Holistic STEAM Education Through Computational Thinking: A Perspective on Training Future Teachers

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Abstract. Computational thinking (CT) skills are argued to be vital to preparing future generations of learners to be productive citizens in our increasingly technologically sophisticated societies. However, teacher education lags behind policy in many countries, and there is a palpable need for enhanced support for teacher education in CT. This paper addresses this gap, establishing an intellectual framework with which to explore the manner in which CT can be inculcated in compulsory school students. Drawing on a deeper awareness of the broader societal and cultural context of the activities we introduce a new approach to designing teacher education. The novelty of our approach is that training computation thinking is framed as an integrative element rather than as a separate study subject. This approach provides better articulation between Engineering and Science oriented subjects and Arts, providing supporting methods to develop the professional skills of student-teachers.

Keywords: Computational thinking · Integration · Culture · STEAM · Compulsory schooling · Teacher training

1 Introduction

In order to educate future generations, new generations of teachers require the requisite skills and capability to scaffold learning in a societal context where technology, and in particular automation and computation threaten to eliminate many skilled professions [20]. By implication the tertiary education sector must respond in terms of teacher education, and their structure, conduct and outcomes to equip pupils with the new skill set required.

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Responding to these challenges, the EU has announced new strategies and requirements for European Higher Education (HE). One of the declared priorities is "tackling future skills mismatches and promoting excellence in skills development" [1]. The motivation for this statement is clear, first, there is a decrease in interest and many "jobs are closely related to those areas that prepare students for jobs where shortages exist or are emerging" [2]. The areas of science, technology, engineering, (arts) and maths (STE(A)M), medical professions and teaching are focus areas.

The European Centre for the Development of Vocational Training (CEDEFOP) avers that the most highly demanded professionals are: "ICT professionals; medical doctors; science, technology, engineering and mathematics (STEM) professionals; nurses and midwives; and teachers" [1,2]. They also conclude that "all students in advanced learning, irrespective of discipline, need to acquire advanced transverse skills and key competences that will allow them to thrive" [1]. These skills, in addition to high- level digital competencies [1,8,10,21] include "numeracy, autonomy, critical thinking and a capacity for problem-solving" [1].

Computational models are central to a large fraction of modern scientific research, and therefore are also central to research-driven education. Computational models arise in collaboration with other disciplines outside computing. In these areas, in addition to the existing physical environment and specific content laboratories, computing can provide an opportunity for digital experiments and simulations. Then, in order to develop, implement, and study practical solutions based on computational models that include both technical and social aspects, students should have additional skills that allow them to develop or implement solutions in a highly digitised educational environment, such as decomposition and generalisation, and skills to design, create relevant algorithms, automate and calculate. Many argue that computational skills, in particular Computational Thinking (CT), are central to every discipline and profession.

Despite the importance attributed to STEM subjects by strategists and government documents [2], the need to motivate more people to study subjects related to STEM remains, including the problem of "tackling the under-representation of women, minorities and other under-represented groups in scientific and technical subjects in HE and subsequently in related professions" [1].

The role of school teachers is crucial to addressing this problem in a sustainable manner. School teachers are person who can motivate their pupils to take an interest in all subjects, including maths and sciences, and play an active role in helping to shape their future choices. During his or her teaching activities, the school teacher is a crucial agent, utilising knowledge, skills and competencies to enhance the intellectual development of students. Consequently, the role and responsibility of HE (especially in regard to the education of future teachers) is to ensure that study programs are provided which develop the required pedagogical models and competence.

This paper describes our recommendation for developing and contextualising future STEM education in the context of the European discourse on higher education and pre-service teacher education. Aligned with our previous discussion we suggest special attention be given to Computational Thinking and to the new demands placed on teachers. Our starting point is therefore to propose a framework of curriculum improvements with respect to computational skills in STEM teacher education in a manner that allows them to be contextualised into the complex European curriculum landscape.

Our target group for this project are teachers for: preschool institutions (kindergartens); primary school; middle and high school STEM and computer science subjects; foreign languages, arts and humanities. The concrete objectives are: (1) to improve the CT skills of prospective teachers, and (2) to foster the teachers' development of pedagogical content knowledge (PCK) related to the teaching and training of various aspects of Computational Thinking (CT). We recognise that it is impossible to provide a generic solution due to the different curricula for teacher education in different countries. However, the goal of the exercise is not to rewrite curricula, or propose new curricula, instead we focus on providing modules that provide practical assistance to teachers and teacher educators. The role of these resources, and how they influence curricula in countries beyond the scope of our initiative (our scope is primarily the Nordic and Baltic countries). We offer the model we have developed as a source of inspiration for others, and as an example of one approach to tackling this educational challenge.

2 Computational Thinking as an Integrating Skill

2.1 Research Perspective

Computational thinking and digital competence are closely related areas. The DigComp framework of the European Union [21] provides guidance in the process of identifying the necessary skills and competencies estimated to be required of future citizens. Jeanette Wing [22,23] widely popularised and promoted the central role of computational approaches. In this regard, a key aspect is the ability to understand the opportunities and limitations which the high speed computational capacity modern computers bring to the practice of all disciplines.

Here it is crucial to recognise that ideas of computation, and computability are not what is new. Computation and computing have been practiced since early times [18], and the ability to compute and automate has lead to large scale social re-organisation, for instance the impact of automation as a primary driver of the industrial revolution [7]. What is new is the rapidity with which calculations can be performed. The speed of calculation possible with modern computing machinery is unprecedented, and it is the application of this power, with the associated implications for what that makes possible that is crucial to the STEAM argument. But indeed, what is even more important, is what cannot be done despite this capability for rapid computation.

There are many ways to conceptualize Computational Thinking. Common aspects include Decomposition, abstraction, algorithms and automation, modelling and simulation, data collection, data representation, data analysis, and parallelisation. This skill set provides capabilities for designing content and context specific models and simulations with (or without) computers.

2.2 Scientific Literacy

The goal of science education is scientific literacy, therefore to teach scientific inquiry is one of the most important aspects for STEAM education. This includes (besides content specific skills) experimentation skills and argumentation skills.

Scientific thinking is understood as the ability to complete scientific inquiry within a specific scientific content. Knowledge of the basics and details of the content specific topics is important. In addition, students should acquire skills for experimentation and data processing, as well as logical thinking and generalisation skills. Creative thinking, as already mentioned, includes skills that allow students to incorporate aspects related to the environment and context into the model that they create and test during their project or problem based activities.

We treat Computational Thinking (CT) as an integrative skill within our holistic STEM model. This position is arrived at based on the following arguments. First, we wish to emphasise the primary role of computational models in modern scientific research and, therefore, in research-oriented education. Such computational models, in addition to the existing physical environment and specific content laboratories, provide an opportunity for digital experiments and simulations.

Subsequently it will be necessary to develop, implement, and study a series of practical modules imbued with the core competences in aspects related to the acquisition and development of CT skills. The process of such integration with the existing curricula will provide solutions based on computational models that include both technical and social aspects, [such that] students should have additional skills that allow them to develop or implement solutions in a highly digitised educational environment, such as decomposing and generalising skills and skills to automate, algorithmize, calculate, and design.

2.3 STEAM Integration

As for science, engineering and technology, focusing exclusively on specific technical knowledge in isolation no longer provides learning advantages. Contextualisation in terms of other disciplines emerges as important, and social contextualisation as a major factor in achieving broader representation of minorities. Revealing a “true” pragmatist approach, focused on the needs and expectations of the community, modelling of complex social aspects is a must for modern research and industry. Such requirements have a direct impact on modern STEM education.

There is a need for context-oriented STEM content and teaching resources, with a clear focus on the trans-disciplinary nature of emerging high level challenges. Indeed there are compelling calls to expand STEM to include aspects of design and the arts. In Sweden the national curriculum calls for CT content to be integrated into existing school subjects such as “art and craft” and Swedish language, as well as the more traditional targets, mathematics, physics and technology. To address this situation a point of departure in design, and a more holistic epistemology of STEM teaching embracing the Arts (STE(A)M) is proposed [19]. In the outline we present below, this integration is the central guiding principle.

To contextualise our effort further we consider the two main trends of development of post-industrial society related to education and research. Foremost digitisation, followed closely by the socialisation and contextualisation of knowledge and experience. There is a movement back to our "socio-cultural origin" - signified by a shift in popular perspective from industrial society with its clear focus on people as potential employees, to a post-industrial understanding of the complex interplay between the nature of people and society. These two directions are intertwined fostering nowadays post-industrial society to become even more complex to act, understand and model. Individuals are immersed in a kind of broth with human, inhuman agents and organisations. In the course of its daily activities, the industry must take into account the influence of the complexity of these social and contextual factors, and in practice this means even higher demands on employees related to skills and level of education [14].

Another argument for the integration is the failure of "automatic transfer" in the original Papert approach. One of the key ideas in Papert's (1980) classical work on the programming language LOGO [13] is that by learning to program, children would develop computational problem solving skills that they could apply to other contexts. Results of empirical studies on this expected transfer were mixed, however. Research suggests that sophisticated applications of computational thinking skills to other subject matter does not come by itself, but requires explicit instruction [16]. This is also confirmed by the work of Palumbo [12] which explores the evidence surrounding how problem solving can be supported by programming activities.

3 An Integrated CT Curriculum for Teacher Education

3.1 Content

There is a need to develop innovative educational approaches to practical STEAM education that are based on Computational Thinking (CT) as related to trans-disciplinary and holistic STEAM perspectives. We promote a pragmatic approach to CT as to a set of tools, techniques and approaches which enable a seamless transition from the early-aged child's unplug activities to a comprehensive modelling and computer simulation activities of K-12 and early years' university students. We put our research and implementation emphasis on educational programs and curriculum enhancement for education of prospective teachers focusing on CT and STEAM related aspects.

We propose an approach that promotes developing of skills related to the contextual environment, such as communication, research ethics, social modelling, politics and society, and include the development of emotional and creative thinking in addition to the skills of scientific thinking, mainly as related to project-based and enquiry driven education.

We propose a multidimensional model of curriculum development: the longitudinal dimension (personal childhood intellectual development), the skills dimension (scientific thinking skills, CT skills, and contextual thinking skills), the contextual dimension (community, society, communication, management, entrepreneurship, culture, diversity, ethics).

Within this three dimensional curriculum CT is positioned as an integrative skill set that links scientific and content- specific knowledge with contextual thinking skills, adding context-specific modelling skills (developing of models and simulations, including modelling of cyber-social systems).

The curricula philosophy emerges from the post scientific tendency to merge scientific and technical knowledge with social and humanitarian knowledge. Here we perceive contextual knowledge as the most valued, and adopt a pragmatist approach to education in terms of sharing community values and solving actual present-day problems. The adapted TPACK framework for CT and STEAM is applied to develop specific curriculum modules in the latter part of the paper.

Students are given the opportunity to evaluate their designs from an economic, environmental, political, and scientific point of view. In fact, the student teacher should also be able to develop and test the contextual model using assessment, evaluation, and communication.

3.2 Pedagogical Approaches

The evolution of school STEM pedagogy expands our scope beyond the traditional discipline specific STEM to tackle the complex challenge of embedding CT and other scientific thinking habits and practices into language and arts and craft subjects. Necessarily this integrated STEM must be seen as STE(A)M – that is include (integrate) arts and humanities subjects with traditional STEM. Our STEAM integration process is based on the development of models and/or simulations in curricula support modules (these could be computer/computational models or other forms of models and simulations) that will provide an appropriate grounding for students' cognitive processes. In doing so we place an emphasis on informatics (computer science) and/or CT.

Project based learning cycle (PBL) as related to STEAM includes practices and activities to (Young, 2018): (1) identify the problem; (2) identify criteria and constraints; (3) brainstorm possible solutions; (4) generate ideas; (5) explore possibilities; (6) select an approach; (7) build a model or prototype (computer model and/or simulation); (8) refine the design. Our approach leverages these stages as a way to scaffold module design.

What are the main aspects of school STEAM education? (1) We must provide students with the instruments to creatively solve the problems they face in their daily lives; (2) In the PBL cycle, students should be motivated to design the investigation to find the best appropriate solution from issues raised from the community; (3) the main principles for the curriculum: the situated problem, creative design, emotional grounding; (4) an integrative approach and focus on competences – scientific thinking, computational thinking, and contextual thinking; (5) systematic assessment.

The school (kindergarten) curriculum must comply with the earlier work of Armstrong [4]: (A) cycles of child's personal development; (B) a holistic longitudinal model of a child's personal development.

The holistic approach to design [3] involves increasing complexity – from simple tasks to complex projects; as we do so we eliminate compartmentalisation and sequencing of problem-solving tasks.

A context-based approach has been shown to be beneficial. In particular, context-based teaching provides meaning, coherence and relevance to conceptual subject matter. We develop a content based on real-world problems or tasks related to children's lives: the multidisciplinary nature of real-world problems places new demand on teaching, requiring collaboration between teachers with different content experiences and expertise.

4 Project: Developing Teacher Education on CT in STEAM

4.1 Objectives

We aim to contribute to the professional development of STEAM teachers by developing modules for teacher education in order to (1) improve CT skills of prospective teachers and (2) to improve pedagogical skills and competencies of prospective teachers based on the integrative multi-disciplinary model previously advanced by Seery et al. [19].

4.2 Design Principles

How should this be achieved? There are many approaches that have shown promise in engaging learners using an explorative/enquiry paradigm. We consider here some variants of problem based learning (PBL), as well as Design Based Learning (DBL) within the broader sphere of social-constructivist learning approaches.

The recommended assessment approach is based on a pragmatic methodology which includes theoretical study, and models practical design cycles including piloting and dissemination stages. As a final practical result, a number of curriculum modules result, providing the basis for training prospective teachers on various aspects of CT as related to STEAM project-based education for preschool and school levels.

The proposed modules adopt several crucial criteria: (1) they are self- sufficient, which allows them to be included in the existing university curriculum; (2) they form part of the coherent CT curriculum for STEAM and related subjects. Expected impact includes opportunities to improve current educational programs for prospective teachers, and in the longer term, to improve European STEM education by moving to interdisciplinary and pragmatic STE(A)M, thus increasing teacher and pupil involvement and increasing motivation of currently less represented groups in order to generate interest in professional careers in the field of science and engineering.

4.3 Methodology

The research and implementation process of the individual modules is structured in four phases: (1) Development and Design Phase: Literature review and/or research on existing practices, the development of a first draft of the intellectual output and its publishing on the web site; (2) Review and Pilot Phase: Refinement of the first draft based on peer review and feedback by experts as well as feedback from the piloting of the module in teacher education programmes responsible for the course of the training events. (3) Optimisation and Production Phase: Development of an improved version of the intellectual output and its publication on the research project web site. (4) Translation and Publishing Phase: translation of intellectual outputs into languages of the research project partner countries and national implementation of the outputs.

In the development of the modules we address the TPACK model, which offers: (C) knowledge of the content includes knowledge of CT and aspects related to STEAM and contextual modelling; (P) pedagogical knowledge includes knowledge related to: (a) pedagogy of CT as a whole, (b) STEAM pedagogy, including interdisciplinary, integrative and contextual aspects, (c) PBL pedagogy; (T) technological knowledge should provide support for PBL and related modelling; (CX) contextual knowledge, among others, includes knowledge of modern school reform and European educational policy. A partial evaluation of the efficacy of these modules and the integrated curriculum model can be conducted using the teacher self-efficacy instrument of Nordén et al. [11].

4.4 Module Structure

The conceptual core is the development of 10 modules for integrating of computational thinking (CT) into existing university trainee teachers' education. This implementation consists of learning resources which can be adapted, contextualised, and integrated into university teacher education covering science, technology, engineering, arts and mathematics (STEAM).

The structure of the pool of resources (see Fig. 1) is designed to cover all the main parts of the educational process. The output of the project is the 10 modules (O1–O10) described in Table 1. Output O1, along with outputs O2 and O9, provide the theoretical and methodological basis for all module development. Outputs O8 and O10 focus on specific CT and STEAM educational environments and aspects of instructional design. Other modules are subject and level specific and focused on CT for STEAM and related subjects. At the same time, each module is self-sufficient and includes supporting material in the form of descriptions and instructions for the user. Each module will ultimately be represented by its own web page on the research project website.

5 Implications

Fostering the application of CT in school subject areas suggests that the learning objectives in existing subjects should be examined for future alignment with

Table 1. Module overview

Module	Contents
O1	Framework for the development of the curriculum modules: CT & STEAM for education of prospective school and kindergarten teachers
O2	General Introduction of Computational Thinking: a basic module suitable for all teachers
O3	CT for pre-school (kindergarten) prospective teachers: specific features, approaches and practical solutions
O4	CT for primary education prospective teachers: specific features, approaches and practical solutions
O5	CT for STEM prospective teachers: specific features, approaches and practical solutions
O6	CT for languages, arts and humanities prospective teachers: specific features, approaches and practical solutions
O7	CT for languages, arts and humanities prospective teachers: specific features, approaches and practical solutions
O8	Educational environments for CT: design and aspects of integration
O9	Using Constructivism, and Project and Challenge Driven Pedagogy for learning Computational Thinking
O10	Technological, pedagogical and instructional design aspects of teaching CT for STEAM

CT competences. This requires developing suitable operationalisations of CT and investigating both generic linking principles and topic-specific connections to CT. Concrete CT 'hooks' have been developed for specific STEM subject matter, for example mathematics [9] and technology [5].

Most of the examples of embedding CT into an existing subject area involve some form of algorithmic problem solving in that subject area, often combined with the construction of digital artifacts such as computer programs or robot as a technological solution to the problem. In some cases, however, it would be preferable to use computational concepts to represent subject matter from another STEM discipline such as physics, chemistry, biology or mathematics, in order to better understand and explore fundamental principles.

An interesting example is the use of algorithms to model the concepts of natural selection and protein synthesis in biology [15]. In the case of such scientific phenomena algorithmic modelling can be utilised, and the phenomenon explored using simulations, stimulating analysis, evaluation and reflection skills. If the emergent properties differ from the expected, this "suggests the rules, and therefore the underlying understanding needs further refinement" [17].

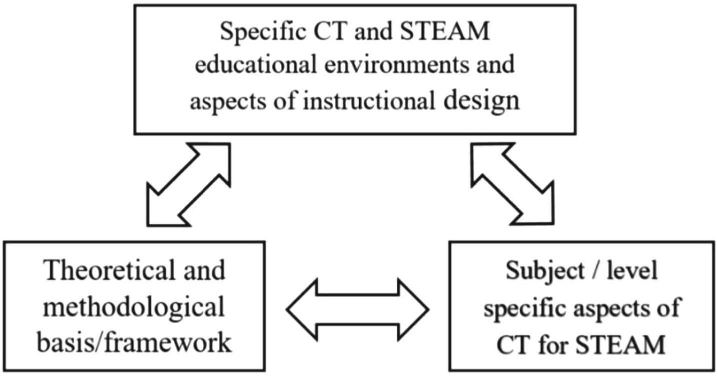

Fig. 1. Contextualised curriculum model

Teaching and assessing development in computational thinking has become one of the main issues in the field of modern education [3,6], and thus the discourse has moved beyond the boundaries of computer science. There is a tendency towards the integration of computational thinking skills into the skill set of today's learners regardless of their technical background. Therefore, to associate these skills with such courses as programming/computer literacy/digital competence might not be an effective or sustainable approach. However, as an alternative we suggest that a search for the possible ways to integrate computational thinking skills into the current educational settings provides a more constructive starting point.

Development of activities about computational thinking skills, and integration them into the curricula of various subject areas can be expected to help learners to meet the requirements of the information age paradigm of education. Teachers play a key role throughout this change because they are the ones who will embed the skills that contribute to the development of computational thinking skills in addition to practice the integrated activities. The computational thinking skills awareness of current teachers in the field of information technology (or computer science) is currently questionable. Moreover, the relationship between these skills and other subject areas are considerably weaker than is desirable. Our modularised approach strengthen that relationship, enhancing teacher education programs and providing support for curriculum revisions. It is expected that computational thinking skills will become obligatory fundamental skills, regardless of the subject areas of teachers. Moreover, the way teachers transfer these skills into their field of practice can be listed as one of the crucial teacher competencies in the near future. We believe that the approach we outline above addresses some central elements of this challenge.

6 Summary

In this paper we provide an educational science and resource design perspective on the challenge of integrating CT conceptual material into existing EU school teacher education programmes.

The aim of the curriculum modules for CT and STEAM education is two-fold: (1) to train pre-service teachers from various subject areas in order to develop their computational thinking skills, and (2) to model CT processes and thought structures to help integrate these skills into realistic educational scenarios. Our target group includes pre-service teachers in the one of the following fields: computer science, mathematics, science, foreign languages, craft, pre-school (kindergarten), and elementary education. Teacher education programs may naturally exhibit differences in terms of curriculum structure, and they can be shaped according to the local needs of countries. Any intervention designed for a single country might produce unexpected results for another one. That's why the context of the particular country should be well-defined by local researchers and thus the collaboration on a European scale developing the European dimension and character of education can become meaningful. In this way, countries can learn from each other's experience. It is consequently of the utmost importance that the pre-service teacher training interventions proposed here be tested and implemented in different countries.

Summing up the initiative and the manner in which it contributes to a new approach to STEAM teaching as an holistic pursuit we offer the following observations.

ELEMENTS OF INNOVATION include a pragmatic view on CT as on a set of tools and techniques which allow contextual integration of educational activities of school students of various levels of a STEM focused education. CT approaches in education, in addition to traditional approach to computer science and programming education, promote unplug activities, support project and design-based activities.

EXPECTED IMPACT (A) framework - is on (1) university teachers – provide a contextual description and module development paradigm; (2) curriculum developers – provide a framework for integration and adaptation of the developed. (B) research project web page – on all groups of interest and dissemination.

TRANSFER POTENTIAL is based on the universality of the structure, which ensures the consistency and self-sufficiency of the curriculum and other modules.

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References

1. EUR-Lex - 52017dc0247 - EN - EUR-Lex, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52017DC0247

2. Briefing note - The skills employers want!, April 2019
3. Angeli, C., et al.: A K-6 computational thinking curriculum framework: Implications for teacher knowledge. Educ. Technol. Soc. (2016)
4. Armstrong, T.: The Best Schools: How Human Development Research Should Inform Educational Practice. Association for Supervision and Curriculum Development, Alexandria (2006)
5. Atmatzidou, S., Demetriadis, S.: Advancing students' computational thinking skills through educational robotics: a study on age and gender relevant differences. Robot. Auton. Syst. **75**, 661–670 (2016)
6. Brennan, K., Resnick, M.: New frameworks for studying and assessing the development of computational thinking. In: Proceedings of the 2012 Annual Meeting of (2012)
7. Grier, D.A.: Human computers: the first pioneers of the information age. Endeavour **25**(1), 28–32 (2001). https://doi.org/10.1016/S0160-9327(00)01338-7
8. Kluzer, S., et al.: DigComp into action, get inspired make it happen a user guide to the European Digital Competence framework (2018)
9. Lu, J.J., Fletcher, G.H.: Thinking about computational thinking. ACM SIGCSE Bull. **41**(1), 260–264 (2009)
10. Mannila, L., Nordén, L., Pears, A.: Digital competence, teacher self-efficacy and training needs. In: Proceedings of the 2018 ACM Conference on International Computing Education Research, pp. 78–85. ACM (2018)
11. Nordén, L., Mannila, L., Pears, A.: Development of a self-efficacy scale for digital competences in schools. In: IEEE/ASEE Frontiers in Education Conference (2017)
12. Palumbo, D.: Programming language/problem-solving research: a review of relevant issues. Rev. Educ. Res. **60**(1), 65–89 (1990)
13. Papert, S.: Mindstorms: Children, Computers, and Powerful Ideas. Basic Books Inc., New York (1980)
14. Pears, A., Daniels, M.: Developing global teamwork skills: the runestone project. In: Castro, M., Tovar, E., Auer, M.E. (eds.) IEEE EDUCON 2010 The Future of Global Learning in Engineering Education (2010)
15. Peel, A., Friedrichsen, P.: Algorithms, abstractions, and iterations: teaching computational thinking using protein synthesis translation. Am. Biol. Teach. **80**(1), 21–28 (2018)
16. Perkins, D.N., Salomon, G.: Are cognitive skills context-bound? Educ. Res. **18**(1), 16–25 (1989)
17. Robins, A.V., Fincher, S.A.: The Cambridge Handbook of Computing Education Research. Cambridge Handbooks in Psychology. Cambridge University Press, Cambridge (2019)
18. Robson, E., Stedall, J.: The Oxford Handbook of the History of Mathematics. OUP Oxford, Oxford (2008). google-Books-ID: IieQDwAAQBAJ
19. Seery, N., Gumaelius, L., Pears, A.: Multidisciplinary teaching: the emergence of an holistic STEM teacher. In: 2018 IEEE Frontiers in Education Conference (FIE), pp. 1–6. IEEE (2018)
20. Tedre, M.: The Science of Computing: Shaping a Discipline. Taylor & Francis, Boca Raton (2014)
21. Vuorikari, R., Punie, Y., Gomez, S.C., Van Den Brande, G., et al.: DigComp 2.0: The Digital Competence Framework for Citizens, June 2016
22. Wing, J.M.: Computational thinking. Commun. ACM **49**(3), 33–35 (2006)
23. Wing Jeannette, M.: Computational thinking and thinking about computing. Philos. Trans. Roy. Soc. A: Math. Phys. Eng. Sci. **366**(1881), 3717–3725 (2008). https://doi.org/10.1098/rsta.2008.0118