended probes:

1. What did I learn most from doing this activity?
2. How will this skill help me progress towards my professional goals?
3. What was something that surprised me about this assignment?
4. What potential weakness did this activity highlight in me that I would like to improve upon?

3.3 Data Analysis

Qualitative in nature, our analysis had a tripartite focus that took into account the curricular intervention itself, students' oral performance, and learning outcomes. More specifically, we adopted elements of a "grounded theory" approach to data analysis [30] that called for the iterative and combined use of interpretative and flexible methods of analysis. There were no a priori hypotheses or codes. Instead, analytical categories emerged and were gradually refined based on close examination of meanings and patterns in the collected data. This analytical approach was aimed simply at the production of emerging interpretations grounded in our data, not a summary theory or model as often done in full-blown, formal grounded theory analyses.

3.3.1 Curriculum Analysis

Curricular characterization of the STEM Entrepreneurship Activity (RQ 1) was accomplished by means of document-based analysis of the curricular materials [34]. Attention was given specifically to the following features of the curriculum: content (what is the instructor teaching?), activities (how is the content structured?), teacher role (how is the instructor facilitating learning?), time (for how long is he teaching?), and materials and resources (with what are students learning?).

3.3.2 Video Analysis of Students' Pitches

Transcribed recordings of oral presentations were carefully examined to assess students' oral performances (RQ 2) in light of the design features identified through our curriculum analysis. This examination was also informed by previous studies of business pitch communication [19, 23, 24]. More specifically, we sought to assess the extent to which students' entrepreneurial pitches were consistent with previously reported discursive structures and linguistic features (e.g., engagement tactics, and rhetorical strategies).

3.3.3 Post Presentation Surveys

Student responses to our open-ended probes were analyzed to determine their perceived learning outcomes, that is, the extent to which students felt that participation in the STEM Entrepreneurship Activity allowed them to acquire entrepreneurial mindset (RQ 3). Also, taken into account was how the students felt about their experience after the activity and how they evaluated its effectiveness (strengths and weaknesses) at promoting their learning of an entrepreneurial application of science communication. Theoretical definitions of entrepreneurial mindset proposed by McGrath and MacMillan [5], as well as Haynie et al. [6] informed this analysis.

4 Results

This section is organized according to our three RQs.

4.1 STEM Pitch Curriculum

Regarding RQ 1, our curriculum analysis revealed that, as designed, our STEM entrepreneurship activity had a good degree of alignment with the *Guiding Framework for Enterprise and Entrepreneurship Education* [35], which contains a list of specific learning outcomes to be targeted in entrepreneurship education. Our activity targeted the outcomes included the need for students to learn to: (1) identify an opportunity; (2) define benefit and value; (3) investigate a market; (4) create a preliminary business model; (5) evaluate feasibility, viability, and desirability; (5) communicate in terms of societal benefits; (6) identify distribution channels; and

(7) build teams. However, other recommended outcomes were not addressed in this activity, such as the need for students to learn to protect intellectual property, identify supply chains, assess policy, and regulatory issues. As emphasized by the guest speaker, the goal was simply to come up with an execution plan to launch Hungry Planet® nationally and articulate a rationale to justify their proposed plan.

Compared to similar educational interventions in previous studies, several design features set our STEM entrepreneurial activity apart. First, it was not framed as a "real pitching competition" wherein the team who makes the most compelling pitch wins. Instead, the activity was framed as a "collaborative simulation" meant to simply provide science students with an opportunity to experience and explore the business world for the first time and apply their newly acquired knowledge about entrepreneurship by making a pitch and then, receiving feedback from an expert. Another distinctive feature of this activity was that all teams pitched the same innovative product (Hungry Planet®), which had been previously developed by other science experts. This technological innovation was simply selected by the guest speaker without any student input and presented as the only product choice for students to pitch. This is in sharp contrast to pitching competitions wherein participants pitch their own products after having dedicated a considerable amount of time and effort to its design and development.

4.2 Students' Pitch Performance

With respect to RQ 2, our video analysis revealed several trends across the students' pitches. Particularly noticeable was the prevalence of discursive structures (organizational patterns) that differed, at times quite considerably, from those reported by previous studies. For instance, the two monetary components of *initial ask* and *negotiation* were completely absent. Students' execution plans for launching Hungry Planet® in Canada did not attend to financial aspects of their proposed ventures such as costs and profits. The financial viability of their STEM business proposals was simply overlooked as students tended to assume that the necessary investors were already on board and that funding was not an issue that needed to be carefully considered. Several contextual factors seemed to contribute to the emergence of such a trend. First, none of the guiding questions provided by the guest speaker focused on financial matters. The goal of pitching assignment was not to literally sell an idea to potential investors, but rather to metaphorically "sell" a marketing plan to peers and instructors (i.e., to present a plan that was compelling and somehow justifiable). Second, no one in the audience was explicitly identified as a potential investor. Instead, it was entirely made up of other pitchers, an expert marketer, and the course instructor. In this instructional context, the financial aspect was not treated as an essential part of successfully pitching a STEM business idea.

On the other hand, student-pitchers provided fairly detailed descriptions of their potential markets, competitors (their target audiences), potential partners (online platforms, local businesses, etc.), marketing strategies, campaign format and content, and evidence to justify their choices. For example, Group 1 pitched the idea of partnering with GoodFood, a very popular online meal kit company in Canada that delivers the ingredients for making meals selected by customers to their doorstep along with a recipe (https://www.makegoodfood.ca/en/home).

From this partnership, we would be targeting the company itself, and by doing so, we would also be targeting their consumers… students, busy families, and seniors. To launch our product, our plan is to send to customers for a free meal kit which includes our plant-based burgers… original recipes will be provided to their subscribers and it's not gonna be only for the preference of vegetarians, we are going to try to cover a broad market so that includes those who are 'carnivores', those who are vegetarians, and vegan.

This proposed partnership was justified with statistical evidence (a bar graph showing the industry's annual sales between the years 2013 and 2020) that meal-kit services is a rapidly growing industry. Another justification was close alignment with the company's values as evident in the statements and descriptions available on its website:

…GoodFood prides itself on using locally sourced and sustainable food products, so that really aligns with our goal for sustainability and the environment. … On a final note, something great about GoodFood is that, for every box purchased, they send a nutritious meal to someone in need. Now, here at Hungry Planet, a project where we are trying to commit to improving human and planetary health… In conclusion, we hope that, through our partnership with GoodFood, we will be able to help the planet.

As can be seen above, selection of GoodFood as a partner is justified in terms of a value analysis as well as a market analysis for STEM communications. Due to space constraints, other student pitches are just summarized on Table 2.

The marketing strategy most commonly pitched by students was to leverage existing social media platforms and online communities (used by all 10 groups). As part of their proposed approaches to launch Hungry Planet® in Canada, all groups sought to harness the power of platforms such as YouTube and Instagram to influence youth and younger audiences, especially millennials. Relatively fewer groups emphasized empowerment (Groups 4, 8, 9 and 10) or attempted a scientific experiment (Group 6)—the other two marketing strategies introduced by the guest speaker. The former groups presented purchase and consumption of Hungry Planet® as a potential source of empowerment for everyday consumers (acts of power). As the speaker for Group 8 stated, "we would like to empower the youth and our environmentally conscious millennials to be able to actually do something about the climate crisis in a delicious way and also to be able to use a bit of scientific foresight." Similarly, Group 10's speaker stated that:

[When dealing with environmental issues and health], people often feel that their impact as an individual is minimal… it can be overwhelming and uncertain… so our strategy is to empower these people, give them an opportunity to act, thus our campaign slogan is 'start here'.

In addition to online platforms, many groups also pitched parallel campaign strategies (e.g., food sampling) with a variety of local partners—another form of leveraging focusing on existing local communities and face-to-face interaction.

Table 2 Summaries of students' STEM business pitches

Group	Partner(s)	Rationale	Marketing strategies
2	*Elgin Street Diner* + YouTube	– A local business that is family friendly and well known in the community for their meat products – Appeal to cultural knowledge (no evidence)	– Free samples to parents and kids to familiarize with taste – Create recipes and give them to social media influencers
3	UOttawa + Instagram	– Local university regularly hosts public events that are attended by large numbers of students (e.g., Frosh Party, Poutine Fest) – Appeal to cultural knowledge (no evidence)	– Set up pop-up shops at UOttawa events like games and campus parties – Instagram ad campaign
4	YouTube + Instagram influencers	– Excite, Engage and Empower youth – Older generations (used to eating "steak and potatoes") are set in their ways. Instead, focus on increasing next generation's awareness of plant-based meat as an option worth trying (without labels such as "vegan food") – No slide deck	– Create videos ("Hungry Planet®, not rabbit food" and using famous athletes eating Hungry Planet®) for a media campaign – The videos would pre roll health and fitness videos on YouTube
5	Meat-focused, local restaurants (*The Keg*, and *East Side Mario's*) + YouTube	– Target people "who are on the fence about" adopting a vegan/vegetarian lifestyle (not vegetarians) – Evidence: graph bar showing amount of greenhouse gases emissions per kilogram of meat for beef, lamb, pork, and chicken; analysis of restaurant menus	Ad campaign using YouTube's algorithm to target specific age groups: (1) 25 y.o. and under—emphasis on sustainability; and (2) 35 y.o. and up—emphasis on health benefits of product

(continued)

Table 2 (continued)

Group	Partner(s)	Rationale	Marketing strategies
6	Small, trendy, nice restaurants in Vancouver and Toronto + YouTube	– Smaller restaurants that are "Instagram destinations" (unlike corporate, fast food chains) in large cities – Bar graph of "projected sales increase" (not actual evidence) – Getting people to talk about Hungry Planet® (creating a "buzz")	– For younger audience (millennials): short YouTube ads (5–6 s) targeted to animal and environmental activists – For older audience: scientist talk (educational) – Free samples at restaurants
7	*Health Canada* (government agency) + YouTube/Instagram	– Health Canada has a new food guide that recommends large increase in the amounts of vegetables and fruits; – Hungry Planet® can help achieve the recommended amount of veggie intake – Evidence: Pie chart of new food guide + demographics	– Partner with barbecue YouTubers and Instagram recipe content creators – Use wLink (influencers receive digital currency per clicks) – Target 17–30 y.o. who are meat-eaters and climate conscious ("on the fence")
8	YouTubers with larger numbers of subscriptions (*Tasty*, *Binging with Babish*, *The Burger Show*)	– YouTube is very popular among millennials – Empower YouTubers and leverage their popularity – Evidence: statistics about the millennial demographics (size, buy power, etc.) + number of subscriptions of popular YouTube channels	– Send packages with samples to popular YouTubers who will use it to create videos – Give YouTubers a cut of orders – Send out coupon codes (measure of campaign effectiveness and impact)
9	Instagram + *Skip the Dishes* (online food delivery company in Canada)	– Instagram is popular among younger demographics – Evidence: statistics about adults	– Instagram ads + hashtags – Empower younger, progressive, environmentally

(continued)

Table 2 (continued)

Group	Partner(s)	Rationale	Marketing strategies
		wanting to reduce meat consumption, and the number of Canadians who use apps to order food delivery to the door – No slide decks (notes on cell phones)	conscious people (millennials) who are more open to change – Send free samples to culinary influencers
10	YouTube + Instagram	– Empower environmentalists (e.g., Instagram activists) and health-conscious people – Evidence: protein content of Hungry Planet® (23 g/burger), number of people who attended "climate strikes"	– YouTube videos – Traditional posters (place "Start Here" posters in restaurants, community centers, gyms, etc.) – Sampling events

Groups 2, 5, and 6 favored partnerships with local businesses (popular restaurants that catered to their targeted audiences), whereas Groups 3 and 7 opted for a partnership with an educational institution (uOttawa itself) and a government agency, respectively.

Overall, students were able to demonstrate having effective pitch communication skills. Among their commonly used engagement tactics were use of slideshows with colorful and creative imagery and ending their pitches with a memorable closing statement—a tactic previously identified as effective earlier in the course. These closing statements took various forms, including humorous comments and motivational/inspirational phrases:

> Group 3: "And, if we can get a Tik Tok challenge trending, we are golden".
> Group 4: "So, what are you waiting for? Partner with Hungry Planet® for a better future."
> Group 5: "Given all of that, who is hungry and who is ready to make some money?".
> Group 6: "If you don't know where to start, you should start with us."
> Group 7: "Eat a burger, save the planet. Satisfy your cravings with a guilt free solution delivered to your doorstep."

On the other hand, it should be noted that slide decks were not always used: Group 9 had their notes on cell phones, and Groups 3 and 4 memorized their pitching lines. Moreover, no demonstrations were performed nor were any stories told.

Another common feature shared by the students' STEM business pitches was the inclusion of evidence in an effort to make their presentations more compelling. This rhetorical strategy was deployed by the majority of students (Groups 1, 5, 7, 8, 9, and 10), as recommended by the guest speaker during his talk. These groups showed graphs with a variety of data, shared research findings, and/or the results of their own analysis of selected partners. In sharp contrast, the remaining four groups did not provide evidence of any sort, instead resorting to alternative strategies. Groups 2 and 3 simply appealed to shared cultural knowledge through strategic reference to potential partners that were well-known locally, hence rendering their proposal more compelling by creating the impression of some degree of market familiarity and expertise. Group 4 made no attempt to provide any sort of evidence. Lastly, Group 6 included a bar graph of "projected sales increase" that did not actually constitute evidence, but simply groundless predictions.

4.3 Students' Perceived Learning Outcomes

In regard to RQ 3, many students emphasized in their survey comments how participation in the STEM Entrepreneurship Activity allowed them to experience a new way of thinking about science and consider scientific ideas and findings from a novel perspective:

> What I learned the most is that it takes ***different mindsets*** when communicating to a general public and this is a key aspect to being a good communicator. In this situation ***we had to think like marketers and business people*** which took us out of our comfort zone in a more unknown environment. (Group 9)
>
> I learned a lot about how ***to think like a consumer***. I found that in order to come up with an effective business pitch I had to ***step into the shoes of the different consumers*** in order to see what would seem the most effective. (Group 1)
>
> Ways to ***integrate an investigative mindset into business ventures***, such as applying the scientific method to advertising campaigns. (Group 7)
>
> Taught me to really try to think about ***science from the perspective of a business***. (Group 5)
>
> In creating an advertising campaign, I had to ***think about different target audiences*** and why this type of presentation might appeal to them. (Group 6)
>
> ***The work was very people oriented***, although I learned about the contents and nutritional value of the product and about the nutritional value for regular food. (Group 2)
>
> This assignment required ***holistic thinking***… ***big-picture thinking***, and attempts to consider ***perspectives beyond my own***. (Group 4)

In the above comments, students recurrently emphasize the transformative nature of their experiences making a business pitch for the first time. As described by the students themselves, such a learning experience gave rise to an alternative mindset that was novel, unfamiliar and sometimes even uncomfortable (e.g., Group 9's statement as "took us out of our comfort zone in a more unknown environment"). In addition to thinking like a scientist, students also had an opportunity to think like an entrepreneur, marketer, salesperson, or consumer while considering scientific issues such as nutrition, health, and the environment. In other words, the pitching activity successfully encouraged students to go beyond a strictly *scientific/investigative mindset* (analytical and thing-oriented) and adopt *an entrepreneurial mindset* that was more people-oriented, required holistic and big-picture thinking, and entailed a multiplicity of perspectives. It was clear from their comments that students became more entrepreneurially minded.

Despite widespread recognition of gain in entrepreneurial mindset among students, some felt that a stronger focus on science and scientific content would have improved the activity. These students were surprised by the lack of detailed scientific information in the final product. As students in science majors who were used to focus their learning exclusively on advanced scientific content, it was a challenge for them to participate for the first time in an interdisciplinary activity whose focus extended beyond the scientific domain:

> I personally found that ***this activity didn't have a lot to do with science***… very little of the research was actually ***science oriented***. (Group 5)
> I feel that ***there wasn't as much of a science*** focus as I had hoped for. (Group 8)
> The pitch itself ***wasn't really about science*** even though the product was, so I had to take off my scientist hat and put on a businessman hat, which was a really weird experience. (Group 5)
> It surprised me how the research that went into this assignment was ***very little about the actual science***, and much more about getting a message out there, about building a business, about marketing. (Group 3)
> I was surprised at ***how little research really mattered*** in this assignment and how more so than the others, it was very much based upon delivery and stylistic elements instead. (Group 10)
> It surprised me that so ***little of the research*** I did for this assignment was ***centered around the actual scientific information*** we would be presenting. (Group 1)

For the above students, the STEM entrepreneurial activity could have been more strongly focused on the scientific aspects of the technological innovation (i.e., the science behind it) being marketed. These students wished to have spent more time exploring the scientific research that informed the development of Hungry Planet®. Such a desire to become more knowledgeable about the science behind innovative product development was consistent with these students' strong interest in science (i.e., it was reflective of these students' disciplinary bias). This personal interest in science seemed to create the expectation that the activity was going to be science-dominated and that little attention would be given to the business/communicative aspect of science-based entrepreneurship.

5 Discussion

Student communicative performance of STEM pitches constitutes an effective means to enhance entrepreneurial mindset in undergraduate science. Pitching a technological innovation provides students who are a priori unfamiliar with the business world with a transformational opportunity to think like an entrepreneur, marketer, salesperson, or consumer while considering scientific issues such as nutrition, health, and the environment. As designed, our pitching STEM activity successfully encouraged students to go beyond a strictly scientific/investigative mindset (analytical and thing-oriented) and adopt an entrepreneurial mindset that was more people-oriented, required holistic and big-picture thinking, and entailed a multiplicity of perspectives. Although the activity did not produce professional entrepreneurs (e.g., start-up founders), students who participated in the activity became more familiar with the business world and skillful in thinking and communicating entrepreneurially.

Yet, despite such promising outcomes, some students called for a stronger focus on science and scientific content. Their comments can be taken as indicative of a common problem in teaching approaches that integrate multiple academic disciplines, namely lack of balance. As our previous work showed [36], STEM curricula often give primacy to the knowledge and skills of one specific discipline (domain of enquiry) while integrating parts from others (instrumental domains), hence giving rise to imbalance. From this perspective, one could simply conclude that the examined STEM pitching activity provided another example of an integrated lesson that showed an imbalance between integrated disciplines. However, it would be hasty to reach such a conclusion without more careful consideration of other important factors. One such factor is the possibility of disciplinary bias on the part of the students. Students' strong interest in and commitment to science could have created the expectation that the activity would be science-dominated. Put differently, students expected the scientific dimension of science-based entrepreneurship to receive more attention relative to the business/communicative dimension (as opposed to equal attention). Therefore, these students' tendency to experience the STEM pitching activity as requiring a stronger scientific focus could alternatively be linked to biased expectations favoring science rather than a lack of appropriate balance between science and business in the activity's design. Nonetheless, students' comments highlight the need for careful consideration to be given to what constitutes an appropriate balance when it comes to integrating science and business.

Finding effective ways to strike a productive balance will be essential for future interdisciplinary efforts to teach for entrepreneurship in STEM classrooms. However, a 50–50 balance may not necessarily be the most appropriate and effective approach for STEM business pitching activities in the science classrooms. Engaging in this type of interdisciplinary activity inevitably means a lessening of focus on one's own academic discipline and also attending to important content and research from other fields. As such, it is possible that, at least in some occasions, science may become an instrumental domain (a secondary domain) from which parts are strategically borrowed and integrated into business communication (the primary domain).

Our curriculum analysis also revealed a need for a higher degree of authenticity. As described above, several design features of our STEM entrepreneurial activity set it apart from an authentic pitching competition [18]. First, the activity was framed as a "collaborative simulation" without winners or losers. Second, all teams pitched the same innovative product, which had been previously developed by other science experts. This is in sharp contrast to "real pitching" wherein participants pitch their own products after having dedicated a considerable amount of time and effort to its design and development [19]. Third, financial matters were largely overlooked—there was no initial ask, negotiation or discussion of costs and profits. The financial viability of their STEM business proposals was simply overlooked as students tended to assume that the necessary investors were already on board and that funding was not an issue that needed to be carefully considered. The goal of our pitching assignment was not to literally sell an idea to potential investors, but rather to metaphorically "sell" a marketing plan to peers and instructors (i.e., to present a plan that was compelling and somehow justifiable). Instead of potential investors, the audience was made up of other pitchers, an expert marketer, and the course instructor.

Such design features seemed to constrain students' pitching performances as evident in the prevalence of discursive structures (organizational patterns) that differed, at times quite considerably, from those reported by previous studies [19, 23, 24]. On the one hand, students' pitches included a business plan with detailed descriptions of potential markets, target audiences, potential partners, marketing strategies, campaign format and content, etc. On the other hand, the two monetary components of *initial ask* and *negotiation* were completely absent, and students did not attend to financial aspects of their proposed ventures such as costs, profits, and investors. Moreover, slide decks were not always used, no demonstrations were performed, and no stories told. Several groups did not provide any evidence to justify their marketing decisions, at times simply appealing to shared cultural knowledge or backing up their decisions with seemingly "pseudo" evidence.

The above findings invite us to reflectively consider possible ways of increasing the authenticity of the examined STEM pitching experience. Among these, we would suggest incorporating an engineering phase in which students had a chance to design their own innovative technology prior to setting out to pitch it. Additionally, encouraging students to carefully consider the financial viability of their product and including actual investors in the audience could render their STEM pitching experiences more realistic. Lastly, students might also benefit from guidance on what constitutes actual evidence when it comes to justifying their business plans. Doing so, we believe, is likely to increase the chances that educational efforts aimed at enhancing entrepreneurial mindsets will be as effective as intended by curriculum developers.

6 Conclusion

As posited at the onset of the paper, interdisciplinary pedagogies wherein business and science communication are infused together can help prepare the next generation of STEM entrepreneurs. One such pedagogy is classroom performance of STEM pitching activities wherein classroom activities in which students are challenged to communicate science informally and persuasively as they attempt to sell technological innovations to potential investors. As the reported findings have shown, this pedagogy can encourage undergraduate science students to go beyond a strictly scientific/investigative mindset (analytical and thing-oriented) and adopt an entrepreneurial mindset that is more people-oriented, holistic, big-picture focused, and comprising of multiplicity of perspectives. Nonetheless, questions remain regarding what constitutes an appropriate balance when it comes to integrating science and business. Should STEM pitching activities pay equal attention to science and business communication (i.e., be 50–50)? Or should science be given more attention and remain the primary field (as opposed to becoming an instrumental field)? Should students' potential disciplinary biases be taken into account in the design of such activities? If so, how? It will be critical for future research to find answers to these complex questions if science educators are to succeed in their efforts to expand scientist training beyond cumulative acquisition of facts, and effectively help science novices become a type of person who (like professional entrepreneurs) are creative, independent, resilient, willing to take risks, and tolerant to ambiguity. It is our hope that the present chapter will provide educators with some initial insight in this direction.

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Part IV
The Ways of Conducting an Assessment of Entrepreneurial STEM Education

15 Bioengineering as a Vehicle to Increase the Entrepreneurial Mindset

Lisa Bosman and Katey Shirey

Cultivating diversity in all its forms - of our content, products, and people - is one of our most important business imperatives.

Jeff Bewkes

Abstract

Bioengineering provides a relevant and engaging learning space to explore how holistic assets can support innovation, deepening the need for interdependence between academic disciplines including connections between the arts, science, and engineering. The purpose of this chapter is to introduce readers to bioengineering and bio-inspired design as a way to increase the entrepreneurial mindset of high school and college engineering students through integrated STEAM (science, technology, engineering, art, mathematics). This interdisciplinary approach can strengthen access and equity within the engineering pipeline. We present six integrated STEAM lesson plans for high school and college (grades 9–16). This chapter concludes with advice for making a case for integrated STEAM learning experiences that capitalize on and leverage bioengineering to grow the entrepreneurial mindset and strengthen students' science, mathematics, and technology literacies.

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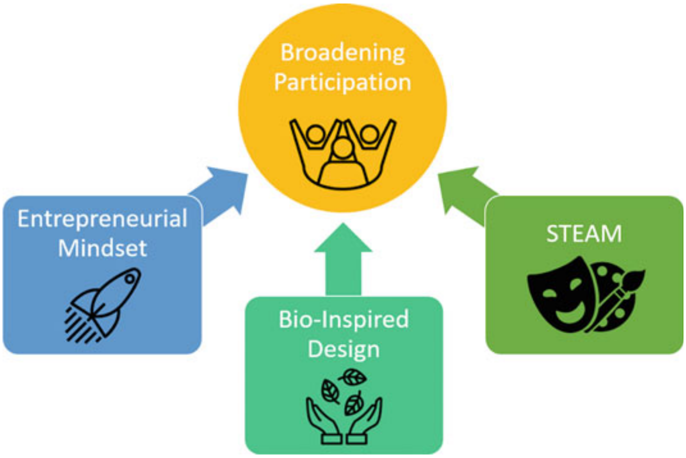
Graphical Abstract



Keywords

Biology · Engineering · Art

1 Introduction

The world's biggest technological, environmental, and social demands will require engineers who can identify issues and develop solutions using diverse knowledge bases and ways of thinking. The entrepreneurial mindset can help engineers to find and solve problems. However, traditional engineering education tends to narrow the discipline of engineering to technical content and practices, limiting the transfer of knowledge from external contexts into engineering challenges, and has the potential to alienate students who have humanitarian interests.

Our focus on biology and engineering capitalizes on documented interest of women and racial minorities towards biology and humanitarian interests [1]. Researchers hypothesize that emphasizing the humanitarian, people-focused characteristics of engineering could support women and minorities to participate more in engineering [2]. Bioengineering, which includes connections to human health and medicine, security, and sustainability, may attract students with humanitarian interests. Thus, our focus on bioengineering can encourage broader participation among persons traditionally underrepresented in science, technology, engineering, and mathematics (STEM), including women and minorities.

The next three sections will, respectively, highlight the hallmarks of the entrepreneurial mindset, integrated STEAM instruction, and biology-inspired engineering and bioengineering. We, then, offer six integrated STEAM lesson plans. Each lesson plan is aimed to elicit the entrepreneurial mindset, bioengineering, and bio-inspired design, and art within a project-based learning experience. The last section concludes with recommendations for assisting allies and advocates with making a case.

2 The Entrepreneurial Mindset

The entrepreneurial mindset is defined as the "inclination to discover, evaluate, and exploit opportunities" [3, p. 13]. Before going too far, it is important to note the difference between the entrepreneurial mindset and entrepreneurship. While there exist multiple kinds of entrepreneurship, the financial type of entrepreneurship, popularized in the *Shark Tank* start-up culture, is a process involving setting up a business to take on financial risks in the hope of profit. Stated simply, people who are financial entrepreneurs build businesses. People with an entrepreneurial mindset, however, think strategically about innovation and continuous improvement regardless of if they work with a company or are working on a startup. In this way, the entrepreneurial mindset can be considered more of a philosophy or a way of thinking.

Entrepreneurial mindset education supports engineers to find and then creatively solve engineering situations using three perspectives as shown in Fig. 1. On the macro level, the entrepreneurial mindset supports engineers' discovery, evaluation, and exploitation of various worthy engineering situations. Within each of these phases, the entrepreneurial mindset encourages engineers to conduct a micro design cycle or other problem-solving strategy to ensure that the outcome from the discovery, evaluation, and exploitation phases are optimized. Finally, the criteria for evaluation of each phase

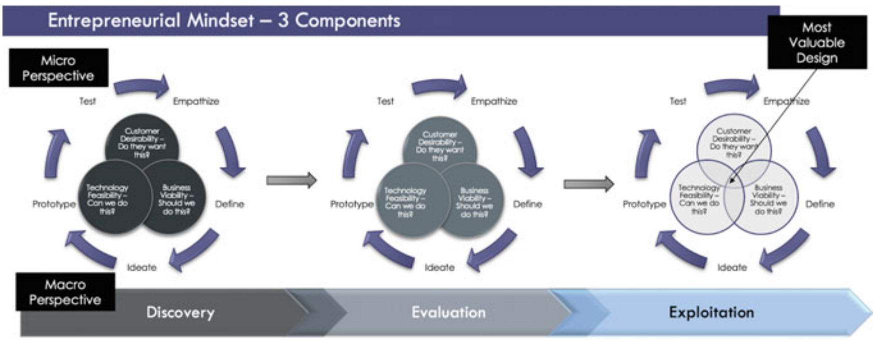


Fig. 1 Entrepreneurial Mindset—three components [4]

involves finding the convergence between consumer desirability, business viability, and technical feasibility. By combining these three perspectives, engineers can use the entrepreneurial mindset to find a most valuable design.

Stronger entrepreneurial mindset may increase engineers' personal, economic, and societal value [5]. Within the United States (U.S.), two leading efforts to increase entrepreneurial mindset in academia are the National Science Foundation (NSF) I-Corps program (created in 2011) and the Kern Entrepreneurial Engineering Network (KEEN) Engineering Unleashed initiative (founded in 2005). While the NSF I-Corps program has a mission to "increase the economic impact of research it has funded [and to] help move academic research it has funded to market" [6, p. 1]. KEEN's tagline is, "Engineers equipped with this mindset understand the bigger picture, can recognize opportunities, evaluate markets, and learn from mistakes to create value for themselves and others" [7, p. 1]. These programs provide an impetus for other educational institutions to get on board; the NSF I-Corps program now includes teams from more than 230 universities [6], and the KEEN initiative now includes 48 engineering institutions [8].

Given over 5300 universities [9] and over 600 ABET-accredited engineering institutions [10] in the U.S. higher education system, there is much work that remains. We need to increase exposure and access to entrepreneurial mindset-focused teaching and learning. Until more universities get on board, our society/world's most pressing problems (often referred to as 'wicked problems') will remain unsolved. Wicked problems are a "class of social system problems which are ill-formulated, where the information is confusing, where there are many clients and decision-makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing" [11, p. 141]. The entrepreneurial mindset provides a systems-thinking framework that leverages STEM content knowledge to rationally find solutions to exceedingly difficult problems, such as wicked problems, by accommodating many stakeholders through the macro and micro perspectives. Entrepreneurial mindset problem solving includes the engineering design process but goes beyond STEM to consider stakeholder desirability, economic viability, and technological feasibility, making a more well-rounded solution for more complex problems. Thus, there is a critical need to effectively prepare future engineers with tools and experiences applying and building skills within the entrepreneurial mindset. This may improve the likelihood of efficiently tackling wicked problems impacting society and may also increase opportunities for economic development at the regional level.

3 Integrated Instruction

Integrated instruction is a method that brings together multiple disciplines to support the teaching and learning process of a given topic or phenomenon [12, 13]. In engineering education, integrated instruction has been developed to "help students make more and stronger connections among mathematics, science, and engineering (and sometimes other subject areas)" [13, p. 147]. Positive impacts of integrated instruction on undergraduate engineering students include increased retention of women and minorities in the major, improved content learning as measured by GPA (grade point average) and concept inventories, student confidence in the individual integrated disciplines [13], and wider student perspectives as they identify and solve multifaceted problems [12]. This may be because integrated learning builds more sophisticated retrieval and application organization structures in the brain [13] which better facilitates transfer, the expert-like practice of applying one subject area's disciplinary content to another disciplinary context [14]. In grades K-12 (U.S. primary and secondary school), early promising impacts of engineering integration on math, science, technology, and engineering learning are tempered by inconsistent STEM integration methods and small study samples [15, 16].

To teach effective integrated instruction, teachers and faculty may lean on real-world phenomena as the ground on which to build and intertwine multiple disciplinary perspectives. Real-world topics and concepts are almost always sufficiently tethered to all content areas allowing a wide range of input. Experts in various connected fields can be assets to one another by contributing their discipline's authority to the content area in question. Teachers and faculty may work in interdisciplinary teams to highlight appropriate relationships, perspectives, problems, and goals from each of their disciplinary perspectives [17].

Integrated-STEAM instruction engages students in learning to design, invent, and innovate by using mathematics and science content, art and engineering skills, and technology tools. Learning in any one discipline may be demonstrated through the transfer of content knowledge to novel contexts, providing assessment opportunities in more than one discipline at a time. STEAM education has been shown to increase student engagement, motivation, and science, math, technology, and engineering content learning [18]. Laughlin, Ong, and Zastavker explain that the "integrated curricular/instructional approach requires different subject matters to blend into a seamless whole, where clear distinctions between (and within) disciplinary fields do not exist" [19, p. 20]. This can be explained by Fig. 2 illustrating a braided integrated STEAM rope comprised of diverse disciplines and multiple perspectives. The braid represents a learning experience that is stronger than the sum of the parts [20]. The strands' different purposes are mutually supportive, overlapping, and interconnected at multiple points.

Imagine the example of how the integrated STEAM braid pulls together disciplines and perspectives in a real-world engineering situation: using mathematical analysis of empirical water quality trends to inform technological solutions for conservation systems. Were a city to take on that problem, the intertwining disciplines would include statistics and computational modeling (algebraic and trigonometric functions), environmental science, ecology, biology, civil engineering, architecture, and human responses to natural and man-made environments. Various perspectives brought to the challenge may include water conservation, environmental sustainability, city resident's needs, local flora and fauna, climate change concerns and zoning regulations and city planning. The full system of thinking, the integrated steam braid, would leverage each expertise towards the

Fig. 2 Integrated STEAM Braid [20]

problem while reinforcing the value of each part of the system. The design could not be engineered without considering local flora and fauna, the city planning would necessarily rely on both models of environmental impact and resident's common space concerns.

We propose that art principles and processes should be additional strands in a STEAM braid, adding explicit instruction and practice for students to learn art skills and be creative in their learning and expressions. Art teachers can work with engineering, science, mathematics, and technology teachers to explain connections from art to real-world STEM phenomena. STEM teachers can capitalize on creative perspective taking and real-world evidence of STEM in the arts.

4 Bioengineering

Bioengineering, the development of technologies to improve the environment or increase human's quality of life [21], is itself an integrated discipline in which biology provides context and motivation for engineering problems [21]. Emerging in the 1950s and accelerating in growth through this decade, bioengineering is a "broad umbrella" term [22, p. 2] covering a wide range of biology, medical, engineering-connected endeavors in social, clinical, and research domains. Interdisciplinary bioengineering involves diverse disciplines such as anatomy, biology, neurobiology, materials science, mechanical, chemical, and electrical engineering, physics, chemistry, biochemistry, bio-inspired design, computer science, mathematics, and statistics. There are over 20 recognized overlapping and intersecting bioengineering/bio-medical engineering divisions [22]. Examples of bioengineering challenges range across security, sustainability, and medical domains including mechanical prosthetics, biofuels, computational biology, and bio-inspired systems thinking/processing.

Because of its orientation towards human impacts and needs, bioengineering may encourage broader participation among persons traditionally underrepresented in STEM, including women and minorities. Research shows that women and minorities may be more motivated towards communal goals than white male counterparts [23, 24]. Women may find that the attention to caring about human needs better aligns with their interests and bioengineering's medical connections may draw interest from women who outnumber men in medical degrees [23].

In the modern world, innovators are using bioengineering and bio-inspired design for a wide range of purposes. Bio-inspired design refers to referencing naturally occurring characteristics in human-made designs with an emphasis on how human engineers can learn from a natural phenomenon and contribute productively to a natural phenomenon. From urban infrastructure to transportation to medicine to fashion, and from bio-inspiration to STEM to art, the overlap results in a plethora of examples. The next sub-sections demonstrate various ways that the STEAM disciplines support one another in real-world bio-inspired design. Some examples highlight technology, and some are grounded in art, but all the following four examples showcase ways that technology and engineering are informed by biological science and capture understandings in artistic expression.

4.1 Design Example 1—Urban Development

Restoring and maintaining the urban environment is one of fourteen Grand Challenges for Engineering in the twenty-first century [25]. Some engineers have drawn on bioengineering via bio-inspired design to address the complex problem of maintaining urban development, seeking lessons from nature to survive with efficient resources. This example shows how engineers used artistic expression and bio-inspired design in the Eastgate Center in Harere, Zimbabwe. The engineers used the entrepreneurial mindset to exploit naturally-occurring termite mound-inspired air circulation mechanics to cool the building as shown in Fig. 3.

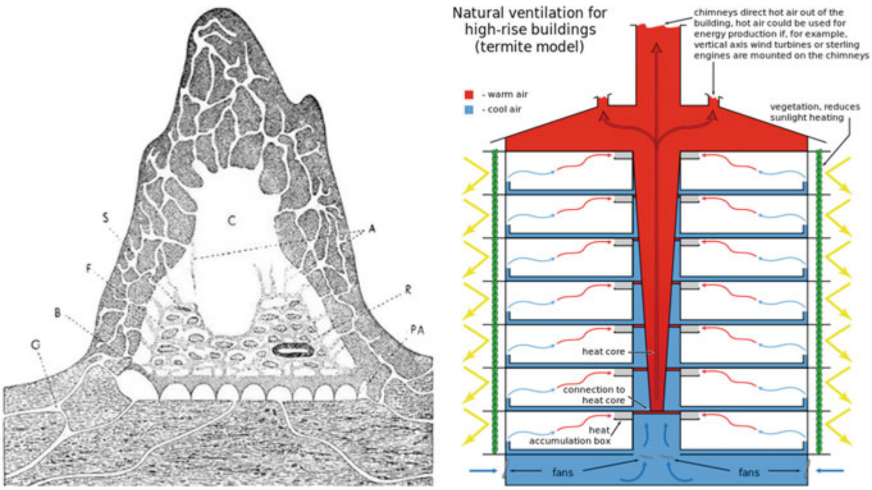


Fig. 3 Termite mound air circulation system used in the Eastgate Center, Harere [26, 27]

Fig. 4 The common kingfisher bird's bill inspired the high-speed train's nose [28, 29]

4.2 Design Example 2—Transportation

This example highlights how the kingfisher's bill inspired an air-cutting high-speed train's front-end design (Fig. 4). Engineers seeking the most valuable design identified the turbulence-reducing kingfisher bird beak as a potential solution in transportation. The train's slick nose cone cuts through air like a kingfisher's bill entering the water, creating minimal turbulence for a smooth and fast ride. The cone is also beautiful, referencing Brancusi's Bird in Space or mid-century modern design aesthetics.

4.3 Design Example 3—Medicine

This example demonstrates how mosquito proboscis (e.g., the stinger mouthpart) inspired engineers to design and create a less painful medical syringe needle. Mosquito stingers like the one shown in Fig. 5 are so effective at entering the skin that biomedical engineers from Terumo Corporation redesigned syringe needles to mimic their points allowing for reduced friction and more painless entry [30]. Additionally, the engineers mimicked the rolled structure of the stinger, reducing the total diameter of the needle. The engineers, working with an entrepreneurial mindset, rethought what was technically feasible in syringe making to make the most valuable product.

4.4 Design Example 4—Visual Art and Aesthetic Design

Three illustrations of visual art and aesthetic design are provided for this example. Theo Jansen brings bio-inspiration to his kinetic, walking, animal-like sculptures called "Strandbeests" pictured in Fig. 6.

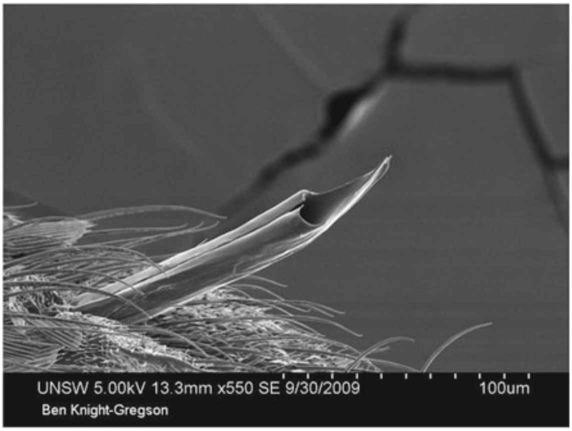


Fig. 5 Mosquito stinger and medical syringe [31]

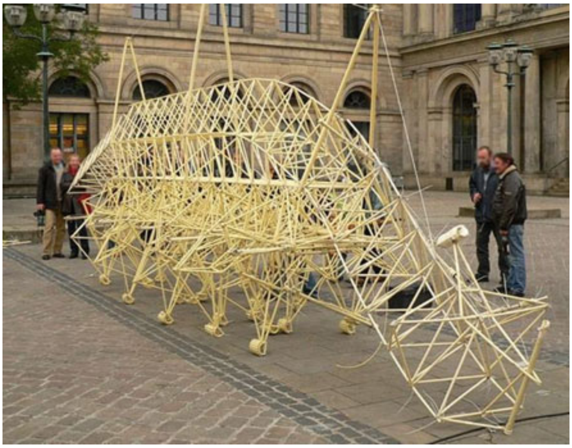


Fig. 6 Jansen's *Strandbeest* [32]

Figure 7 shows Heather Dewey-Hagborg's bioengineering-inspired art titled *Listening Post*. A mechanical "ear" mounted to a post uses a microphone and artificial intelligence to listen to surrounding noise, process a narrative synthesis of the ongoing recorded input, and project the synthesized audio to a remote listening location. Chromat designer Becca McCharen-Tran fuses bio-inspiration with architecture design to create webbed structures augmenting and embellishing the shape of the human body, also shown in Fig. 7. This dress uses sensors to monitor the wearer's vital signs such as pulse rate, breathing rate, and perspiration. When this dress senses an increase in the wearer's breath rate and perspiration, indicating the wearer may be feeling nervous, the 3-D printed panels in the back of the dress expand to create a metaphorically protective shell around the figure, hopefully putting the wearer more at ease.

In all these examples, biological and bioengineering inspiration improved the final design. The engineers and artists who developed novel uses for bioinspiration

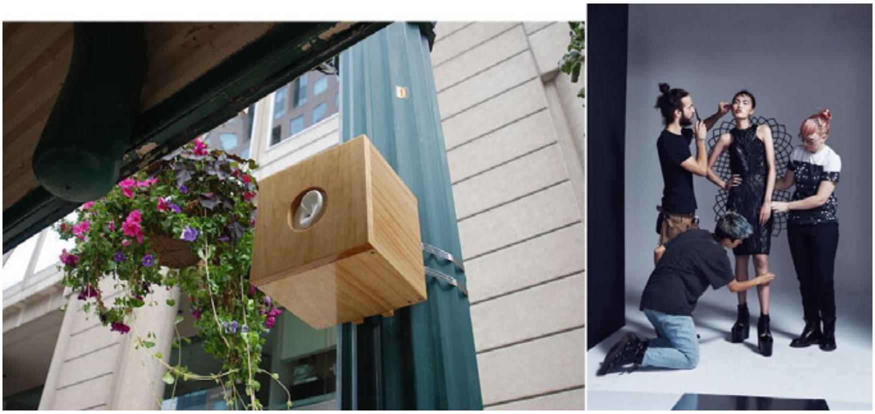


Fig. 7 Dewey-Hagborg's *Listening Post*, 2009 [33] & McCharen-Tran's bio-sensing dress for Chromat [34]

or bioengineering used an entrepreneurial mindset to discover, evaluate and exploit opportunities that were technically feasible, desirable for the audience or consumer, and financially viable. Technological advancement and creative technology-related art both serve our society by raising and solving problems through design. Whether the designer takes a more artistic or more technological form of expression, the effect is still to share innovative design inspired by biology and achieved through the blending of the STEAM disciplines. In the following section, we will describe how educators can begin to propel their students to be entrepreneurial problem-solvers by using bioengineering in integrated-STEAM instruction to develop the entrepreneurial mindset.

5 Lesson Plans for Education Projects

The following lesson plans intentionally integrate science, engineering, art disciplines, and artistic processes to promote diverse participation in the innovation process. Each plan provides a foundation to develop a lesson plan that could be used in high school or college-level engineering instruction. The lesson plans include a description, objectives, options for instruction and assessment. Because learners vary in their preparation, preferences, and needs, opportunities to differentiate or adapt the project for student readiness, interest, and learning profiles are included [35]. Readiness refers to a student's current skill set and level of understanding also called preparation, grade-level, or skill level. Interest refers to a student's level of engagement in the learning activity and topic area. Learning profile refers to the varied modalities through which an individual student may learn, also called modalities of learning.

Lesson Plan 1: Children's Book Writing Focused on Biomedical Engineering (Adapted from [36, 37])

Description

In this semester-long project, undergraduate engineering students research and write a children's book on biomedical engineering problem solving and value creation. Students are introduced to various biomedical engineering disciplines while improving their communication skills (written and visual) in a constructivist-based approach.

Learning Objectives

By the end of this project, students will be able to:

- Develop affective attitudes towards the education and career pathways for biomedical engineers. [Note: bioengineering learning objective]
- Report on famous underrepresented biomedical engineers value creation through innovation. [Note: entrepreneurial mindset learning objective]
- Author, illustrate, and publish a children's book to communicate a biomedical engineering problem-solving process undertaken by biomedical professionals. [Note: humanities/art learning objective]

Learning Activity and Assessment Options

Online Discussion

Online discussion prompts stimulate discovery, communication, and interactivity. Faculty may assess them formatively.

- Sample prompt 1: Unfortunately, many misconceptions exist about what engineering is and what engineers do. How would you explain the role of bioengineers to an adult and a child? Select a peer's post and respond with follow-up questions as if you were an unknowing adult or child.
- Sample prompt 2: Biomedical engineers integrate foundational engineering methods with the medical sciences to create innovative devices, computer systems, software, and equipment [38]. Search the Internet to find a commercially available biomedical engineering design you think is especially innovative. Explain the product and why you think it is innovative. Select a peer's post. Compare and contrast your own post to a peer's post.

Research Presentation

Work in teams of 2–3 to research and present a summatively-assessed PowerPoint on the following: Career opportunities in the bioengineering disciplines; Famous underrepresented heroes in the bioengineering disciplines; Research and design innovations in the bioengineering disciplines; Software and technology application(s) used in the bioengineering disciplines; Education and requirements (degrees, courses, majors or minors) to become a professional in the bioengineering disciplines.

Book Development

Work in teams of 2–3 to write, illustrate, and publish a children's book using a narrative guide, such as The Hero's Journey depicted in Fig. 8. For accessibility by young readers, the book should be 10–20 pages long with illustrations on at least half of the pages, a Flesch-Kincaide readability index of 80 or above (appropriate for 6th-grade and below) [39] as calculated by Microsoft Word Editor Insights, include a glossary of vocabulary terms, a front cover illustration, a title page, and a back cover summary. An example book's covers are shown in Fig. 8. An index and table of contents are optional. Publish your book using a free book publisher, such as Kindle Direct Publishing which works directly with Amazon.com. Additional books can be viewed here: https://www.amazon.com/hz/wishlist/ls/2T4WE1GSUOWMF?ref_=wl_share . This is a summative assessment.

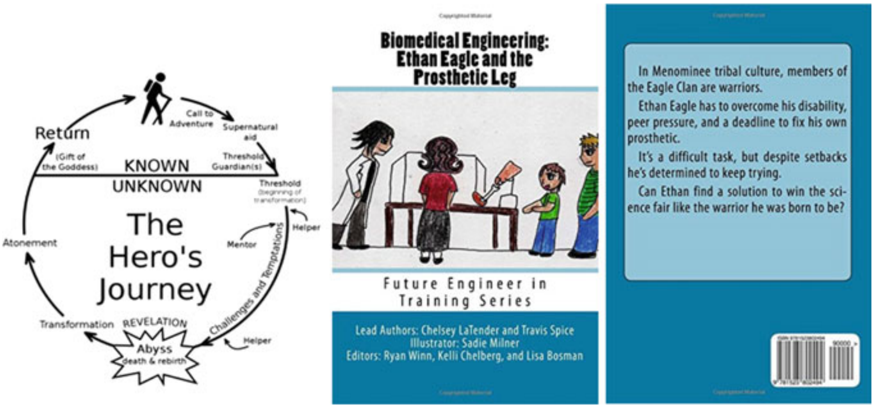


Fig. 8 Hero's Journey narrative model [40] & front and back covers of example book. *Image credit* Lisa Bosman via Amazon.com

Differentiated Learning: To accommodate diverse learners' preparation levels, paces, interests, and learning styles, this lesson plan can be tweaked and scaled as follows:

Readiness: For less ready learners, more opportunities for practice and greater structure are encouraged. Start with an outline and add a greater quantity of details and pictures as the project progresses.

Interest: Encourage students to pick a topic and design characteristics of their choosing.

Learning Profile: This assignment includes visual, auditory, reading/writing, and listening kinesthetic opportunities. Depending upon student preferences, the presentation component can be completed individually or in a group.

Lesson Plan 2: Infographic Development Showcasing the Intersection of Artificial Intelligence and Biomedical Imaging (Adapted from [3])

Description

In this project, undergraduate or high school engineering students design a digital infographic which visually communicates scenarios depicting the intersection of artificial intelligence (AI) and biomedical imaging. Infographics will be developed on canva.com, a free online graphic design platform.

Learning Objectives

By the end of this project, students will be able to:

- Synthesize information relevant to biomedical imaging and AI. [Note: bioengineering learning objective]
- Increase their awareness of and form opinions on ethical issues associated with new biomedical imaging technology development. [Note: entrepreneurial mindset learning objective]
- Design and create comparison, timeline, statistical, or process infographics to visually communicate information relevant to biomedical imaging including judgements of ethical issues. [Note: humanities/art learning objective]

Learning Activity and Assessment Options

Research

Students will individually research medical and social biomedical imaging and AI technology uses. Students will reflect on and defend their reactions to AI in biomedical imaging. For instance, if a student learns that AI is used to flag potential basal cancer cells on patient pictures, then they may be concerned that AI has been shown to have less sensitivity to contrast in darker complexion skin tones, making it less reliable as a preventative technology for darker skin tones than lighter skin tones.

Infographic Development

Students will develop an infographic such as those in Fig. 9 to describe their research findings and conclusions. Canva's (www.canva.com) free poster, flyer, and resume templates can be downloaded as a PDF in 8.5-inch × 11-inch sizes which are easy to print out. The instructor may choose to assign a single infographic as a summative assessment, or the instructor may choose to assign multiple infographics as formative assessments over time in the development of infographic communication skills. Students would conduct multiple rounds of research and come to multiple conclusions to share.

Students will learn about and select from among several types of infographics to communicate their research and conclusions.

Fig. 9 Various infographics. *Image credit* https://www.canva.com/

1. Comparison infographics provide an unbiased ethical comparison of diagnostic biomedical imaging versus the traditional diagnostic approaches. Example focus areas could be a specific use of computed tomography (CT) scan, magnetic resonance imaging (MRI), ultrasound, or positron-emission tomography (PET).
2. Statistical infographics integrate statistical data from multiple sources to tell a story explaining the customer type(s) and other market information (e.g., size, location, need) related to diagnostic biomedical imaging technology.
3. Timeline infographics highlight how diagnostic biomedical imaging has changed over time. The graphic could identify when different types of diagnostic biomedical imaging with AI were introduced to the public.

Process infographics showcase the ethical issues associated with AI and biomedical imaging. The graphic could highlight potential causes of diagnostic error and the consequences of false positives and false negatives.

Differentiated Learning: In order to ensure that diverse learners' needs and preferences are met, consider the following:

Readiness: Scaffold the infographic design process if needed. First, provide both a graphic template and sample data. Second, have students find their own data and create an infographic about it using a given template. Finally, have them find both the information and a template to use.

Interest: Interest in this assignment is promoted by empowering students to choose their own Canva template and/or build an infographic based on the information and design characteristics of interest to them.

Learning Profile: This assignment integrates visual, reading/writing, and kinesthetic learning to promote opportunities for different types of learning styles to excel.

Lesson Plan 3: Pitching Biomimicry-Inspired Design Innovations Using Video Production (Adapted from [41] and Rose Hulman Institute of Technology's professional development programs)

Description

This is a video development project which requires students to pitch the value proposition (e.g., the promise of value to be delivered) associated with a biomimicry-inspired design innovation. A "Madlibs" type worksheet guides students through a fill-in-the-blank elevator pitch writing process with an explicit focus on proposing the innovation's value added. This project can be completed individually or in teams with undergraduate engineering students or high school engineering students as a one-time, summative assignment, or as a formative assignment required multiple times throughout the semester to provide students practice with communicating value addition through pitch videos.

Learning Objectives

By the end of this project, students will be able to:

- Summarize biomimicry-inspired design characteristics. [Note: bioengineering learning objective]
- Justify the components of an effective elevator pitch including design innovation needs and value proposition. [Note: entrepreneurial mindset learning objective]
- Create a video to communicate (experientially) a biomimicry-inspired design innovation and value proposition. [Note: humanities/art learning objective]

Learning Activity and Assessment Options

Elevator Pitch Format

During class, students should be introduced to the "Madlibs"-style Elevator Pitch worksheet in Fig. 10. "Madlibs" is a popular fill-in-the-blank activity book for children. In this worksheet, students fill in the blanks to create compelling arguments for innovation including why the design innovation is needed and how the design innovation will work to add value. The instructor will explain the worksheet to the students. The instructor may also provide a non-engineering example such as how to pitch the need for a new car to one's parents. The new car stands in for the design innovation to make it clear how a design pitch should be structured.

- Students, as an example, imagine you are "pitching" your desire for a new car to your parents. You must include both the "why?" and the "how?" in your pitch.
- First, state why the car [a.k.a. the design innovation] is needed. For the car, you should remind your parents of why it's necessary. Here's what you say, "Mom and dad, you currently face time constraints when scheduling work around kid pick-up times. You often face discomfort when thinking about the teenage kids "racing" around in their car. And our grandparents

General Elevator Pitch – All Purpose Form for Promoting Innovation and Change

Why is the design innovation needed?
(Focus on the customer needs and wants, including the gap with current solutions.)

1. ____________________ currently face ________________________________.
[stakeholder group] [suboptimal outcome]

2. ____________________ currently face ________________________________.
[stakeholder group] [suboptimal outcome]

3. ____________________ currently face ________________________________.
[stakeholder group] [suboptimal outcome]

What is the design innovation?
(Focus on the Value Proposition summary.)

The best way to address these needs is through ________________________________.
[value proposition]

How does the design innovation work?
(Focus on the design gain creators and pain relievers, including key product features.)

Upon implementation, we think it will:

4. ____________________ will ________________________________.
[stakeholder group] [desired outcome]

5. ____________________ will ________________________________.
[stakeholder group] [desired outcome]

6. ____________________ will ________________________________.
[stakeholder group] [desired outcome]

The Ask
(What do you want from them?)

This is what we would like from you: ________________________________.

Fig. 10 "Madlibs"-style elevator pitch planning worksheet. *Image credit* Lisa Bosman

currently face sadness because us kids do not have transportation to visit them at the nursing home. The best way to address these needs is through buying me [the student] a car."

- Next, state how the design innovation will work emphasizing the value proposed by the design innovation. For the car, perhaps you say, "A new car will reduce your scheduling conflicts, mom and dad. Your new car will be well taken care of. Our grandparents will be happy because we can visit them more. We will know that we have succeeded when you, mom and dad, sleep well at night."

Biomimicry-inspired Innovation Elevator Pitch Development

Once the students understand this approach to the elevator pitch, have them reconsider the pitch concerning a new biomimicry-inspired design innovation. Students will need to conduct Internet and Journal research or interviews to gather information about a biomimicry-inspired design innovation. Students will complete the "Madlibs"-style elevator pitch worksheet (Fig. 10) to lay out the arguments for why this innovation is needed and how it will work.

Next, students should work individually or in teams to convert the filled-in elevator pitch worksheet into a three-minute video pitch for their biomimicry-inspired design innovation. Many video production options are available to record their pitch, however, an easy place to start is through the use of voice-narrated PowerPoint converted to a MPEG video file. The pitch worksheet and video will be assessed by how well they justify that the innovation is biomimicry-inspired as well as how well they justify its qualities as an innovation.

Differentiated Learning: Scale this project according to readiness, interest, and learning profile as follows:

Readiness: Provide appropriate opportunities for practice and structure as needed. Perhaps first provide students with an example video pitch and ask students to fill in the elevator pitch worksheet from that pitch to see the structure in action. Students at a higher readiness level may integrate animations and music to create a more engaging video.

Interest: Empower students to pick a topic and design characteristics of their choosing.

Learning Profile: This assignment includes visual, auditory, reading/writing, and kinesthetic learning to promote opportunities for different learning profiles to excel in at least one of the learning application areas.

Lesson Plan 4: A Novel Use of NASA Bio-Inspired Technology (Adapted from [42])

Description

NASA utilizes various biomimicry-related technologies in their diverse efforts including space-bound payloads, satellites, rockets, rovers, and human-support technologies. In this digital design challenge, high school students will learn what biomimicry-related technologies are and how they are used by NASA for biomimicry-inspired technologies. Then, they will imagine how Earth-bound humans can capitalize on these NASA designs and re-design biomimicry-inspired NASA technologies to meet a current human need.

Learning Objectives

By the end of this project, students will be able to:

- Infer the biomimicry-inspired design elements from within NASA technologies. [Note: bioengineering learning objective]
- Propose and defend how a biomimicry-inspired NASA technology could be repurposed to meet a real-world problem for a specific stakeholder(s) on Earth. [Note: entrepreneurial mindset learning objective]
- Create a virtual-world illustration or digital interactive to clearly demonstrate the use of the NASA biomimicry-inspired technology in the context of solving a real-world problem. [Note: humanities/art learning objective]

Learning Activity and Assessment Options

Biomimicry-inspired Technology Innovation Exploration

In groups of 2–3 or individually, students will investigate NASA's use of biomimicry in space exploration and biomimicry-inspired design. As a starting point, teachers may provide students with a catalog of images or biomimicry-inspired descriptions for students to research. Example images are provided in Fig. 11. The left image shows technicians working at NASA's Astrotech's payload processing facility (Titusville, Florida, USA) on the stow solar array #2 against the body'f NASA's Juno spacecraft. The right image is a picture of Brian Trease, a researcher at NASA's Jet Propulsion Laboratory (Pasadena, California, USA) holding a prototype of a solar panel array that folds up in the style of origami. Both NASA designs were inspired by the natural phenomena of petal and leaf folding for which ample documentation exists online at various reading levels [43–46].

Fig. 11 Solar panel at Astrotech. *Image Credit* NASA/JPL-Caltech/KSC [47]; Brian Trease. *Image credit* NASA/JPL-Caltech [46]

Students examine lists of real-world challenges, including the United Nations Sustainable Development Goals [48], the National Academy of Engineering (NAE) Grand Challenges for Engineering in the twenty-first century [25], and NASA's Space Technology Grand Challenges [49]. Students select a challenge that they will attempt to solve with inspiration or aid from a NASA technology and define the problem identifying stakeholders, criteria and constraints, and measures that will indicate success.

Virtual-world Illustration or Interactive Development

After students find a use for the NASA biomimicry-inspired innovation to exploit on Earth, they illustrate its use in a virtual space such as Minecraft Education, code.org, Sketch-up or Tinkercad. During critiques, students justify how their technology and application meet their stakeholders' needs. Students revise their design and any justifying documentation before submitting to a class album. Summatively assess the digital artifact and justifying commentary for (1) accurately inferring the biomimicry involved in the original NASA technology design, (2) appropriately reframing the biomimicry-inspired NASA technology to meet the needs of stakeholder(s); and (3) communicating the use of the reframed technology in a (virtual) real-world context.

Differentiated Learning: This lesson can be adapted to meet the needs of diverse learners as follows:

Readiness: Provide concrete guidance to research of NASA bio-inspired technologies e.g., solar panels that fold like cicada wings, Velcro that behaves like gecko feet, or astronaut under-suits that distribute water like the circulatory system.

Interest: Students might find inspiration in non-space uses of NASA technology such as origami for folding, Ziploc for adhesion, or hydroponics for circulation.

Learning Profile: Drawings, sculptural maquettes, computer-aided designs, or collages could be used to capture student thinking if the virtual space is not conducive to student success.

Lesson Plan 5: Artistic and Technical Expressions of the Brain Challenge

Description

One of the NAE Grand Challenges in the twenty-first century [25] is to reverse-engineer the brain to create computers that can better emulate human thinking. Artists also explore human consciousness through many creative and literal expressions. In this unit, high school engineering students learn about artistic expressions of thinking as they model brain circuitry with increasingly complex circuits and microprocessors. Students create a circuit-integrated art artifact about their own emotional and physical brain systems to demonstrate their own brain's network of inputs and outputs.

Learning Objectives

By the end of this project, students will be able to:

- Evaluate current technological achievements against challenges in artificial intelligence and reverse-engineering the brain. [Note: bioengineering learning objective]
- Respond empathetically to several artistic movements or pieces that illustrate human emotion and cognition and compare with personal feelings about illustrated subjects. [Note: entrepreneurial mindset learning objective]
- Design an art-embedded Arduino circuit to model their own personal thinking with inputs, microprocessor coding logic, and outputs. Embed the circuit in an expressive artistic work that captures their own feelings and processing. [Note: humanities/art learning objective]

Learning Activity and Assessment Options

Cognition Represented in Art and Technology

Students explore various artistic expressions of emotion and cognition in the fine arts or literature and write a response to the works, describing their perceptions of the artists intentions, feeling, and understandings. Consider including the surrealist art movement, feminist or LGBTQ poetry, or dance choreography that represents brain functions, such as love, fear, and addiction.

Next, students next investigate the scientific understanding of the brain and thinking including historical and modern models of artificial intelligence and cognition from simple machine learning to quantum computers. Students also explore the NAE's Grand Challenge, "Reverse Engineering the Brain" to discover the current limits of the engineering enterprise as it relates to the brain. Students create a t-chart to compare artistic and scientific/technical explanations about brain function.

Create an Art-embedded Circuit to Externalize Thinking

To demonstrate their understanding about how the brain works, students will create a piece of art with embedded circuitry that mimics their own brain function. Students reflect on a personal feeling or emotion that they would like to externalize. They analyze their thinking using technological terms including the inputs, outputs, processes (logic), and black-boxes (unknowns) that impact their thinking.

Students construct a microprocessor-controlled circuit to model their brain function. The electrical device should include at least one input (touch, temperature, pressure, light, etc.) and one output (display, lights, sound, movement) coordinated through a coded microprocessor program (e.g., the Arduino or Raspberry Pie). Students will embed the electronic device in a painting, drawing, print, or sculpture that artistically represents their interpretation of their own emotions.

Final products will be assessed for how well the circuitry represents the understanding of the brain, and how well the circuitry's function aligns to and reflects the emotion or feeling expressed in the surrounding artwork. A student self-evaluation could include a reflection contrasting how well the students feel their artistic skills communicated thinking versus how well their programming and circuit skills communicated their thinking.

Differentiated Learning: The students may have a wide variety of social emotional, biology, art history, and computer programming content preparation. This lesson can be adapted to accommodate students as follows:

Readiness: Some students might be starting from a very limited understanding of the brain and the body's central nervous system. Try emphasizing inputs that the brain processes as nervous signals, and then action as an output, differentiating between reflexes and processed thought. More ready students can make a parallel analogy to the complexity of the atom from the Bohr model to electron clouds, to quantum uncertainty.

Interest: Allow students to explore a representation of thinking and emotion that captures their interest. Alternative perspectives might include examples from psychology, mythology, magic and illusion, addiction diagnosis and treatment, mental health and depression, movies and TV, or literature.

Learning Profile: Students should be encouraged to both utilize their strongest learner stance and to investigate learning in alternative stances, as if stepping outside of their own understanding of their brain to investigate their thinking from another angle (a great parallel to understanding our own cognition).

Lesson Plan 6: Make a Bio-inspired Vehicle for a Specific Habitat

Description

Transportation often leans on bio-inspired engineering, such as the kingfisher bird's influence on the bullet train in Fig. 4 or claw-like tires on monster trucks. By investigating how an animal's body structures affect its locomotion and survival, students can discover the secrets to create new innovations for future human vehicles. In this project, high school engineering students will consider the hallmarks of various and bio-inspired locomotion methods in technology. Students will design a biomimicry-inspired vehicle for a specific habitat utilizing structure to function reasoning.

Learning Objectives

By the end of this project, students will be able to:

- Draw analogies between an organism's successfully evolved structure as related to its survival functions (such as locomotion, respiration, friction, insulation, or feeding) and various technologies' structures and functions. [Note: bioengineering learning objective]

- Compare entrepreneurial mindset problem-solving processes (macro, micro, and most valuable design perspectives) to the evolution of biological organisms based on successful adaptation to various natural environments over a long period. [Note: entrepreneurial mindset learning objective]
- Design a bio-inspired vehicle capitalizing on habitat-specific biological survival structures and functions. [Note: humanities/art learning objective]

Learning Activity and Assessment Options

Biomimicry-inspired Vehicle Analysis

Students research at least three locomotion technologies that are inspired by biological forms or organisms. The technologies may be functional or fantastical. One functional technology is shown in Fig. 12, a biomimicry-inspired Antarctic traverse vehicle from the Moon Regan Transantarctic Expedition, taken upon its arrival at the South Pole in 2010. Figure 6, Jansen's *Strandbeest,* is a fantastical but functional biomimicry-inspired locomotion artwork. Students create a table comparing the form and function of the product/technology/art to a related form and function from a real organism. For example, the art vehicle *Strandbeest*'s numerous joints create smooth movement across hard surfaces just as the human foot contains multiple joints which allow for smooth movement and continuous friction on the ground. This table will serve as research and justification in their vehicle design and should be assessed formatively for alignment between structure and function.

Biomimicry-inspired Vehicle Design

Students select a habitat and a native organism. Students study the organism's locomotion and infer the unique characteristics of its structure that allow it to move. Students document these unique traits and identify the scientific or mathematic properties that govern the motion such as friction, air resistance, drag, repetitive motion, circular motion, or pendulum-like motion on a poster or a digital slide.

Next, students invent a novel locomotive device to mimic the motion of the organism in its environment. On a labeled diagram of the device, students label the elements of the design that are inspired by the organism's biology. Students iterate their ideas after a formative assessment critique.

Finally, students build a physical model of one part of the vehicle that demonstrates the biomimicry in their design as a proof of concept which is tested in a proxy habitat. The entire vehicle need not be constructed. Local or recycled materials should be used, if possible. The final proof of concept artifact, labeled diagram, original biological inspiration, and comparison to native forms of transportation should be documented and shared. The design

Fig. 12 Antarctic traverse vehicle from the Moon Regan transantarctic expedition. *Image credit* Katey Shirey]

and proof-of-concept will be summatively assessed for structure to function alignment and biomimicry incorporation.

Differentiated Learning: To ensure opportunities for success for all students, this project can be adjusted as follows:

Readiness: Use inspiration cards to present acceptable ecosystems and organisms that a student may choose from, if needed. Confining the options to a particular ecosystem such as “freshwater estuary” or even a particular place, such as “high elevation Gold Butte deserts around Mesquite, Nevada” might help students find and move forward with an idea more quickly.

Interest: Encourage students to explore their own interests by thinking about a place that they care about, are curious about, or plan to go to one day. To find student interest in transportation vehicles, invite them to think about how humans traverse land, sea, and sky in various climates and throughout history.

Learning Profile: Students may research and design in multiple modalities including fictional stories and encyclopedic texts; film and photographs or podcasts and interviews. Try using visual brainstorming, vision boards, storyboards, and acting out their designs in addition to written descriptions and diagrams.

6 Discussion

As stated in the introduction, traditional engineering education can be narrow in scope, focusing on the engineering discipline alone. We hope that this chapter and its examples will provide motivation for educators to integrated bioengineering and bio-inspired STEAM instruction to grow high school and college engineering students' entrepreneurial mindsets. However, we know that institutional change is difficult. This discussion is aimed at helping advocates make a case for trying integrated STEAM and bioengineering learning experiences for EM in existing engineering programs.

While the implementer may be excited for change, often, surrounding educational systems are inert and hard to reform. The first step in making a case for curriculum reform requires empathy and understanding of those who resist the change. In other words, understanding "who" the stakeholders are in your context and "why" they may have resistance to the reform. In this case, stakeholders include teachers and faculty, students, administration, industry, and society. Each of these stakeholder groups has a diverse set of motivations and perspectives to consider when making academic change happen.

Kantar [50] notes ten reasons why people resist change: loss of control, excess uncertainty, surprise, everything seems different, loss of face, concerns regarding competence, more work, ripple effect, past resentments, and sometimes the threat they are anticipating is real. As you consider curriculum change, consider each stakeholder's needs, motivations, and hesitations. It is advisable to remember that while "student success" may be the common goal for all stakeholders, it may look different from person to person. Determine what objectives, assessments, indicators, and evidence would support stakeholder's goals in order to find ways to overcome opposition to change. Perhaps they have hesitations towards interdisciplinary instruction in general, to humanitarian concerns (helping others) as related to engineering, to the use of arts in engineering, or to emphasizing the entrepreneurial mindset.

The second step in making a case for reform is to focus on the many benefits of the reform, how the reform will overcome any perceived barriers, and how the reform can be both easy and useful. For high school teachers and university-level educators alike, benefits may include increased student interest and retention in engineering, more diverse classes, and more unique opportunities to bring personal interests into the engineering classroom. Students at any level may benefit from interdisciplinary thinking, increasing their capacity for transferring knowledge and forming more expert-like understanding of the content [14].

In the next sub-section, we focus on making arguments to university faculty, specifically. Although there is a culture of "academic freedom in teaching" within the U.S. higher education system, which implies faculty are free to teach the course in the manner they see fit, there are various realities as well such as needed to perform well on teacher evaluations, recruit funding and research opportunities, and grow collegial networks.

6.1 Making Your Case to Higher Education Faculty

For faculty, implementing new curriculum reform has the potential to improve teacher evaluations, increase funding prospects, expand research coverage, and grow networking opportunities.

Teacher evaluations can improve because as students start to see greater value within the learning experience, they may also start to have increased motivation to learn and acquire better appreciation for the course and teaching and learning approaches. According to Ambrose and colleagues [51], motivation to learn is driven by three key factors: seeing value, self-efficacy, and a supportive environment. Integrating the entrepreneurial mindset into human-focused STEM innovation problems may allow student participants to see the value and real-world practical purpose. As a result, students may become more engaged in the classroom, which could be positively reflected through teacher evaluations.

Research coverage can expand given the interdisciplinary nature of this educational curriculum reform. Networking opportunities between academic areas, research centers, government agencies, and companies will grow in part due to the increased funding prospects and research coverage, in part due to the potential to involve multiple disciplines, and in part due to the entrepreneurial mindset aspect of the curriculum. Funding and research success is increased through collaborations, which will naturally require connecting and networking with others to establish a team.

Funding prospects may increase because faculty may consider submitting innovative and transformative educational research proposals to funding organizations, including foundations and government agencies, alike. Potential funders investing in entrepreneurial mindset education in the US include private foundations such as VentureWell, KEEN, Lemelson Foundation, and Kauffman Foundation. With respect to government agencies, the NSF has many STEM education-focused funding prospects; the most common prospects are within the directorate of Education and Human Resources and include the following focus areas: Graduate Education, Research on Learning in Formal and Informal Settings, Undergraduate Education, and Human Resource Development. In addition, the NSF has many innovation and commercialization-focused funding opportunities which include the following: NSF I-Corps, NSF Partnerships for Innovation, NSF Small Business Technology Transfer, and NSF Small Business Innovation Research.

Presenting at conferences allows the opportunity to network with like-minded individuals. The interdisciplinary character of the curriculum permits faculty to reach outside their current content knowledge and partner with other faculty from across disciplines to include participation within science, engineering, and art. New curriculum changes can be disseminated through conferences and journals with more society divisions and journals becoming potential publication or collaboration spaces as there are more disciplines tethered to this work. Example STEM education-related conferences include: the National Science Teachers Association (NSTA) conference for K-12 educators, Professional and Organizational Development (POD) Network in Higher Education, Frontiers in Education, EduCon, VentureWell Conference, and the IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE). Peer-reviewed journals focused on the scholarship of teaching and learning, include the following: College Teaching, Journal for STEM Education Research, IEEE Transactions on Education, Active Learning in Higher Education, Educational Review, Higher Education, Open Education Studies, and Education Sciences.

Finally, the entrepreneurial aspect of the curriculum invites connections with other entrepreneurs including your local start-up community including collaborating with organizations that offer co-working spaces, accelerator startup programs, pitch events, entrepreneurship week workshops, and business model competitions.

7 Conclusion

Growing the entrepreneurial mindset in high school and undergraduate engineering students may provide training to identify and solve the biggest problems faced by our society. However, we also need diverse engineers, so our curriculum needs to welcome and value student-engineers' interests and assets. If diverse young engineers are more drawn to humanitarian causes, or feel a connection to creative arts integration, then our engineering instruction should welcome and reflect those capacities, helping students to realize the important place for their diverse talents in engineering. This chapter has described the value of bioengineering including biomimicry-inspired design to solve engineering problems and to draw in engineers' humanitarian interests. Additionally, we've made a case for integrating the STEAM subjects to draw out students' knowledge transfer of science, technology, engineering, math, and arts knowledge while solving problems. Our six lesson plan proposals provide ideas for integrating bioengineering, STEAM, and entrepreneurial mindset objectives into high school or undergraduate engineering courses. Reforming high school and undergrad engineering curriculum to normalize STEAM and bioengineering in the service of developing the entrepreneurial mindset may invite and retain more engineering students with creative problem-solving skills to grow into the engineers of the future.

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Theatre-Based Creativity Activities for the Development of Entrepreneurial Mindsets in Engineering

16

Joshua Saboorizadeh, Hao He, Suzanne Burgoyne, Ferris Pfeiffer, Heather Hunt, and Johannes Strobel

In higher education, and even in the liberal arts context, we allow students to silo. They pick a major and a minor and focus on those areas; if they go on to graduate school they focus further on one small area. There's nothing wrong with that, but in a world where there are ambiguous uncertain challenges and problems - and boy, are there ever a lot of those - people need tools to practice empathy and see things across different perspectives…creativity skills training is necessary.

Fred Leichter, Director, the Rick and Susan Sontag Center for Collaborative Creativity

Abstract

Previous research papers have shown how creativity can flourish in learning environments where students are not admonished for taking risks or facing failure. Unfortunately, these types of learning environments/creativity practices are not interwoven methodologically into most STEM curricula; indeed, studies demonstrate that engineering students' levels of creativity decrease over the course of their training. Recent studies have revealed that when creativity is

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methodologically incorporated into curricula, students are able to apply it immediately and in the long-term. The Creativity Academy, funded by the National Science Foundation, is a program designed to teach and support engineering faculty in higher education with the integration and implementation of evidence-based creativity training into their classrooms. The long-term goal is to prepare an innovative engineering workforce by creating, implementing, and testing a new educational framework that incorporates creativity training throughout the engineering curriculum at the University of Missouri. Our research operates from the twenty-first-century skill requirement that educators must train students not only to understand and apply engineering practices, but also to innovate upon them. This chapter will explain three facets of the Creativity Academy: (1) the academy design and module learning objectives, (2) a description of the journal reflection assignment that participants completed during the Creativity Academy, and (3) an outline of one theatre-based creativity exercise. These three sections identify key methods for integrating creativity training into curricula: designing learning objectives, reflection through writing, and an embodied theatre exercise that allows students to confront rarely challenged habits.

Graphical Abstract

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Active learning · Curriculum design · Assessment · Interdisciplinary · Innovation

1 Introduction

A group of five engineering professors, one theatre professor, and one theatre graduate student stand in a circle. An engineer raises her hands above her head and exclaims, "I failed!" followed by uproarious applause and support from the rest of the group. Phrases can be heard: "give it another try!", "great!", "we're here to support you!", and "yeah you did!" The classroom fills with an energy that can only be matched at the university's football games. This process continues until all in the circle have had the opportunity to shamelessly claim their failure. Afterwards, participants reflect on how strange this exercise makes them feel, because most have been taught to associate failure with fear and shame, not celebration (Fig. 1).

The scenario described above is from one of the first sessions of the Creativity Academy, funded by a grant from the National Science Foundation. The academy is designed to teach and support engineering educators in higher education with the integration and implementation of evidence-based creativity training into their classrooms. This chapter defines creativity as "the interaction among *aptitude, process and environment* by which an individual or group produces a *perceptible product* that is both *novel and useful* as defined within a *social context*" [2, p. 90, emphasis in original]. The main pedagogical approach used in the Academy is active learning, "anything that involves students in doing things and thinking about the things they are doing" [3, p. 2]. What makes this project additionally innovative is that the design, approach, and activities are rooted in theatre-based methods (and theatre is an active-learning pedagogy) [4]. The long-term goal is to prepare an innovative engineering workforce by creating, implementing, and testing a new educational framework that incorporates creativity training throughout the engineering curriculum at the University of Missouri (MU). Our research operates from the twenty-first-century skill requirement that we must train students not only to understand and apply engineering practices, but also to innovate upon them [5]. The students, teachers, and classrooms we refer to in this chapter are in relation to the university environment.

In an article from the Journal of Experiential Education, Sophia Rodriguez and Hannah Lieber define the entrepreneurial mindset as "a constellation of noncognitive skills that empower students to recognize opportunities, overcome and learn from setbacks, and apply these skills to future careers, which may include starting one's own business" [6, p. 278]. If we want our students (or our employees, teams, and leadership) to develop an entrepreneurial mindset, they must first be willing to

Fig. 1 Associate Professor Heather K. Hunt, center, and Curators' Distinguished Teaching Professor Emerita Suzanne Burgoyne from MU's theatre department, lead an activity at the Creativity Academy [1]

act on an "opportunity where others see chaos, contradiction, and confusion," even if that action is inherently risky or could lead to failure [7, p. 3]. If we want our students to bravely approach—and be willing to take—risks, even knowing that they might fail, instructors must co-create a learning environment where students are motivated to try something new and make mistakes. An environment where students are not made to feel shame or expect punishment for failure, but instead, are invited to celebrate their failures, learn from their mistakes, and try again. Environment remains a key component in the cultivation of creative practice, as well as conceptually defining the parameters of creativity [8, 9]. In addition, the future of engineering demands an interdisciplinary workforce whose academic training extends to broader understandings of increasingly complex systems and processes, as well the ability to design, test, and manufacture meaningful solutions to urgent problems with efficiency and efficacy [10]. Therefore, we must bear the responsibility to train our students (or our employees, teams, and leadership) not only to understand current practices in these respective fields, but also to innovate upon them. Our team believes innovation is a key component of entrepreneurship [11] and also that creativity is a foundation of the entrepreneurial mindset [12].

This chapter argues that if educators and leaders want to cultivate entrepreneurial mindsets within their students or employees, they must provide experiences for the learners that intentionally focus on the process of strengthening creative muscles. Additionally, the purpose of this chapter is to provide tools for educators to place into their existing curriculum, which include: a list of learning objectives, a journal reflection assignment, and two theatre-based activities that allow learners (and educators) to practice using their creative muscles. After elaborating on the role of creativity in the university STEM classroom and job preparation, this chapter will explain three facets of the Creativity Academy: (1) the creativity curricular design and module learning objectives, (2) a description of the journal reflection assignment and its purpose in the academy, and (3) a brief outline of one exercise taught in the academy. These three sections are intended to explicitly provide readers with a deeper understanding of how we integrated creativity training into the Creativity Academy curricula and implicitly how this work contributes to the development of an entrepreneurial mindset.

2 The Scope of Creativity and Its Role in the Engineering Curriculum

Previously published research has described the successful transformation of environments when failure is embraced and reframed as a necessary and inevitable step in the learning process [13, 14]. If it is obvious that failure is an unavoidable stage in the learning process, and indeed, central to the learning process in any classroom environment, it is startling to consider how commonly failure is admonished, particularly in highly technical environments, like Science, Technology, Engineering, and Mathematics (STEM) university-level courses [15–19]. These courses have, intentionally or unintentionally, become defined by narrow and confined views of how things must be done to ensure academic rigor. It is important to acknowledge the rigor necessary for human/environmental health and safety within STEM fields, and that finding the “best” solution, however “best” is defined, involves a deep and accurate understanding of the underlying mathematics and science principles. For example, it is inexcusable for an engineer to fail with a multi-million dollar bridge project or for a heart surgeon to fail during an operation. But in the classroom where the entrepreneurial mindset is being cultivated, failure must be celebrated during the learning process.

Students that have been taught to fear failure early in their academic careers are often ill-prepared to take risks at the end of their academic careers therefore ill-prepared for the workforce. During research laboratories or design classes, which typically occur at the end of the curriculum, students are suddenly faced with problems that do not have one “right” answer. It is at this late point in an undergraduate student’s STEM preparation where coursework embraces failure and risk-taking. In waiting until the end of the students’ academic preparation, STEM educators have spent years inculcating the expectation that risks should be avoided. As creativity expert, Sir Ken Robinson, points out in his TEDtalk “Do schools kill creativity?”, this seemingly insurmountable dichotomy is confusing to students, and prevents them from developing the knowledge, skills, and attitudes that can allow them to tackle increasingly complex problems in new and innovative ways [20]. If students are not given the opportunity to routinely practice taking risks during their academic careers, they will not take risks in the workforce. Students are ill-prepared for the workforce if they fear failure [21–23]. When employers were asked about the level of preparedness for innovative thinking in recent hires, 25% of employers believed students lacked preparation in creativity and innovation [24, p. 5]. Employers do not see developed creative capabilities in recent graduates and continue to demand more creative thinking [21–23].

The problem that students are ill-prepared for laboratory work, design classes, and the workforce arises partly because creativity is not interwoven methodically into most STEM curricula [15–17, 22, 25–29]. Another reason may be that STEM educators, who are the primary implementers of the STEM curricula, often lack the knowledge and training required to teach creative expression, leaving creative thinking and expression largely absent or unsupported in the classroom. Even when STEM educators intend to include creativity in their curriculum and pedagogy [18, 30], studies demonstrate that engineering students' levels of creativity decrease over the course of their training [16, 19, 31]. It is paradoxical, then, that STEM educators are tasked with nurturing creativity, promoting innovation, and cultivating the beginnings of an entrepreneurial mindset without having acquired the appropriate tools to do so [15, 25, 26].

To address this polarity, many universities have enthusiastically adopted curricular improvements, centers, and programs focused on educating university students and faculty about entrepreneurship and innovation, largely by adding stand-alone classes to the curriculum that walk participants through valuable exercises to show them how to start a new company or how to identify needs [32–36]. Yet, in educating students and faculty members on how to start a new company or how to identify needs, programs have typically overlooked the most fundamental elements of entrepreneurship and innovation; creative thinking and creative expression, or the generation of ideas, is crucial for entrepreneurship as it starts with ideas, and ideas themselves come from somewhere [36, 37].

Creativity may be defined by the results of the creative activity itself; that is, creativity results in the production of something that is (1) original and (2) recognized as useful [38, p. 19]. However, researchers often view creativity in terms of the "four P framework": Product, Person, Process, and Press (environment) [ibid, p. 21]. Psychologist and creativity scholar, Mihaly Csikszentmihalyi, divided creativity into 'Big C' and 'little c' regimes, where "Big C" creators produce major ideas that change their discipline, while "little c" creators come up with ideas that improve everyday life [39]. Finding the 2-C model too limited, Beghetto and Kaufman added two additional c's: (1) pro-c level creativity, demonstrated by professionals who haven't reached Big-C eminence yet and (2) mini-c creativity, which focuses on personally meaningful discoveries that may occur while a student is learning [40]. All of these definitions reflect the idea that creativity is multifaceted and can be analyzed within different frameworks. Our research team's approach to creativity training as well as the focus of this chapter centers on a process involving creative work or creative thought. This study operates from the ideas that creativity is the foundation of innovation and that creativity generates spaces where meaningful ideas impact society [41].

One prevailing assumption our research team has encountered is the belief that creativity is something one has or does not have. Sir Ken Robinson points out that many people believe creativity is an inborn talent—those folks have been conditioned by parents, society or the school system to think you're either creative or you're not [42]. Keith Sawyer identifies a dozen Western cultural "myths" about creativity, including the idea that "creativity is a general personality trait, like IQ," or a mystical "gift of the gods" that can therefore not be learned or taught [43, p. 12]. Australian engineering professors, Arthur and David Cropley, draw attention to the benefits of creativity in education, observing that "modern research has demonstrated that although students with high IQs usually obtain good grades both at school and university, they are consistently outstripped by those with not only a high IQ but also high creativity" [44, p. 207]. Arthur Cropley and Klaus Urban also pinpoint specific creative abilities that must be taught and assessed [45]. Engineering Professor, Joseph Berk, argues that we are "conditioned" into believing we lack creativity: "in short, our education system and our social environment do a pretty good job of beating the creativity out of us" [46, p. 6]. Berk's research supports the assumption that "creativity is at its peak when we are about 5 years old" but that "we lose as much as 98% of our creativity by the time we finish high school" [ibid, p. 5]. While the conditioning of students to believe they lack creativity is heavily present in the preceding references, there is also evidence that demonstrates the opposite and provides evidence on: how to strengthen creativity.

David H. Cropley, an engineering scholar with expertise in creativity and innovation, states, "it seems axiomatic... that teaching engineers (and other STEM disciplines) to think creatively is absolutely essential to a society's ability to generate wealth, and as a result provide a stable, safe, healthy, and productive environment for its citizens" [15, p. 405]. Given that the creative process is critical for an innovative workforce, it is important to consider how creativity is nurtured and promoted throughout our curriculum in order to build and promote an entrepreneurial mindset that actually leads to real innovation. Recent studies have demonstrated that when creativity is methodically inserted into the engineering curriculum, students are able to apply it immediately and in the long-term [47]. For instance, in our work, we have found that senior engineering students' self-efficacy in engineering design substantially increased after theatre-based creativity training was incorporated into the senior design capstone course [48]. Results from teaching creativity in the engineering curriculum display overall increases in student performance [49, 50]. Therefore, MU has created a new paradigm of engineering education that not only teaches the foundations of science, engineering, problem-solving, and critical thinking, but also the foundations of innovation: creativity throughout the curriculum. Although the MU College of Engineering has not adopted the Creativity Academy's activities in *all* the degree programs, many of the activities have been integrated into the Bioengineering degree programs following the Creativity Academy. Participants have expressed their interest in advocating for curricular revisions, throughout all Engineering degree programs at MU, that include elements from the Creativity Academy.

If creativity is a skill that can diminish over time, it must also be a skill that can be strengthened. Famous American psychologist and creativity expert E. Paul Torrance argues, "I know it is possible to teach children to think creatively… I have done it. I have seen my wife do it; I have seen other excellent teachers do it. I have seen children who had seemed previously to be 'non-thinkers' learn to think creatively, and I have seen them continuing for years to think creatively... I also know that these things would not have happened by chance because I have seen them 'not happening' to multitudes of their peers" [51, p. 269]. In support of Torrance's idea, we have designed the Creativity Academy around providing participants opportunities to practice their creativity every time we meet. During the Creativity Academy, we frequently communicate with students through the metaphor that creativity is a muscle—your creativity is only as strong as how often you exercise and use those muscles. Figure 2 shows a sample activity demonstrating creativity as muscle.

The activity described at the introduction of this chapter, which is central to interweaving creativity into the classroom, provides students (and instructors) the experience to stretch their creative muscles by claiming and celebrating failure in the classroom. Although our team primarily positions our research solely within the realms of creativity, there is meaningful overlap between entrepreneurial mindsets and creative competencies. To better understand how the Creativity Academy incorporates entrepreneurial mindsets and creativity activities into the classroom, it is helpful to understand the structure of the academy and its objectives.

Fig. 2 Assistant Teaching Professor Scott Christensen, second from left, participates in a team activity during the Creativity Academy [1]

3 Academy Design and Learning Objectives

In 2020, the Creativity Academy content was designed for in-person practice over a three-week period, Monday through Friday. The COVID-19 pandemic required our team to shift to a virtual workspace. The theatre practitioners, who had previously only facilitated the creative exercises in-person, were required to adapt the exercises for virtual participation.

In the Creative Academy, each class was called a "module," and modules moved in a numerical and sequential fashion; for example, we began with Module #1 on day 1 and ended with Module #15 on day 15. There were 5 modules a week, beginning on Monday and ending on Friday. Each module was compartmentalized into three sections: theatre facilitators leading participants in theatre-based creative exercises, participants applying what they are learning to develop a solution to a group-selected problem, and each participant redesigning appropriate creativity exercises for integration into one of their classes. Each section was approximately one-hour in length. This chapter will only focus on the first section of class design led by the theatre practitioners, which will be referred to as the "creative practice segment".

Each creative practice segment had a title based on the topic considered, and one to four relevant learning objectives of the topic were practiced during the lesson. Table 1 presents the titles of each segment and a brief summary of each segment's learning objectives. Although the Creativity Academy does not explicitly connect creativity training to developing an entrepreneurial mindset, our team believes the creativity activities help develop skills associated with an entrepreneurial mindset.

There are a few modules that intentionally repeat content, for example the "Creative Process" (Modules # 7 and #15) and "Metaphors & Analogies" (Modules #8 and #9). During the "Creative Process" (Module #7), participants drew their own creative process in visual form and interpreted their peers' drawings. This activity was repeated during the "Creative Process" (Module #15) so that participants could reflect on how their creative processes may have changed or how they individually achieved new insight based on content learned during the Creativity Academy, as listed in the learning objectives. The content of the Metaphors & Analogies module was not repeated but it was spread between two lessons due to requiring more time to discuss.

4 Exercise—"Renaming Objects"

The purpose of this section is to define the typical structure of most creativity exercises from the facilitator's perspective and to briefly describe one exercise. Our hope is that this explanation sparks intrigue within the reader to learn more about our academy as well as other exercises we do with participants.

Table 1 Every creative practice segment, listed as "module" in this image, had a topic and learning objectives (LO). This image displays each module title and the LOs for that session [52]

Creativity practice segment				
Module 1	Enabling Creativity			
	LO1: List assumptions about creativity and assess the truth of each assumption	LO2: Explain why it is valuable for engineers to develop their creativity	LO3: Compare the value of extrinsic and intrinsic motivation when practicing creativity	LO4: Demonstrate some methods of overcoming fear of taking risks as an obstacle to creativity
Module 2	*Convergent and Divergent Thinking*			
	LO1: Apply metacognitive skills to distinguish between convergent and divergent thinking	LO2: Design an exercise which will help your students to practice convergent/divergent thinking		LO3: Design an activity which will allow your students to practice the four creative abilities: fluency, flexibility, originality, and elaboration
Module 3	*Assumptions and Design Fixation*			
	LO1: Explain why closed-mindedness is an obstacle and open-mindedness is an advantage for creative thinking	LO2: List assumptions and habits that may close your mind (or your students' minds) to new ideas		LO3: Demonstrate techniques that may be used to confront students with their own closed-mindedness
Module 4	*Unlearning and Transformation*			
	LO1: Demonstration activities that can be used to help students challenge their assumptions and change habits	LO2: Demonstrate activities that help students practice using their imaginations to transform one thing into something else		
Module 5	*Collective and Collaborative Creativity*			
	LO1: Explain the value of active listening in building a creative problem-solving team	LO2: Demonstrate a method that helps students to learn and practice how to listen actively		LO3: Explain the essential principle of improvisation ("yes… and") and why it's valuable for everyone on a creative problem-solving team to contribute and build off one another's ideas

(continued)

Table 1 (continued)

Creativity practice segment			
Module 6	*Framing and Reframing the Question*		
	LO1: Explain how the "checklist of good questions" method allows you to interpret the problem/question from a different perspective and revise the problem/question		LO2: Evaluate your group problem statements and explain which one you think is most valuable and why
Module 7	*Creative Processes*		
	LO1: Draw a visual representation (diagram, map, symbolic picture) of your personal creative process	LO2: Interpret other peoples' drawings to describe their creative processes	LO3: Compare other peoples' processes with your own, assessing whether aspects of someone else's processes might add value to your own process
Module 8	*Confronting the Inner Critic; Metaphors and Analogies*		
	LO1: Explain the terms "inner critic" and "inner cheerleader" as well as what roles each plays in creativity	LO2: Demonstrate methods you (and your students) can use to balance the input of "the critic" with that of "the cheerleader" so you don't have to censor your own ideas when brainstorming	LO3: Explain how metaphoric/analogic thinking can work to "make the strange familiar" and "make the familiar strange."
Module 9	*Metaphors and Analogies*		
	LO1: Demonstrate techniques you (and your students) can use to practice metaphoric/analogical thinking as a creative problem-solving method		LO2: Demonstrate a technique you can use to explore metaphoric/analogical thinking as a creative problem-solving method for your group problem
Module 10	*Generating Solutions*		
	LO1: Explain the value of brainstorming and other idea-generating group methods for creative problem-solving	LO2: Describe habits students should develop to improve their brainstorming skills	LO3: Design a session of your own class in which you would implement at least one brainstorming method and explain the value of the activity for that class
Module 11	*Evaluating Solutions*		
	LO1: Design a process whereby students review and possibly reframe criteria for solutions to a particular problem statement		

(continued)

Table 1 (continued)

Creativity practice segment			
Module 12	Prototyping		
	LO1: Finalize a solution for your group problem		
Module 13	Problem finding		
	LO1: Explain the value of problem-finding in the creative process	LO2: Describe methods of problem finding	LO3: Make a list of potential problems you might encounter with integrating creativity into your engineering class next year
Module 14	*Group Work Using CATME*		
	LO1: Describe insights you gained by asking questions and practicing exercises you weren't sure about, including an exercise you want to use in your class		
Module 15	*Creative Process*		
	LO1: After drawing a visual representation of your current conceptions of your creative process, compare and contrast the current one with the one you created in module 7		LO2: Analyze how your creative process may have changed as a result of participating in the academy

During "Unlearning and Transformation" (Module #4), participants are asked to come to our session with an interesting object that holds personal value but is not fragile or very expensive. The facilitator is encouraged to bring in an object and play as well. These objects are used for an exercise called "Renaming Objects". During the exercise, facilitators ask participants to place their objects in the center of the room, which can be on the floor or on a table, leaving enough space for everyone in the room to walk in a circle around all the objects. The instructions for the exercise are simple: continuously walk in a circle, point to an object, and call it anything other than what it is. For example, a deck of cards could be called a wallet, fishing pole, or anything else you can think of. Participants continue to walk in the circle and rename objects for three or four minutes. After participants have spent some time renaming, facilitators conclude the exercise by having participants give each other a round of applause.

The facilitator, then, allocates another five or so minutes to debrief with participants. The facilitator asks questions to the students that require elaboration based on participation in the activity and encourages them to share more than the outcome of what they did but also their experience. A couple of questions our facilitator team tends to ask at the start of debrief sessions are:

7. Was this exercise easy or difficult? Why?
8. How might this exercise relate to creativity/problem-solving/innovation?

Generally, participants describe how surprisingly difficult this exercise is for them to do because they give a different name to an object they know well. The habit to call the object how it is commonly known is so deeply engrained that when given the opportunity to name an object anything other than what it is, students' cognition and even physical bodies freeze. We have heard participants say things like, "I can call these keys literally anything, but for some reason it still takes me a few seconds to come up with something". Participants have reflected after the exercise with ways that made this activity easier for them to do. For example, some have said it was too difficult to think of something unrelated, so they categorized the object and came up with new names based on other items in the same category; for example, car keys could be categorized as anything car or transportation related.

What might practicing this skill teach our participants? By disrupting rarely challenged habits, this exercise allows participants to confront how they have been conditioned to see things. Seeing objects in a new way opens our minds to use objects differently, which contributes to building a future rooted in innovation. The Renaming Objects activity liberates participants from how they were taught to define what they see, or in other words, liberates them from the *right* way of seeing. Seeing objects in new ways and challenging societal conditioning is a skill that can be practiced through this exercise. Developing this skill can prepare participants when they are faced with problems beyond the classroom, which, in turn, helps develop an entrepreneurial mindset. To provide context to the importance of seeing objects for what they are not, we typically share an example from NASA's Apollo 13 Mission. Once the astronauts moved to the lunar module for their return to Earth, there was a critical issue of removing carbon dioxide from the module because of damage to the module during liftoff. NASA engineers repurposed existing materials onboard to construct a new device that would keep the astronauts from dying on their trip back to Earth. In this example, seeing objects in a different way kept people alive.

5 Assessment Through Reflective Journals

One question we repeatedly hear educators ask us is, "but how do you assess creativity?" which we believe is a rigorous question that may not have one right answer. Many of the learning objectives are successfully completed once a student participates in the creativity exercises. Alongside assessment, one method used to measure how participants are learning the material is a reflective journal assignment. The reflective journal allows participants to reflect on their experience and consider new ideas through writing. Each participant in the Creativity Academy is required to submit one journal per day. Participants are asked to reflect on what they learned and elaborate exactly how they learned it. See a prompt for the journal assignment in Fig. 3.

The theatre practitioners and one engineering research member assessed each journal assignment following the completion. An additional component to the assessment was for the theatre practitioners and engineering research members to

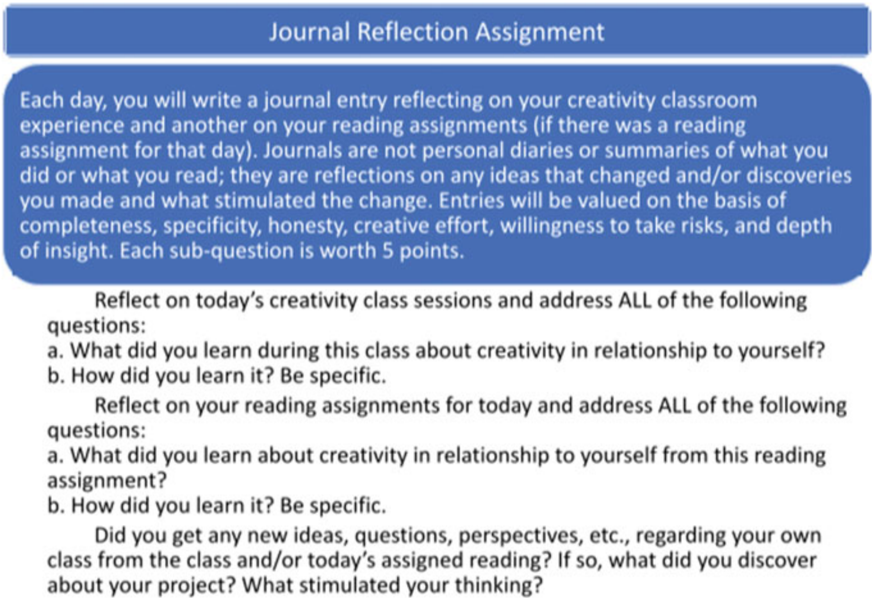

Fig. 3 The journal reflection assignment given to participants during the Creativity Academy

type a response to each journal entry, with the intention to initiate further dialogue as well as build deeper relationships with the participants. With five participants, this totals to 75 journal entries over the span of three weeks. These journals are a data source that can be qualitatively analyzed through methods like thematic analysis or grounded theory, allowing our team to make evidence-based claims about research questions related to how the Creativity Academy had impact on the participants. The research team has already published an article, "Investigating How Early-Career Engineering Faculty Perceive the Role Creativity Should Play in Engineering Education" which analyzes interview transcriptions with thematic analysis [52]. It is the research team's hope to understand more deeply how the Creativity Academy supports faculty and their efforts to prepare students as innovative problem solvers. Doing so could help students leave the engineering program at MU with the confidence to actively build the future of their field, and not just passively accept current assumptions about how the future should or might be.

6 Conclusion

Developing an entrepreneurial mindset requires creative thinking. Cultivating creative thinking requires faculty of all programs to provide systematic opportunities for all students to practice their creative thinking throughout entire curricular programs. The long-term goal of this research project is to prepare an innovative engineering workforce by creating, implementing, and testing a new educational framework that incorporates creativity training throughout the engineering curriculum at MU. Given that the creative process is critical for an innovative workforce, it is important to consider how creativity is nurtured and promoted throughout our curriculum in order to build and promote an entrepreneurial mindset that actually leads to real innovation. To address these needs, the Creativity Academy has embodied a new paradigm of engineering education that not only teaches the foundations of science, engineering, problem-solving, and critical thinking, but also the foundations of innovation: creativity throughout the curriculum. This paradigm operates from the twenty-first-century skill requirement that we must train students not only to understand and apply engineering practices, but also to innovate upon them. If we want our students (or our employees, teams, and leadership) to develop an entrepreneurial mindset, they must be willing to act on opportunities that may seem risky or could lead to failure. Creative thinking and creative expression remain crucial for entrepreneurship.

If educators and leaders want to cultivate entrepreneurial mindsets within their students or employees, they must provide frameworks and experiences for the learners that intentionally focus on the process of developing creativity. Given that the creative process is critical for an innovative workforce, it is important to consider how creativity is nurtured and promoted throughout our curriculum. Environment remains a key component in the cultivation of creative practice as well as conceptually defining the parameters of creativity. These environments range from macro-levels like curriculum design down to micro-levels like the classroom.

The future of engineering demands an interdisciplinary workforce whose academic training extends to broader understandings of increasingly complex systems and processes, as well as being able to design, test, and manufacture meaningful solutions to urgent problems with efficiency and efficacy. Therefore, we must bear the responsibility to train students (or employees, teams, and leadership) not only to understand current practices in these respective fields, but to also innovate upon them. Our team believes innovation is a key component of entrepreneurship and that creativity is a foundation of the entrepreneurial mindset.

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Ferris Pfeiffer sets ideas in motion. As a Ph.D. student at the University of Missouri, Pfeiffer developed a way to convert medical scans into three-dimensional computer models and transport them into a program that mimics body weight and movements. His techniques have been used by doctors to evaluate spinal surgery options. He founded his own company offering engineering design, testing and analysis for orthopaedic purposes. In 2010, Pfeiffer returned to the university as head of Biomechanics and Bioengineering at MU's Comparative Orthopaedic Laboratory. Not long after, he partnered with colleague Dr. Matthew Smith to perfect a minimally invasive surgery for rotator cuff injuries. Now Pfeiffer is collaborating with another colleague, Dr. James Stannard, on a new treatment for a painful joint condition called Osteochondritis dissecans (OCD). The new treatment could repair defects with a single graft of cartilage. Dr. Ferris is an assistant professor with shared appointments in the School of Medicine's orthopaedic surgery department, the College of Engineering's bioengineering department and the College of Veterinary Medicine. He holds five patents.

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Johannes Strobel directs SRI's STEM & CS Education program, in which he engages in design, entrepreneurship, research and evaluation in STEM (science, technology, engineering, mathematics) & CS (computer science) education. With a background in philosophy, religious studies, information science and learning technologies, he engages in "Humanistic STEM Education," a STEM education approach focused on the holistic development of human beings and their communities. As a "learning engineer," Strobel works to address questions of equity, diversity, and inclusion, making STEM education accessible and closing the opportunities gap. Before joining SRI in 2021, Strobel was full professor of information science & learning technologies, leading a maker space initiative. Strobel is founding editor of the *Journal of Pre-College Engineering Education Research* (J-PEER) and has served on several boards of engineering education, learning sciences, and educational technology journals in the United States and internationally.

17 The Use of Digital Formative Assessment for Integrated Entrepreneurial STEM Education

Sila Kaya-Capocci and Erin Peters-Burton

It would be possible to describe everything scientifically, but it would make no sense; It would be without meaning, as if you described a Beethoven symphony as a variation of wave pressure.

Albert Einstein

Abstract

STEM Education provides possibilities for students beyond the siloed science, technology, engineering, and mathematics subject matter. Integrating the STEM subjects helps students build skills and habits of mind across the disciplines, and offers instances for authentic, realistic problem solving. However, incorporating an entrepreneurial mindset into integrated STEM settings increases learning opportunities for financial, social, and innovative entrepreneurship, which can establish even more authentic contexts for students. Because these learning opportunities can be divergent, instructors will need mechanisms to monitor student learning so that they reach their objectives. Instructors will need approaches to gather

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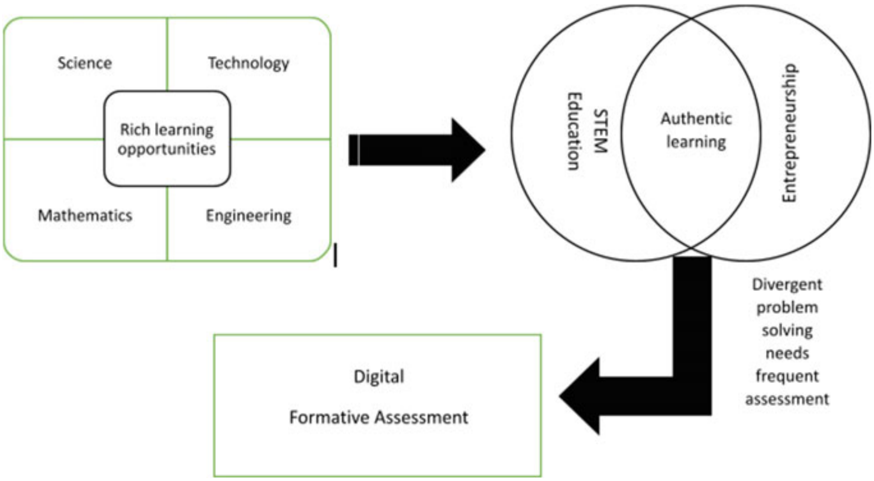
information on student learning, provide guidance to students to further their learning, and when necessary, adapt their instruction to meet student needs. Digital formative assessment is an approach that instructors can use to monitor the complex learning of integrated Entrepreneurial STEM knowledge and skills due to the ability to offer an interactive environment for communication and analysis of learning. In addition to a discussion of entrepreneurial STEM education and a framework for digital formative assessment, this chapter explains an example of a STEM lesson, integration of entrepreneurship, and ideas for digital formative assessment.

Graphical Abstract



Keywords

Digital formative assessment · Entrepreneurial STEM · Entrepreneurship · STEM education

1 Introduction

STEM education, its importance, and benefits have been discussed for many years. Some have viewed it as an interdisciplinary approach, some multidisciplinary, some transdisciplinary; some focused on developing twenty-first century skills, while some focused on producing products when it comes to STEM. This integration of multiple disciplines can support learners to develop a more complex understanding of the phenomena they experience, and benefit them in many ways [1, 2]. STEM should be for developing and contributing to society, environment, economy, and science. Making new discoveries through STEM, coming up with innovative STEM ideas, finding creative and innovative solutions to everyday problems through STEM and applying all these in different contexts will support scientific developments. Development of science can strengthen a country's economy and wealth. Furthermore, transferring STEM outcomes as knowledge or after transforming them into services and products can benefit the society and environment. However, to achieve all these we need an entrepreneurial mindset. Incorporating an entrepreneurial mindset into integrated STEM settings increases learning opportunities for financial, social, and innovative entrepreneurship, which can establish even more authentic contexts for students. Entrepreneurial STEM education can help students realize where and how STEM is used in everyday life [3], increase interest and motivation in STEM disciplines [4], equip students with twenty-first-century skills and competences, and bring solutions to everyday problems [5].

Although entrepreneurial STEM education is becoming more and more important in this global and digital world, there is a scarcity of studies focusing on ways of assessing entrepreneurial STEM education [6, 7]. Although summative assessment is commonly used in education, the implementation of formative assessment, particularly digital formative assessment, is limited. Digital formative assessment can increase knowledge and achievement, and enhance the student capacity to self-regulate [8], improve student motivation [9], and provide opportunities to learn anytime and anywhere [10]. Therefore, this chapter aims to introduce entrepreneurial STEM education and how it can be assessed through digital formative assessment. In the chapter, first, STEM education, entrepreneurship and the need for entrepreneurial STEM education are discussed. This is followed by introducing digital formative assessment and its missing place in entrepreneurial STEM education. The chapter is finalized by providing a step-by-step example on how entrepreneurship can be integrated into a STEM lesson and how this entrepreneurial STEM lesson can be transformed into digital formative assessment.

2 Integrated STEM Education—STEM Habits of Mind

A goal of formal education for all ages of children that has gained momentum over the last ten years is integrated STEM education. World-wide resources are being corralled for STEM education initiatives, producing academic STEM centres, inclusive STEM high schools, and afterschool programs, to name a few. The subject areas of STEM are well-defined, however the definition of what is exactly meant by *integrated* STEM is just now converging [11]. This interdisciplinary instructional approach does more than show how one content area can inform another, it is intended to integrate design, inquiry, analysis, and twenty-first century skills (www.p21.org).

The assumption with an integrated STEM approach is that the learner learns something more academically than the knowledge from the individual subjects of science, technology, engineering and mathematics, and that there is more to the whole of STEM than the sum of its parts. The disciplines of mathematics and science strive to answer questions about the natural world. Scientists and mathematicians aim to improve our understanding of the universe. The disciplines of engineering and technology tend to pursue projects that optimize the human experience. Engineering uses design cycles to investigate, prototype, test, and improve iteratively to develop solutions for human needs. In the same vein, technologists take the designs of engineers and adapt them for functionality. However, science and mathematics and engineering and technology cannot exist without each other. Engineering and technology must engage with science and mathematics principles while testing. Without science and mathematics knowledge, the engineering design process would be merely trial and error, because an engineer needs to know how the design will work in the real world. Technology works in a similar way. Technology must obey the laws of the natural world, and technologists need to be knowledgeable about mathematics and science to be sure designs will function as they are intended. Similarly, science and mathematics would not progress if it were not for engineering and technology. Mathematics and science need the tools created with engineering and technology so that phenomena can be observed beyond the human senses [12]. The integration, revisiting the subjects of design, inquiry, analysis and skills of STEM within and across each subject, can give learners a more complex understanding of the phenomena they experience. There may also be an effect of increased learning with integrated STEM, given the same amount of time as studying each individual subject.

In addition to engaging with multiple disciplines simultaneously, STEM education offers the affordance of working with realistic and authentic problems in the classroom [1, 2]. Classrooms engaged in STEM education address parallel problems and processes as STEM professionals, with adjustments for developmental needs [13]. In the US, the National Research Council (NRC) recently made a call for educators to provide students more authentic experiences that mimic STEM professionals [14]. Similar calls have been made globally, for example, in Australia [15], Canada [16], Japan [17], Taiwan [18], and Thailand [19]. These positions were made, in part, due to the declining competencies of students to apply scientific, mathematical and design thinking to practical problems (e.g., how to make observations during investigations). Global calls for integrated STEM include a greater emphasis on helping students establish connections between concepts and an integrated understanding of the natural and designed world [20], it is clear that educators are being charged with helping students develop more dynamic and flexible thinking skills. Not only can an emphasis on integrated STEM education help students develop twenty-first century skills, but it can also help students develop a perspective of connectedness and systemic thinking. Through the authenticity of integrated STEM education, students may be able to see how their decisions affect others around them.

STEM should be for developing and contributing to society, environment, economy, and science. Making new discoveries through STEM, coming up with innovative STEM ideas, finding creative and innovative solutions to everyday problems through STEM and applying all these in different contexts will ultimately be supporting scientific developments.

3 Entrepreneurship and Entrepreneurial Mindset in Education

Although entrepreneurs' existence goes as far back as Marco Polo, who was a merchant and lived in the thirteenth century, the word entrepreneur was first used by French-Irish Economist Jean-Baptiste Say in the nineteenth century. Since then, an entrepreneur and entrepreneurship have been defined in many ways. To integrate entrepreneurship into education courses, what is meant by entrepreneurship, what our perspective should be in education, what we should pay attention to when teaching entrepreneurship at different levels of education should be clarified.

Most definitions of entrepreneurship are rooted in business and economy and have been taught at business schools and economics departments since entrepreneurship first emerged there. These definitions commonly refer to starting a business as well as making money and profit. In addition to such subject-specific definitions, entrepreneurship also has broader definitions. The broader definitions mostly refer to entrepreneurship as a process, skill or an effort to create something new. From the broader perspective, entrepreneurship is a discipline that emerges based on opportunity or needs [21] and can operate in an independent or interdisciplinary way [22]. Therefore, recently, entrepreneurship has been mentioned in different fields, such as sociology, psychology and education [23]. Even though broader definitions are used in such fields, the financial perspective coming from the business and economics fields still dominate. However, the perspectives, goals, and the concepts of the definitions rooted in the business and economics fields differ from the others. For example, as well as producing a product or creating something new, developing students' skills and intention of social utility is highly important in education. Using the definition of entrepreneurship derived from business and economics departments without conceptually adapting to education may raise many issues, such as creating citizens who prioritise finance to social and scientific benefits [24]. Therefore, entrepreneurship should not directly be integrated into education without adapting it to education first. Because education departments should not see students as customers nor people who intend to start businesses, the entrepreneurial perspective should be reviewed and adapted to education from a broader perspective. Saying that, Kaya et al. [25, p. 464] analysed the broader definitions of entrepreneurship and defined it in education as:

> the process of establishing new economic, social, institutional, cultural and scientific environments or organisations to create future products and services by realising the opportunities and their possible failures and using required resources.

As in the entrepreneurship definition within education, innovation, or the learning from failure and creating social and cultural environments, is also significant. Entrepreneurship can be viewed from different perspectives; for example, financial, social, and innovative entrepreneurship. To decide about which perspective we should embrace in education, first, we need to know about different perspectives to entrepreneurship. Entrepreneurship is often viewed from the financial perspective. This perspective commonly views entrepreneurship as creating jobs, starting a business, making money, and making profit. Many studies view entrepreneurship as financial entrepreneurship, which commonly focuses on profit making [26, 27]. Recently, in a number of studies, entrepreneurship started to be perceived from a social entrepreneurship perspective. Social entrepreneurship was motivated by issues such as inequality, poverty, and human welfare, and viewed as a driver of social change rather than having individualistic monetary expectations [28, 29]. Even though social entrepreneurship is highly significant for social change, Gupta, Chauhan, Paul, and Jaiswal reviewed the literature and found only 188 studies published on the topic of social entrepreneurship between 2007 and 2018 [30]. Innovative entrepreneurship has also drawn attention in the last decades. Although it is considered as a key to economic development [31], innovative entrepreneurship is also significant to improve people's life quality [32]. Obviously, financial entrepreneurship is highly important for the economic development of a country, which can have an impact on increasing the wealth in the future, and there are many studies on this perspective and it already dominates the fields. Looking at the needs of society and the limited number of studies, social and innovative entrepreneurship should be supported more in education.

So far, we agree that entrepreneurship should be integrated into education after conceptually adapting it, and social and innovative entrepreneurship is missing in education so they should be supported more. However, we still need to discuss what we should pay attention to when teaching entrepreneurship at different levels of education. One of the most important topics that we need to consider is that students' developmental stages and needs vary at different ages. We cannot expect students' to start a business or build a career when they are at, for example, primary school. However, at these ages, we can develop their entrepreneurial skills, such as learning from failures, realizing opportunities, adaptability, resource management, innovativity, problem-solving and risk-taking [33, 34] and build on students' entrepreneurial intentions. When students reach secondary or higher education, they can then be guided to develop entrepreneurial knowledge and behaviour to turn their intention into an action. Liñán, Rodríguez-Cohard, and Rueda-Cantuche investigated the factors that play an important role in decisions to start an enterprise [35]. The authors developed a scale to determine these elements and found that education initiatives should include entrepreneurial content to promote, such as raising awareness, creativity and opportunity recognition in the primary and secondary schools.

One common mistakes is that when we are integrating entrepreneurship at different levels of education, we are hiding the failures and disadvantages of integrating entrepreneurship behind its gloss. This is problematic in many ways. Firstly, when students do not learn about the negative aspects of entrepreneurship, if they go through an entrepreneurial process in the future and experience a failure, they might experience disappointment which may even affect their psychological health. Secondly, if students do not consider the potential negative impact of the entrepreneurial process that they are going through, the process may harm different areas such as people, organisms, and environment. Furthermore, there are various races, cultures, ideologies and other perspectives to consider. Students have to learn if an entrepreneurial mindset is used in a wrong way, their entrepreneurial actions may result in ethical issues, and they should be aware of potential negative results of their actions on people and the environment as well as its benefits.

Starting at early ages, students should begin to understand that entrepreneurship has advantages and disadvantages. When entrepreneurship is learned with its pros and cons, it can help students develop their skills [36, 37], improve life quality [32], and be a driver of social change rather than having individualistic monetary expectations [28, 29]. Students should be focusing on social needs and public benefit rather than individual financial profit.

4 Entrepreneurial STEM Education

Recently, entrepreneurship also became associated with STEM and entrepreneurial STEM education has been studied across different disciplines worldwide (e.g., [38, 39]). In entrepreneurial STEM education, STEM content is taught through an entrepreneurial lens, which supports developing an entrepreneurial mindset and intention in STEM. Entrepreneurial mindset can be defined in different ways. For example, Bosman and Fernhaber define entrepreneurial mindset as the "inclination to discover, evaluate, and exploit opportunities" [40, p. 13]. Haynie et al. define it as "the ability to be dynamic, flexible, and self-regulating in one's cognitions given dynamic and uncertain task environments" [41, p. 218].

Entrepreneurial STEM is also referred to in different ways in the literature; for example, STEM + E, E-STEM, Entrepreneurship and STEM, and STEM-Entrepreneurship. This chapter refers to it as entrepreneurial STEM because STEM knowledge and resources are transformed into digital technologies, scientific inventions, and STEM products or services and transferred from academia to the public through an entrepreneurial lens, and this transforms STEM content into entrepreneurial practices. Entrepreneurial STEM education may help students to realize the needs of the public [42] and where and how STEM is used in everyday life [3], which in turn may increase interest and motivation in STEM disciplines [4]. Furthermore, through entrepreneurial STEM education, students become equipped with twenty-first-century skills and competencies and apply them to different contexts to bring solutions to everyday problems [43, 44]. Here, what we should pay attention to is that an entrepreneurial mindset may help shift STEM learning from being deficit problem solving to a positive orientation, which can refer to positive judgements about the individual and the individual's personal life and future [45]. Furthermore, developing an entrepreneurial STEM mindset can help students view a situation from different perspectives and consider advantages and disadvantages of every situation they face. Students can understand the content of STEM and how it can be turned into a practice through entrepreneurship. Understanding how STEM works, how it is transformed for public use, and how it can be transferred to the public can contribute to students developing a holistic understanding of STEM education. Through an entrepreneurial STEM mindset, students may also realize new opportunities and this can help them in the future to be open to create new jobs and progress in their career—i.e. career development [25, 46]. Having a variety of mindsets may help students realize their full potential [37]. Creating citizens who have an entrepreneurial STEM mindset can contribute to the social, scientific, economic, and environmental development of countries. Particularly, utilizing innovative and social entrepreneurship in education can be a driver of long-term economic growth and improved societal welfare [30, 47]. This would also help prevent, overcome, or fight against many issues in the future, such as global pandemics or global warming.

The theory and practice of entrepreneurship in STEM education is addressed by a number of studies. For example, Deveci and Seikkula-Leino [48], Ribeiro et al. [49], and Marquez et al. [50] argued the link between entrepreneurship and STEM education and their importance for each other. Eltanahy [51] and Kidman et al. [52] developed frameworks to integrate entrepreneurship and STEM education. Various current studies present examples for integrating entrepreneurship and STEM (e.g., [53–59]). Some other current studies present the challenges, opportunities, and impacts of integrating entrepreneurship and STEM (e.g., [60–62]). However, a limited number of studies present a way of assessing entrepreneurial STEM education [6, 7]. Thus, the following section introduces the digital formative assessment to utilize for entrepreneurial STEM education.

5 Digital Formative Assessment

Because the integration of entrepreneurship into STEM education may be new for students, monitoring their understanding frequently and providing students feedback in a timely manner can help support their knowledge and skills. Formative assessments are administered while students are in the process of learning for the purposes of identifying student strengths and weaknesses as well as informing future instruction [63]. Formative assessment, when designed well, can positively influence students' academic performance as long as classrooms are student-centered [64, 65].

Shepard provides a synthesis of prior research to identify characteristics that make formative assessment effective [66]. An instructor's contribution to effective formative assessment includes a focus communicating clear learning goals that are considered a valuable educational outcome with authentic contexts beyond a classroom. Entrepreneurship integrated into STEM education can help make the context even more authentic to a student. Instructors should also design formative assessments to identify students' current knowledge and skills, with a focus on the steps needed to achieve the learning goals, typically through a rubric or specific grading criteria. In identifying the steps toward successful completion of the learning goals, instructors should encourage students to self-monitor their own progress. Students engaged in formative assessments should take responsibility for their own learning and be proactive in identifying successes and mistakes, making plans for adapting their strategies or seeking help when needed. Once instructors provide students with non-judgemental feedback that is timely, specific, and provides opportunities for revision, students should reflect on this feedback in a meaningful way and be metacognitive about their strengths and weaknesses. Five strategies are commonly used to integrate formative assessment to the teaching and learning process [67]:

1. Clarifying and sharing learning intentions and criteria for success,
2. Engineering effective classroom discussions, questions, and learning tasks,
3. Providing feedback that moves learners forward,
4. Activating students as instructional resources for one another (peer-assessment),
5. Activating students as the owners of their own learning (self-assessment).

These strategies are also used by many other researchers (e.g., [68–71]). The results point to the effectiveness of formative assessment. However, it is commonly challenging for teachers to integrate formative assessment into their teaching.

Although research on formative assessment began in the 1990s and instructors have been using formative assessments for many years, technological advances, particularly digital technologies, offer new ways to structure formative assessment opportunities and provide different information for instructors and students than traditional paper-and-pencil forms of communication. With the inclusion of digital technologies in formative assessment, digital formative assessment can be employed in classroom settings. Digital formative assessment can be viewed as a type of formative assessment that utilizes "all features of the digital learning environment" to contribute to students' learning progression [72, p. 10]. Digital technologies allow for faster gathering of information about student knowledge and skills, and ways for instructors to provide real-time feedback. Similarly, because technologies can gather and sort information quickly, instructors can gather learning analytics or click-stream data on students to assess their progress while the learning is happening. Thus, digital formative assessment does not interrupt the student while they are learning, such as in a teacher asking for students to fill out a quick quiz to determine their knowledge level. Rather, digital technologies allow for the gathering of student behaviours while they are happening. Furthermore, digital formative assessment can benefit learning by increasing knowledge and achievement and improving complex cognitive processes by enhancing the student capacity to self-regulate [8]. Digital technologies can be used for formative assessment in different ways. According to the Formative Assessment in Science and Mathematics Education (FaSMEd) initiative, technology can be integrated into the formative assessment process in three ways [73, p. 5–6]; 1. sending and displaying, 2. processing and analysing, and 3. providing an interactive environment.

Table 1 Digital formative assessment framework

Formative Assessment Strategies	Digital Technology Functionalities		
	A. Sending/ displaying	B. Processing/ analyzing	C. Interactive/ environment
Clarifying/sharing learning outcomes and success criteria	1A	1B	1C
Classroom discussion/questioning/learning tasks	2A	2B	2C
Feedback	3A	3B	3C
Peer/self-Assessment	4A	4B	4C

Source [74, p. 6]

As part of a research project titled "Assessment of Transversal Skills in STEM (ATS-STEM)", funded by the European Commission under Erasmus+, a framework was developed to use for digital formative assessment by teachers (www.atsstem.eu). The Digital Formative Assessment Framework (See Table 1) included 12 cells, which emerged by crossing over four digital formative strategies (it is four due to categorizing peer and self-assessment as one strategy) and three functionalities of technology.

We believe that Table 1 can provide a good foundation for educators to transform their teaching into a digital formative assessment process. Next section provides an example of how a theoretical framework can be turned into a practical application.

6 An Example for Assessing Entrepreneurial STEM Education Through Digital Formative Assessment

There are different ways of integrating entrepreneurship into STEM education. For example, developing incubator programs, organizing expert meetings, and using design thinking. In this section, we will take an integrated STEM lesson and demonstrate ideas for integrating an entrepreneurial mindset, then we demonstrate the example lesson through digital formative assessment.

6.1 STEP 1—Integrated STEM Lesson Plan: Design Challenge

Description

This STEM investigation is geared towards students aged 8–14. In this example, students research and design packaging to transport fragile, crispy snacks across the world. The driving question for the investigation is "How do companies ship fragile, crispy snacks from place to place without them breaking?".

Learning objectives

Students will be able to

- apply geometric properties of three-dimensional shapes to the packaging of a product of choice.
- apply engineering design to the packaging of a product of choice.
- discuss sustainability issues when creating packaging.
- communicate a packaging innovation to an audience.

Learning Activity

Students conduct background research to answer their questions about packaging for food and then they pursue a design challenge. The design challenge is to find a product that they feel is not packaged well and redesign the packaging for shipment by both air and land. This means they will need to design a package that will be durable, protect the contents, maintain integrity at high altitudes, and be ecologically sound. The following are the steps that students can follow during the design challenge.

Background research

Students can begin their background research by looking up ways their item of choice is packaged and shipped, particularly at high altitudes. There are many excellent web pages and videos on the Internet that are dedicated to these logistics.

Collaborative groups

Once students have a good idea of how industry packages and ships their item, then they can work in a collaborative group to identify ways to improve the package

Conducting discussions on the product

Students should first brainstorm ideas and then collaboratively narrow their focus on the variables they want to change.

Creating designs/Prototyping

With their focus variables in mind, students should create a conceptual model of their design.

Testing the prototype

Next, students collaboratively test their ideas using a prototype. For example, if they are examining the ways they can maximize the number of crisps they can fit into a snack back, they can test different amounts of air and crisp ratios to maximize the amount of product in a bag. In their testing, they may find that other variables can enter into their model, such as the water droplets in air making the crisps soggy, and they can take these variables into consideration as well.

Presenting results

When collaborative student groups feel that they have optimized their packaging, they present their design and results to the class for feedback.

6.2 STEP 2—Entrepreneurial STEM Lesson Plan: Design Challenge

In this step, the description of the activity will not change. However, the learning objectives will be tailored or new objectives will be added to accommodate an entrepreneurial mindset.

Learning objectives

The modified parts and new additions are italicized. By doing so, social, innovative, and financial entrepreneurship are waved into the learning objectives below.

Students will be able to:

- apply geometric properties of three-dimensional shapes to *innovate* the packaging on a product of choice.
- apply engineering design to *innovate* the packaging on a product of choice.
- discuss sustainability issues *by considering the environmental, social, and economic impact of the product on the public.*
- communicate a packaging innovation to an audience, *detailing benefits and drawbacks and explaining sustainability and environmental impact of the packaging for the product.*
- *develop a business plan to explain the environmental, social, and economic goals of the product, how these goals will be attained, and the time-frame for achieving these goals.*

Learning activity

As the engineering design process is used for implementing entrepreneurship into engineering fields, the activity already aligns with entrepreneurship. Social and innovative entrepreneurship can be integrated into this section with small modifications.

Background research

In this part, students can conduct two types of investigation: 1. STEM background research and 2. Entrepreneurship background research. In the STEM background research, students can investigate ways their item of choice is packaged and shipped, particularly at high altitudes. In entrepreneurship background research, students can investigate different aspects regarding entrepreneurship, such as the needs of the public, advantages and disadvantages of the product, and potential customers.

Collaborative groups

Once students have a good idea of the STEM background (e.g., air pressure, packaging material) and entrepreneurship background of the item (e.g., public needs, partners, cost), then, they can work in a collaborative group to identify ways to improve the package.

Conducting discussions on the product

Students should first brainstorm ideas and then, collaboratively narrow their focus on the variables they want to change. In the STEM part, students discuss some ideas with their reasons, for example, if they should fill up the package or leave partially empty, whether altitude affects the packaging, would there be any gas in the package and what type, and what type of materials they could use to protect the environment. In the entrepreneurship part, students discuss the packaging problem and how they can solve it, targeted customers and how they can reach the customers (e.g., communication channels, activities), partners (e.g., distributors, suppliers), resources required, and cost structure showing the spendings on key resources, partners, and activities, and the expected income. While the STEM part is intertwined with innovative entrepreneurship, this part so far targets financial entrepreneurship. Encouraging students to discuss the advantages and disadvantages of the product for the environment, society, and economy and how the public can benefit from what they are doing can relate to social entrepreneurship

Creating designs/Prototyping

With their focus variables in mind, students should create a conceptual model of their design.

Testing the prototype

Next, students collaboratively test their ideas using a prototype. For example, if they are examining the ways they can maximize the number of crisps they can fit into a snack back, they can test different amounts of air and crisp ratios to maximize the amount of product in a bag. In their testing, they may find that other variables can enter into their model, such as the water droplets in air making the crisps soggy, and they can take these variables into consideration as well. In this process, regarding entrepreneurship, students can communicate with potential customers and partners and the public to see their views on the prototype. Furthermore, they can briefly test how much waste they were producing before and how much it is with the new prototype. This can also point to their savings with the new prototype.

Presenting results

When collaborative student groups feel that they have optimized their packaging, they present their design and results to the class for feedback. During this presentation they can mention the STEM background as well as entrepreneurship background. Many wrappings are used in the shipment of crunchy products which creates waste and slowly destroys the environment. Such a system is not sustainable in the long term due to its disadvantages to the environment and economy. Students can help prevent this and increase awareness in their presentation, which can be viewed as an aspect of social entrepreneurship. Furthermore, if their prototype works and they decide to produce the product, they can consider starting a social responsibility project that can target donating a certain percentage of sales to a selected charity. In this way, the activity can turn into social entrepreneurship.

6.3 STEP 3—Entrepreneurial STEM Lesson Plan: Digital Formative Assessment Through a Design Challenge

In this step, we will take STEP 2, add the digital formative assessment aspects, and present it aligning with Table 1. We will be discussing the implementation under four formative assessment strategies. Digital technologies can be used for each strategy in three different ways; sending/displaying; processing/analyzing; providing interactive environments. We do not have to use all three ways of integrating digital technologies into teaching so at least one way of integrating it will be mentioned when presenting each strategy. The digital tools and environments presented here do not have to be used, teachers are free to select other learning management systems/virtual learning environments.

- Clarifying/sharing learning outcomes and success criteria

At the beginning of the lesson, it is recommended that teachers share and clarify the learning outcomes and success criteria with the students. To do so, teachers can send the learning outcomes to students using Google Documents the night before the lesson. Students read the learning outcomes, come to the classroom and analyze the learning outcomes via Slido. Teachers, then, share the success criteria on Microsoft Teams to clarify them in an interactive environment.

- Classroom discussion/questioning/learning tasks

After having the basic idea of the investigation, students work in groups. The teacher sends a learning task to students on a learning management system, such as Blackboard to investigate the question of "How do companies ship fragile, crispy snacks from place to place without them breaking?" in terms of the STEM background (e.g., what affects the packaging) and entrepreneurship background of the item (e.g., public needs, partners, cost). After this research, teachers can create a Padlet for students to discuss and analyze their opinions on the STEM and entrepreneurship background of their product. Furthermore, the teacher can create a Kahoot activity with questions for students to discuss the STEM and design aspects impacting the product as well as entrepreneurial aspects of the product such as who they will target as a customer and partner, how they can reach the customers and partners (e.g., communication channels, activities), what resources are required, and cost structure showing the spendings on key resources, partners, and activities, and the expected income. Then, as an interactive environment, students can create a Whatsapp group and discuss the advantages and disadvantages of the product for the environment, society, and economy based on their discussion on Padlet. They could also argue how the public can benefit from what they are doing.

- Feedback

After the research and discussion, students create a prototype of their design. The teacher can review the prototype and record a few minute feedback and send it to students. The teacher also organizes an online meeting using, for example, Zoom, Microsoft Teams, or Skype. In the meeting conducted in an interactive environment, students and teachers can discuss the feedback and how the student should progress.

- Peer/Self-Assessment

Here, the teacher can create and play a game with students. Each student can be matched with a fellow student from a different group. In pairs, each student evaluates the strengths of the prototype and its aspects to improve for their own prototype and their fellow's prototype. Then, the teacher displays the responses and analyzes and discusses the similarities and differences between the answers. By doing so, all students become more familiar with their prototype and their friends' and learn from each other. In this activity, the teacher displays the peer/self-assessment and students analyze the assessment.

7 Conclusion

Developing an entrepreneurial perspective in different subjects, particularly STEM education, is significant. It can give students many perspectives in which to explore natural phenomena and concepts about the designed world and human needs. Students who are typically reluctant learners may have renewed motivation to learn when given a realistic and authentic context. An additional benefit of learning about ideas with these types of integration is the ability for students to think in a diverse way. However, instructors may have difficulty assessing learning to determine if each student has met learning objectives, particularly when students are pursuing different paths. Instructor formative assessment of student learning at benchmarks that are timely and provide relevant feedback for student learning is necessary for entrepreneurial STEM education to be effective. Further, digital formative assessment provides two dimensions of assessment, strategies and functionalities, that can be systematically applied to entrepreneurial STEM lessons so that students can be guided to learn skills, knowledge, and habits of mind in an optimal way.

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