

The Long and Winding Road from the Intended to the Attained, from the Ideal to its Realization: Evaluating K-12 Computer Science Curricula

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Abstract. K-12 computer science (CS) education has gained momentum globally, leading to diverse curricula. Evaluating the extent to which such curricula achieve their goals is essential yet highly complex. This paper presents a framework for evaluating K-12 CS curricula, adopting a processive perspective in which a curriculum is viewed as an evolving entity, whose seed is the policymakers' vision and whose fruits are its outcomes. The framework explores this evolution through the prism of educational goals, both cognitive and affective, building on established models from curriculum theory. We developed the framework while evaluating a national 4th-grade CS curriculum, which we employ to demonstrate how the framework leads to research questions and methodological decisions, and how it enables the identification of gaps that may divert a curriculum from its goals. The framework offers a structured yet flexible approach for investigating specific curricula, facilitates cross-national comparisons, and supports evidence-based improvements in CS education.

Keywords: evaluation; curriculum; curriculum representations; k-12 computer science education; primary school.

1. Introduction – how the story started

In 2016, the Ministry of Education in our country announced the introduction of computer science (CS) and robotics as a new primary school subject. This decision was based on viewing CS as a discipline whose fundamental ideas, concepts, and skills are important for everyone in the 21st century. Generally, this new subject was intended to promote acquiring a core knowledge of CS (hence, essentially more than mere programming), and a basic knowledge of robot-centered system design. It aimed at promoting the development of algorithmic and system thinking, as well as a set of abstraction, analysis and design skills, which are widely employed in CS problem solving. Having a clear focus on CS, the new

* Corresponding author. This research was part of Ph.D. research conducted at the Weizmann Institute of Science.

subject did not involve information and communication technology (ICT) or computer literacy (which are already included in another nationally designated subject for primary schools, starting from the first grade).

As a research group that deals with the teaching and learning of CS, we considered the introduction of this new primary school subject as a major milestone in CS education in our country, where CS had been taught as an elective subject in high schools for a few decades already (Gal-Ezer et al., 1995) and had been incorporated into middle schools for several years, mostly as part of a national ongoing endeavor for promoting excellence in mathematics, science, and technology (Zur Bargury, 2012; Zur-Bargury et al., 2013). We were of course aware of the two basic challenges that lay ahead of the new subject: first, the young age of the students, specifically, their cognitive development level; second, the fact that usually primary-school teachers are generalist teachers who teach several subjects and most of them lack CS knowledge. Taking these challenges into consideration, we were interested in the new subject for its own sake as well as serving as a first link in an entire educational CS spiral, both cognitively and affectively. We asked ourselves questions such as what CS knowledge will the students possess as a result of learning this new subject, in terms of scope, conceptual understanding, robustness, and transferability? Will they develop new thinking patterns and skills related to computational thinking? How will learning the new subject affect the student's conception of the nature of CS as a discipline? How will learning the new subject affect their attitudes, motivation, and views regarding CS as a discipline, profession, and school subject? Would it increase the number of students who take CS in high school, or perhaps the other way around? Would it introduce new challenges to middle- and high-school educators, challenges such as stubborn misconceptions or self-efficacy issues, formed during the learning of the new primary-school subject?

The formal curriculum for the new subject was published by the Ministry of Education in 2016, including a one-year CS module for the 4th grade and a one-year CS and robotics module for the 5th grade. Each of these two modules consisted of 60 hours. In addition, there were two optional 30-hour modules. The first was intended for schools interested in extending the CS knowledge and skills of students during the 4th-5th grades, and the second was intended for the 6th grade. The 4th-grade module as well as the two optional modules utilized Scratch; the 5th-grade module involved robotics activities combined with Scratch. Specifically, the 4th-grade curriculum introduced the basics of algorithmics, including topics such as input and output, logical expressions, variables, conditional execution, and iterative execution. Since the 4th-grade curriculum utilized Scratch, it also incorporated concepts of event-driven programming, including communication between agents and concurrency. In the 5th grade, the curriculum expanded to systems that integrate algorithmics and technology, through simple robotics-based system design, and included topics such as systems and sub-systems, control, sensors, dual-motor motion, control systems and intra-system communication, combined with technological applications in Scratch and robotics. The elective advanced CS module provided opportunities for handling more complex problems, in terms of scope and algorithmic level, extended iterative execution, and included a final project. The 6th-grade elective module introduced

procedural design (utilizing Scratch user blocks) and featured advanced problems, compared to those problems included in the first two modules.

The curriculum was published as a single, yet very extensive and long formal document, comprising about 260 pages (excluding references). This document began with several opening statements from policymakers, followed by three sections dedicated to the 4th, 5th, and 6th grades, which together included all four modules. Of these four modules, the two basic modules for the 4th and 5th grades comprised the largest part, with about 90 pages each. Although lengthy, their content was not textbook-like. Rather, they contained a detailed description of the corresponding parts of the curriculum, including worked examples for the benefit of the teachers.

The Ministry of Education started to implement the new curriculum in the 2017/18 school year, in about 300 schools. At about that time we decided to initiate a wide research project to evaluate the curriculum and its effects. More specifically, and in line with the challenges mentioned above as well as the questions specified above that interested us at this point, we aimed to examine two facets, the teachers' and the students', with respect to both cognitive and affective aspects. Namely, we were interested in examining (1) the teachers' CS knowledge, their self-efficacy as teachers of the new subject, their motivation to teach it, and other affective factors that may influence their teaching; (2) how learning the subject affected the students' CS conceptual knowledge and skills, their attitudes toward the new subject and toward CS, and their motivation to pursue CS studies further at the K-12 educational system or beyond.

We planned to complete the first phases of the research, from the formulation of the research questions, and including the design of the methodology, the preparation of research tools as well as the recruitment of schools and teachers, by the beginning of the following school year, being ready then to start data collection. This turned out to be a very interesting year, bringing about a process that fully matured a little later, during the first stages of the data collection. As a result of the insights we have gained during this process, at its completion we ended up in a rather different place from where we had started, in terms of our perception of the planned study. In a way, this paper will tell the tale of this process. More precisely, the purpose of this paper is to present the framework that shaped our curricular evaluation and that developed during this process. However, we believe that the insights that we have gained during this process and that impacted the gradual formation of the framework can also contribute to its understanding and benefit its employment. Hence, the story is almost as important as its moral. In line with this, the metaphoric theme of a story will occasionally surface throughout the paper.

But first, let us say something about the importance of the moral, that is, the value of the framework to the CS education research community. First, its generality makes it useful for guiding multi-facet evaluations of different CS K-12 curricula as well as more focused evaluations regarding specific facets. It supports both conceptual and methodological aspects of designing the evaluation. Furthermore, it is structured; thus, it also facilitates comparisons between different curricula, and concomitantly it is flexible, allowing researchers

to adapt it to their own research and educational foci. Therefore, it can help researchers identify the strengths and weaknesses of specific CS curricula. Moreover, as we will see later, it is process-oriented, namely, underlying it is a perception of a curriculum as an evolving entity. Hence, it can also help researchers identify some stumbling blocks or hurdles that led to such weaknesses, thus supporting evidence-based improvements of CS K-12 curricula and of K-12 CS education in general.

The rest of the paper is organized as follows: Section 2 tells the next chapter of the story, in which we reexamined our initial research intentions, which were briefly described above, and shaped our research focus and goals. Section 3 elaborates on some relevant literature, and Section 4 tells another chapter – our quest for an appropriate theoretical model of a curriculum. Section 5 describes the framework and its properties. Finally, Section 6 concludes our story.

2. Context and rationale

After deciding to conduct the research, we began to organize our research interests and goals. One of our decisions was to focus on the 4th-grade curriculum. Although this decision is certainly important for the specific research we were planning, we will not discuss it further here. This section deals with two other issues that were debated and have gradually shaped the focus of the research. The first concerned assessment standards, and the second concerned interpreting the concept of a curriculum.

As mentioned in the introduction, we were interested in examining the implementation of the curriculum regarding both the students' and the teachers' facets. Our interest in the first facet was straightforward – the students are the 'end-clients' of the curriculum; therefore, any assessment of the curriculum should explore how they are affected by learning according to it, both cognitively and affectively. In addition, being aware that the teachers are a key factor in any in-school curricular initiative, and considering their probable lack of CS knowledge, the importance of the second facet was clear.

Regarding the students, our original approach was based on several goals of K-6 CS education that were compiled from the literature and were compatible with our own educational views. These goals included (Armoni & Gal-Ezer, 2014) (1) fostering a reliable image of the nature of CS, since many, including K-12 students and their parents, hold an inaccurate image of the discipline. (2) Positively affecting students' attitudes towards CS. (3) Motivating students to pursue computing in higher education. (4) Promoting the acquirement of basic CS knowledge, including meaningful age-appropriate learning of CS concepts and fundamental ideas. The first and the fourth goals are cognitive, and the other two goals are affective.

These goals would lead to the development of external standards, against which the outcomes of the curriculum could be evaluated. However, we decided to change our approach and instead adopt an internal one. That is, we chose to examine whether the 4th-grade CS curriculum achieves its intended educational goals. To this end, a first phase, or an auxiliary research goal should be to identify these goals.

Hence, at that point, three viewpoints started to form: (1) the educational goals of the curriculum, as intended by the curriculum's initiators; (2) the outcomes of the curriculum, as reflected in students' knowledge and other related measures; and (3) the teachers – as agents who are both affected by the curriculum and affect its outcomes.

These viewpoints naturally led to the well-known theoretical perspective of curriculum representations (van den Akker, 2013; van den Akker, 2003), namely the perception of a curriculum as an entity with several representations, the most basic of which are the three representations of the intended curriculum, the implemented curriculum, and the attained curriculum (Valverde et al., 2002). This perspective (on which we elaborate further in Section 3) indeed proved useful for our research goal; however, the basic tripartite model was insufficient for our context. In Section 4, we describe our search for an appropriate model anchored in the perspective of curriculum representations, but first, we lay the grounds by providing the relevant background and related research literature.

3. Background

Next, we will provide the relevant background, starting with a short description of K-12 CS education worldwide (Section 3.1) and then will move to the body of research on K-12 CS curricula (Section 3.2). Last (Section 3.3), we will refer to the theoretical perspective of curriculum representations, which was briefly mentioned above, and to its use in the context of K-12 CS curricular research.

3.1 K-12 CS Curricula Around the World

The integration of CS education into K-12 curricula has gained significant momentum worldwide, driven by the growing recognition of computational thinking as a fundamental skill for the digital age. International organizations such as the OECD (Bers et al., 2022) and the European Union (Caspersen et al., 2018; Council of the European Union, 2024) have emphasized the importance of early exposure to CS, leading to national and regional efforts to introduce computing concepts as early as the primary school level. According to Code.org's 2021 Annual Report, as of 2021, over 70 countries have introduced CS education into their primary and secondary school systems (Code.org, 2021). K-12 CS education is a constantly active arena, which has extended to include more countries, and in which programs are constantly extended, updated, or replaced at national or lower levels.

The motivation for adopting CS curricula varies; yet a common goal across this global trend is to equip students with computational and problem-solving skills that will prepare them for an increasingly digitalized world (e.g., in South Korea, Neethipudi et al., 2021; Brazil, Ribeiro et al., 2023; and India, Shah, 2018). Another prevalent motivation sees CS education as a tool for social mobility, particularly in disadvantaged communities (e.g., Ribeiro et al., 2023).

The introduction of K-12 CS education varies significantly across countries in terms of curricular structure and instructional focus. Some countries (e.g., Greece, Lithuania, and

Serbia) have established CS as a standalone subject (European Education and Culture Executive Agency [EACEA], 2022), whereas others (e.g., Sweden, Finland, France, and Turkey) have embedded (mostly at the lower age levels) CS principles across various disciplines to enhance their real-world applicability (EACEA, 2022; Partanen et al., 2017).

The starting age for CS education varies significantly between countries. For example, in England, computing has been a statutory subject from age 5 since 2014, so that algorithms and simple programming are taught from the first year of primary school (Sentance & Csizmadia, 2017), whereas in Bulgaria and Romania it starts in the third and sixth grades, respectively (EACEA, 2022). In contrast, some countries, such as the United States and Canada follow a decentralized model, where local policies and school district decisions influence when and how CS is introduced. This results in significant variability in the starting age and depth of CS education across different regions (Canada Learning Code, 2020; Code.org, 2024).

Countries vary in whether CS education is compulsory or elective. For example, in Japan, CS education is now mandatory in primary, middle, and high schools (Sprenger et al., 2024), whereas in India, CS education is offered primarily as an elective subject, with regional flexibility in its implementation (Shah, 2018). In Croatia it is optional in the first four grades and compulsory in the fifth and sixth grades (EACEA, 2022). The UK, as mentioned above (Brown et al., 2014), mandates computing from ages 5 to 16, whereas the US exhibits state-by-state variability, with some states requiring CS and others having it optional (Code.org, 2024).

The curricular focus of CS education also differs. First, in many countries (e.g., England and Lithuania) the subject that is dedicated to CS (whether named CS, computing, informatics, or a similar name) is in fact broader than CS, also combining ICT topics that deal with the use of digital tools. In Australia and New Zealand, the subject that covers CS is in fact discipline-based and it is separated from ICT (Australian Curriculum, Assessment and Reporting Authority, 2022; Bell et al., 2010) even though its name – Digital Technologies – may seem to suggest otherwise.

Second, countries may vary in the role that programming plays in the CS curriculum. In many countries (EACEA, 2022), programming (sometimes referred to using the more technical term of ‘coding’) is considered a core element of CS education; however, in some countries programming is at the center, making CS education actually programming education, whereas others treat programming as part of algorithmic problem solving and aim at teaching the latter, including programming. In line with this perspective, the CS curricula of some countries (e.g., Lithuania) incorporate non-programming initiatives such as Bebras (Combéfis & Stupurienė, 2020; Vinikienė et al., 2023), by which students engage with algorithmic concepts through problem-solving activities that do not involve actual programming.

This diversity in curricular focus has meaningful implications for how the field of computer science is understood in schools. A narrow focus on coding may reduce CS to a vocational skillset, whereas an overlap with ICT (by content or name) may dilute its scientific

identity. In contrast, curricula that emphasize algorithmic thinking and problem solving tend to frame CS as an intellectually rigorous discipline, akin to mathematics or the natural sciences. These varied approaches shape not only classroom instruction, but also how students engage with and pursue further studies in computer science.

A common cross-national challenge faced by most countries that have decided to integrate CS education into K–12 curricula concerns the shortage of teachers with adequate subject-specific knowledge (e.g., Code.org, 2023, 2024; Ni et al., 2023; The Royal Society, 2017). Most of the existing teaching workforce lacks a strong background in CS, let alone the pedagogical content knowledge that is needed to effectively teach the subject. Consequently, the successful implementation of K-12 CS education is frequently hindered by a lack of teacher preparedness and confidence. Hence, many countries invest considerable efforts in trying to bridge the gaps in professional knowledge, which are especially prevalent among primary-school teachers whose current standard training does not include CS knowledge. For example, in the Canton Vaud in Switzerland, the introduction of CS into primary schools was accompanied by a formal mandatory 2-year professional development program initiated by the canton Minister of Education and organized at the canton level (El-Hamamsy et al., 2021). In England, the National Centre for Computing Education (NCCE), established with Department for Education funding in November 2018, plays a role in teacher training, providing curriculum-linked resources, online professional development, and a network of local computing hubs (Fowler & Vegas, 2021; Sentance, 2024). The NCCE also offers teacher certification (Fowler & Vegas, 2021).

3.2 *Research on K-12 CS Curricula*

The vast growth of K-12 CS education is clearly reflected in the body of research on K-12 CS curricula, which has been growing rapidly, partly by extensive efforts of different international research working groups. Roughly speaking, several kinds of publications on K-12 CS curricula can be found: The first includes publications on principles and perspectives that guide the development of K-12 CS curricula (e.g., Dagienė et al., 2021; Webb et al., 2017). The second kind focuses on specific new curricula, presenting and examining their different aspects from different perspectives. Among these publications, to name but a few, are the following that deal with CS curricula in the Netherlands, New Zealand, Australia, Italy, Israel, Poland, and Latvia (Barendsen et al., 2016; Bell et al., 2010; Falkner et al., 2014; Forlizzi et al., 2018; Gal-Ezer & Harel, 1999; Sysło & Kwiatkowska, 2015; Vezis & Krumins, 2019). The third kind compares the curricula of different countries from different perspectives (e.g., Committee on European Computing Education, 2017; Dagienė et al., 2013; Maiorana et al., 2020; Oda et al., 2021; Schulte et al., 2012).

In 2011, an ITiCSE working group aimed to promote efforts to collect, evaluate, and integrate research findings on K-12 (specifically, secondary schools) CS in different countries. To this end, this working group developed a model (in fact, a category system) – the Darmstadt Model (DM) – by which researchers can relate to secondary CS education in different countries using common concepts and terminology, thus supporting the transfer

of research results across national or regional boundaries (Hubwieser et al., 2011). The DM is an adaptation and expansion of the long-standing Berlin Model (Uljen, 1997) into the context of CS. The DM is a very fine-grained 3-dimensional model that can be used to catalog, describe, and classify all aspects of information available for a CS education system in a specific country/region. The first dimension consists of three super-categories that together can characterize such a CS education system: its preconditions, decisionareas, and consequences. The second DM dimension includes the levels of responsibilities or ranges of influence that enable examining a CS education system at different resolutions, from the very high-resolution student level to lower-resolution levels, such as the school level, the district level, and the national level. The third dimension includes the many issues and aspects that are directly relevant or relate to CS education systems, such as the organizational structure of the school system, the teachers' qualifications, students' enrollment, certain content areas of the subject-matter knowledge, competencies, gender make-up, and so on. One can use the DM to specify all kinds of information regarding CS education in a specific country (or region). For example, that in a certain country the curriculum designers decided that developing abstraction abilities is a learning goal of K-12 CS education, and also decided that the middle-school CS content includes the topic of concurrency, whereas in high school the CS topic of computational models is elective at the school level but not at the student level; that research results indicate that currently one of the consequences of middle-school CS education in that country is an unbalanced gender makeup of high-school CS students' enrollment and therefore, the stakeholders decided to include balanced gender-related attitudes as an educational goal of CS education already from primary school; or that in that country learning-by-doing and discovery learning are leading educational strategies; therefore, they set a precondition to which K-12 CS education must adhere. The developers of the DM model recommended using it for structured descriptions of K-12 CS education in different countries, thus supporting comparisons. Later, the DM model was used by Hubwieser (2012) to describe CS secondary education in Bavaria, Germany. Thereafter, the journal *ACM Transactions on Computing Education* decided to dedicate two special issues (14(2) and 15(2) from 2014 and 2015, respectively) to K-12 CS education worldwide, featuring papers that used the DM to describe CS K-12 education in different countries. These included, for example, papers that addressed the UK (Brown et al., 2014), France (Baron et al., 2014), US-Georgia (Guzdial et al., 2014), India (Raman et al., 2015), South Korea (Choi et al., 2015), and North-Rhine Westphalia, Germany (Knobelsdorf et al., 2015). Overall, 14 papers from 2012, 2014, and 2015 employed the DM to describe K-12 CS education in 15 countries/states. In 2015, these 14 papers were analyzed and compared by another ITiCSE working group (Hubwieser et al., 2015) regarding several aspects that are addressed by the DM (e.g., educational goals, competencies, learning content, and assessment).

The DM is indeed a powerful tool that enables the presentation and comparison of K-12 CS education across countries regarding multiple aspects. It can be used in a flexible manner, thus potentially yielding very fine-grained analyses, but at varying degrees of richness and elaboration. However, its rich nature is also a weakness. It refers to all aspects of K-12 CS curricula; they are all there. Moreover, it acknowledges that educational programs do not

exist in isolation but instead are shaped by broader social, technological, and institutional factors. Concomitantly, by using the DM, curricula are dissected into multiple components, which may be mixed among additional educational information, possibly resulting in a panoramic view of many trees that at the same time may lack forest-like perspectives.

Other descriptive or comparative studies used additional, different perspectives to examine various aspects of K-12 CS curricula. For example, Larke (2019) used Ball and Bowe's model of the cycle of educational curricular policies (Ball & Bowe, 1992) to investigate England's national computing curriculum. Ball and Bowe defined a "policy cycle" that moves between policy arenas, differentiating between the intended policy, namely, the official ideologies that aim at affecting policies, the actual policy as written in law and official standards, and the policy-in-use as practiced by educators. Larke views teachers as "gatekeepers" and examines which aspects and components they "let in" and which ones they withhold, based on their views and beliefs. This perspective of policy cycles seems to be reminiscent of the tripartite model mentioned above, on which we elaborate in the next section, but they are derived from different theoretical frameworks. A Koli-2012 working group (Schulte et al., 2012) with a follow-up by Dagienė et al. (2013) also focused on the current state of CS curricula, namely, their implementation in schools, comparing curricula from 22 countries. To this end, they used a survey intended for K-12 CS education scholars close to their national school system, which included questions on content, educational goals, teaching methods, challenges, and the support available for teachers.

Pasterk and Bollin (2017) compared six CS curricula for primary schools, presented as detailed curricula (from UK, Australia, and Switzerland), as educational standards (of CSTA and from Germany), or as competency models (from Austria). Each curriculum was then described by a graph with annotated vertices and directed labeled edges, where a vertex corresponds to one intended learning outcome (that refers to a single knowledge item) and the edges represent the relations "required-by" and "expanded-by". Then, several graph metrics were employed. This enabled a comparison of the curricula regarding their main focus, central knowledge items, complexity, and structure. Duncan and Bell (2015) compared CS curricula published in English for ages 5-14: the CSTA's standards and curricula from England and Australia. Their comparison focused only on the subject matter content of six topics (algorithms, programming, data representation, digital devices and infrastructure, digital applications, humans and computers) across age levels.

3.3 Curriculum Representations and their Employment in Disciplinary Educational Studies

The basic tripartite model of curricular representations (Figure 1), which was briefly mentioned in Section 2, was developed as part of the longitudinal efforts of the International Association for the Evaluation of Educational Achievement (IEA), which was established at the end of 1950s and initiated the comparative assessment studies that later evolved into the TIMSS (Trends in International Mathematics and Science Study) ongoing series of studies (Schmidt et al., 2018).

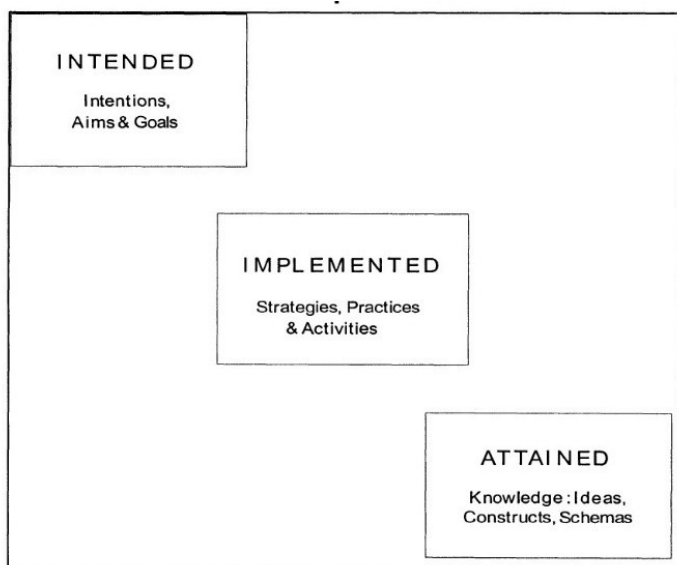
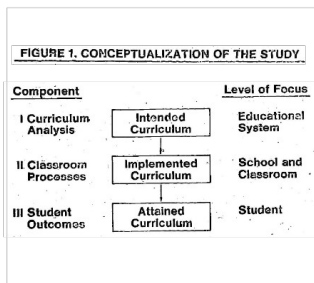


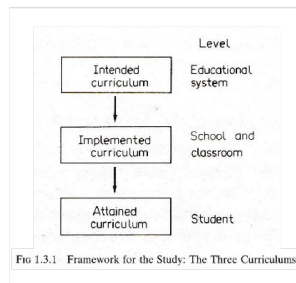
Figure 1. The IEA Tripartite Curriculum Model (originally Exhibit 1.1, Valverde et al., 2002, p. 5; *reproduced with permission from Springer Nature*. This figure is not included under the CC BY license of this article).

The IEA's initial motivation was to investigate the global role and impact of schooling, which is one of the central responsibilities of countries all over the world (Schmidt et al., 2018). Namely, does schooling succeed in its general goals of preparing students to be informed and responsible citizens who can in turn further contribute to the development of their countries? What criteria could be used by countries to determine how well they have done in this regard, that is, in providing effective education? The importance of comparative educational research that is based on empirical evidence was acknowledged in the early days of the IEA. The IEA's researchers were looking for methods to assess and compare students' performance across various educational systems worldwide and to relate students' achievements to the different aspects that together form and portray educational systems, aiming "to look at achievements against a wide background of school, home and societal factors" (Purves, 1989, p. v). The outcomes of such investigations can then serve "to instruct policy makers at all levels about alternatives in educational organization and practice" (Purves, 1989). National schooling was viewed as a "natural experiment" (Husén, 1967a, p. 65) whose inputs are educational policies and practices and whose central outputs are the students' academic achievements and attitudes toward education. Gradually, IEA has conceptualized schooling as a multi-level entity (Martin, 1996; McKnight, 1979; Travers & Westbury, 1989) that concerns three levels: the system level, the school (classroom) level, and the student level. This entity is concerned with providing the students with "opportunities to learn" (Husén, 1967b; Martin, 1996; Schmidt & Houang, 2003), which are decided upon by policymakers at the system level ("what is to be taught?") and implemented by instructors at the classroom level ("what is actually being taught?"). When preparing for the Second International Mathematics and Science Studies (SIMS

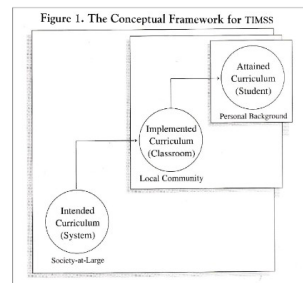
and SISS, respectively), the conceptualization of the studies stipulated the curriculum as a central variable, a broad explanatory factor that underlies learning outcomes. Therefore, it has three manifestations, one for each of the schooling levels, where each manifestation in fact defines a distinct object of investigation covered by a different part of the study (see Figure 2(a) and Figure 2(b)): the intended curriculum is contextualized at the educational system level and is investigated through curriculum analysis. It denotes the official, planned curriculum as delineated by policymakers, curriculum designers, or relevant educational authorities that specify what should be taught. It includes goals, objectives, and content outlines, as publicized by official syllabi, curriculum guides, and textbooks. The implemented curriculum—often referred to as the actual or enacted curriculum—is contextualized at the school and classroom level and encompasses what teachers actually do and cover in the classroom. It should be investigated by analyzing data that concern classroom teaching processes. In the IEA studies (e.g., Burstein, 1992; Schmidt & Cogan, 1996), it was operationalized by means of school and teacher questionnaires, which collected multiple data about school characteristics (e.g., size and composition), and teachers' characteristics, including age, gender, education, pre- and in-service training, pedagogical beliefs, attitudes, restrictions imposed on teachers (e.g., can they choose the textbooks? Is there a final external exam?), and the opportunities to learn that they provide to their students regarding each test item. The attained curriculum is contextualized at the student level and captures what students learn and can demonstrate, including knowledge, skills, and attitudes. It is investigated by analyzing students' outcomes on achievement tests and attitude questionnaires. This three-curricula conceptualization was adopted again, with slight modifications, for the Third International Mathematics and Science Studies (hereafter denoted by TIMSS-95, since the original acronym TIMSS now serves the ongoing international assessments that followed; Robitaille et al., 1993) (see Figure 2(c)).



(a)



(b)



(c)

Figure 2. The IEA Tripartite Curriculum Model, as defined for SIMS and TIMSS-95 (permission for reuse is granted by IEA).

- The SIMS conceptual model as depicted in McKnight (1979), p. 17
- The SIMS conceptual model as depicted in Travers and Westbury (1989), p. 6
- The TIMSS-95 conceptual model as depicted in Robitaille et al. (1993), p. 9

As evident in Figure 2 by the arrows included in all three drawings, there is an underlying order relation between the three manifestations of the intended, implemented, and attained curricula, which is absent from the visualization in Figure 1 (from Valverde et al., 2002), which is also a TIMSS-95-related publication. However, as described in the SIMS formal publications (Travers & Westbury, 1989) and in other IEA publications that followed (e.g., Martin & Kelly, 1996; Robitaille et al., 1993), the three curricula were viewed as three different co-existing embodiments or strands that are investigated independently.

Some discrepancy between the three embodiments is natural. For instance, changes in scheduling, local contexts, varying teacher expertise and beliefs, as well as instructional preferences can cause differences between the intended and implemented curricula, namely, between classroom instruction and official guidelines. Similarly, minor modifications may enrich the learning process by adapting curriculum goals to students' needs. However, significant gaps can undermine the realization of curricular objectives (Schmidt, 1992). For example, if teachers lack core competencies or misinterpret key concepts, the attained curriculum may diverge substantially from the intended aims. Conversely, strong teaching approaches sometimes compensate for less comprehensive official guidelines, resulting in better-than-expected attainment.

The tripartite model has also been extensively employed outside IEA studies to analyze curriculum dynamics across multiple educational domains (e.g., Gamoran et al., 1997; Kurz et al., 2010). In computing education, it was mostly used for comparative studies that compared curricula across countries. For example, an ITiCSE-2015 working group (Barendsen et al., 2015) used the tripartite model when exploring how CS concepts are addressed in K-9 CS intended, implemented, and attained curricula across several countries. They analyzed four K-9 computing curriculum documents (of CSTA, The CAS organization in the UK, England and Italy) to learn which CS knowledge areas were included in these intended curricula and to what extent. To gain insights into the implemented curricula, they interviewed 13 teachers from England and Italy about their classroom practice, focusing on three knowledge areas. Regarding the attained curricula, they did not investigate students' performance. Rather, they explored which concepts students' performance is assessed on and how it is assessed. This was done in two ways:

First, in the interviews, the teachers from England and Italy were also asked about their assessment methods. Second, the authors studied the assessment conducted via Bebras contests¹ by analyzing Bebras tasks over 5 years, examining which concepts were assessed by means of these tasks and how.

A few years later, another ITiCSE working group (Falkner et al., 2019b) set out to compare implemented K-12 computing curricula across countries. They developed a designated extensive instrument, METRECC, which could actually collect wider data also concerning the intended curricula. METRECC consists of a country report template and a teachers' survey. The country report should be filled in by a survey administrator who is responsible for collecting data from one country. It was designed to extract information about the

¹ <http://bebras.org>

intended curriculum in that country as well as some background and aggregated information about its implemented curriculum. The teachers' survey should be administered by the survey administrator of a certain country to in-service computing teachers in that country, to learn about the implemented curriculum in their classrooms including some personal relevant data (such as teachers' qualifications and self-esteem). It also collected information regarding teachers' professional development and its impact on classroom practice. METRECC was piloted and validated in seven countries (Australia, England, Ireland, Italy, Malta, Scotland, and the US); members of the working group acted as survey administrators of their own countries, collecting data from about 250 teachers in total. Later, the authors reported on some of the findings that emerged from the pilot study in two publications: The first (Falkner et al., 2019a) compared some aspects of the intended curricula across the seven countries and compared the adherence of some aspects of the implemented curricula in these countries to the intended ones. The second publication (Vivian et al., 2020) focused on teachers' self-esteem. The METRECC instrument was used in another study (Tshukudu et al., 2023), which compared K-12 computing education in four African countries.

Sprenger et al. (2024) investigated the intended and implemented CS curricula in Japan. To this end, they qualitatively analyzed official documents of the Japanese Ministry of Education and the transcripts of interviews with four teachers.

Rutstein et al. (2019) studied the implementation of the K-12 Exploring Computer Science (ECS) curriculum and specifically aimed at identifying the predicting factors for teachers' implementation of certain instructional strategies and for their extent of adapting the curriculum materials as well as the relationship between the teachers' implementation and students' outcomes. Data were obtained via designated surveys that asked teachers about their background, their professional development, and their use of certain instructional strategies when teaching the curriculum and also via summative assessment tools to evaluate students' outcomes. Curriculum enactment was operationalized only by examining the number of topics teachers modified, skipped, and added during each curricular content unit.

4. Another chapter of the story – the quest for the model

4.1 The perspective of curriculum representations

As was briefly mentioned in Section 2, when looking for a theoretical basis for the research, the well-known tripartite model (Figure 1), a simple utilization of the perspective of curriculum representations, was a natural starting point. As mentioned in Section 1, the formal curriculum published by the Ministry of Education was very detailed and long, including explanations of its knowledge content components as well as resources that can be used by teachers in class. Even after our decision to focus only on the basic 4th-grade curriculum, the corresponding part in the formal document consisted of about 90 pages. Possibly, this was done to cater to the future teachers, who were assumed to lack content

knowledge of the discipline (let alone pedagogical content knowledge). As noted in Section 3.3, in the original tripartite model, written embodiments of the intended curriculum are considered as part of the intended curriculum representation. That is, the formal curriculum document can represent the intended curriculum. However, in practice, written embodiments such as textbooks are often realizations of the policymakers' intentions that are carried out by others; hence, they may misrepresent the intentions that the policymakers had when they decided to include CS as a mandatory primary school subject. This was the case in our context; the policymakers delegated the task of producing this document to an educational CS author. Namely, a large part of the curriculum was in fact a potentially different representation of the intended curriculum.

This additional refinement could be well accommodated by a somewhat different model (Schmidt et al., 1997; Valverde et al., 2002), an extension to the tripartite model that was composed as part of the analyses of TIMSS-95. In the refined model, an additional curriculum representation, named the potentially implemented representation and defined as "Textbooks and other organized resources materials" was added to the original tripartite model, as shown in Figure 3. Such resources are designed to serve the teachers in class, namely, they take the view of the implemented curriculum. However, only their actual use by teachers can be considered as part of the (many and different) real implemented curricula. At the same time, as we just argued, they do not fully belong to the system level, and may deviate from the intended curriculum. Hence, the new representation is placed between the intended and implemented representations. As shown in Figure 3, it may also partly overlap them. The existence and extent of an overlap (to any of the two adjacent representations) can express additional relevant information. For example, when such a document constitutes a formal publication of the educational system (as was the case in our specific study) or is authorized by it, it can be seen as an expression of communication between decision makers, curricular developers, and the authors. Hence, a partial overlapping with the intended curriculum is in place. When in-service teachers are also contacted (or even involved in writing the document), then the document also expresses (to some extent) an authentic in-class teaching experience and an overlap with the implemented curriculum is appropriate.

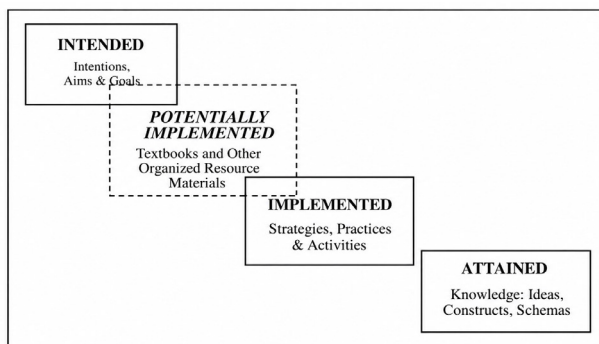


Figure 3. The extended tripartite curriculum model (originally Figure A.1 in Schmidt et al., 1997, p. 178; used with permission of Springer Nature BV; permission conveyed through Copyright Clearance Center, Inc. This figure is not included under the CC BY license of this article)

The formal elaborated curriculum published by the Ministry of Education in our country could certainly be considered as an organized resource; therefore, we decided to replace the tripartite model with its 4-component extension. However, it was not too long before we realized that the search for an appropriate model had not ended and that it may even require a change of perspective.

4.2 A processive perspective on curriculum representations

As could be expected, since CS was a new subject in primary schools in our country, and primary-school CS teacher preparation tracks were still unavailable in universities and colleges, alternative paths for teacher training were necessary. As clearly follows from Section 3.1, this constitutes a major challenge faced by most of the countries that embark on adding CS as a new K-12 subject, especially at the primary-school level. Regarding the primary-school CS curriculum in our country, similar to other countries, the Ministry of Education offered a professional development program intended for primary-school teachers of other subjects (with potentially no knowledge in CS whatsoever). Planning such designated training programs is a complex endeavor. For example, ideally, such training should address the urgent issue of the lack of content knowledge but it should also provide the new teachers with a core of CS pedagogical content knowledge. In practice, the nature of such teacher training, in particular, its content, is affected by various factors, such as the number of hours that can be allocated for it. In any case, teachers' training clearly plays a substantial role when introducing a new curriculum for a new subject, and even more so when misconceptions regarding the nature of the underlying discipline and its essence are so prevalent, as is the case for CS.

The significance of this role became even more evident, as we started preparing for an empirical in-school phase for the following school year and contacted teachers who were participating in the first year of implementing the new subject, which was then taking place. We learned that the teachers had been referring to the ministerial training as a formal authorized source of information and knowledge; furthermore, many of them did not look for and read the formal elaborate curriculum, namely, the training was their sole source of knowledge. It became evident that the training and its materials are yet another representation of the curriculum that expresses the trainers' interpretations of the formal elaborate curriculum, and as always is the case with interpretations, they might not be fully compatible.

Apparently, this discrepancy between the model and reality could be remedied quite easily without any change of perspective, by adding another component to capture the training representation of the curriculum, placed between the potentially implemented and the implemented curricula. However, we decided not to do that, since in our view, a lack greater than an omitted representation had surfaced. A model is an abstraction, and hence by definition, it emphasizes certain facets of the modeled entity, while not emphasizing or even ignoring others. At this point of the quest, we started to think that essentially the standard perspective of curricular representations is too basic in terms of the facets it emphasizes.

As described in Section 3.3, this perspective especially emphasizes the facet of variability, namely, there are several agents that engage with a curriculum and each of them holds a version of the curriculum that is affected by that agent's interpretations, or in other words, there is always more than one version of the curriculum. This perspective yields a modular model that may easily accommodate new agents. However, we preferred a processive perspective that also expresses the facet of change, and thus views a curriculum as a dynamic evolving entity, rather than a static collection of representations. This entity has a clear origin or seed – the policymakers who initiated its existence – and a target audience, namely, the students. The road to the target audience is indirect, involving several mediating entities, each of which has its own impact. This processive, dynamic perspective seems to be more appropriate for a constructive assessment of a curriculum, as it allows for the identification of points along the way at which alterations occurred and subsequently introduced incompatibility with the original intentions, aims, and goals.

An evolutionary, processive perspective assumes a progression axis, along which the evolution process takes place. Namely, there is an underlying order relation, for example, the goals, aims, and intentions of the policymakers precede the writing of the elaborate curriculum. Similarly, teacher training may affect the teachers' conceptual understanding and thus affect their interpretation of the curriculum, i.e., the teacher training precedes the implemented curriculum. However, such a perspective involves more than merely using one of the original visualizations of the tripartite model (Figure 2), or a similar 4- or 5-component one, which includes directed arrows between the representations. We find this modification too simplistic. Rather, a processive perspective should acknowledge the inherent complexity introduced by the agents, the human mediators who drive the curricular evolution, by further refining their parts in the model, thus allowing for capturing changes that relate to one agent. For instance, the teachers' perceptions of the curriculum may differ from their actual implementation of it, but this cannot be captured by the simple, coarse 3-, 4-, or 5-component models that include one representation for each agent.

The literature on curriculum design and evaluation offers several more refined models, which possibly include more than one representation per agent. For example, the 5-component model that includes the following five representations (Goodlad & Associates, 1979): (1) the ideal curriculum, which describes the policymakers' original views; (2) the formal curriculum, which describes the curriculum as presented in formal documents; (3) the perceived curriculum, which describes the curriculum interpreted by the teachers; (4) the operational curriculum, which describes the curriculum delivered by the teachers; and (5) the experiential curriculum, which describes the curriculum as experienced by the students. In this model, both the 3rd and 4th representations relate to the same agent – the teachers.

Some other models (van den Akker, 2003) include the representation of the learned curriculum, which like the experiential curriculum, relates to the students, but unlike the subjective experiential curriculum, it represents the actual learning outcomes. Several additional suggestions for additional representations can also be found in the literature (van den Akker, 2003).

Figure 4 depicts another refined model, the typology of curriculum representations (van den Akker, 2003), which groups related representations, resulting in a hierarchical structure of layers and sub-layers, which in our opinion better fits the combination of in- and between-agent complexities. It has three layers that correspond to the intended, implemented, and attained curricula. At the intended layer, it distinguishes between the original vision of the policymakers and its realization in the form of the formal written curriculum. At the implemented layer, it differentiates between the curriculum as interpreted by teachers and the curriculum-in-action, i.e., the actual teaching process. At the attained level, this model differentiates between learners' subjective learning experiences and the objective cognitive outcomes of the learning process. An implicit order relation exists between and within layers, by their order of appearance, with the exception of the last layer for which the dependencies between the two sub-layers of the experiential and learned curricula do not necessarily comply with an order relation.

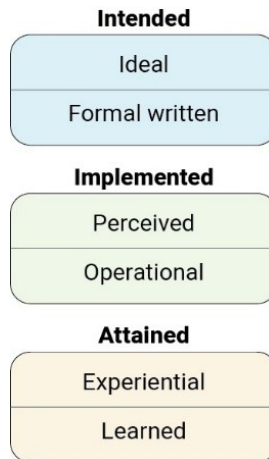


Figure 4. The typology of curriculum representations

The partitions within the implemented and the attained layers capture agent-specific aspects, i.e., the teachers and the students, respectively. The first partition addresses the transition between the policymakers' views and their realization as a written formal document by a different agent; thus, essentially nothing is lost by choosing the typology model over the 4-component version of the tripartite model. However, similar to the 4-component model in Figure 3, the typology model in Figure 4 does not include components that concern teacher training; hence, it suffers from the same drawback – it does not fit the situation that is internationally common for CS: a new school subject for which pre-service teacher preparation paths are scarce at best and therefore a designated training for teachers of other subjects is necessary, playing an important role in the evolution of the new curriculum. However, now the required modification is simple, resulting in the 4-layer typology model presented in Figure 5. The new (second) layer corresponds to the teacher training; the upper part represents the curriculum as perceived by the teacher trainers, and the lower part represents the implementation of the teacher training and its teaching materials. For the

second layer we chose the name processed curriculum (rather than a more specific tailored name such as the training curriculum), thus making it somewhat more generic and suitable for other situations in which the evolution is affected by some other new mediating agent whose interpretation of the formal written curriculum leads to another representation.

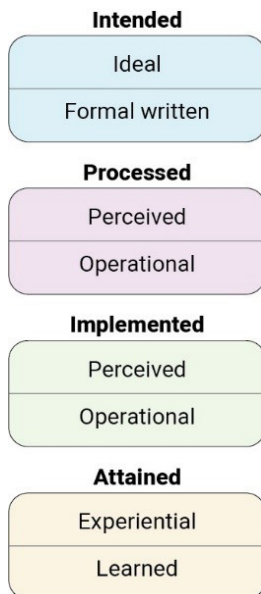


Figure 5. The four-layer version of the typology of curriculum representations

We see another difference between the original or the extended tripartite models (Figs. 1-3) and the processive model of Figs. 4 or 5. In the IEA models the implemented curriculum represents the classroom level, and covers various aspects, e.g., teachers' educational background, beliefs, attitudes, and practice. Consistently, as noted in Section 3.3, the implemented curriculum was operationalized in the IEA studies by extensive questionnaires, which collected rich data regarding the teachers and their practice. The TIMSS-95 publications (Martin, 1996) emphasized this by formulating four general research questions, of which the first ("what are students expected to learn?") and the fourth ("what have students learned?") correspond to the intended and attained curricula, respectively, and the second and third questions both address the implemented curriculum ("who provides the instruction?" and "how is instruction organized?"). The second question concerns the "characteristics of the teaching force [...] (education, experience, attitudes and opinions)" (Martin, 1996, p. 1-5) and the third concerns the ways "teachers go about instructing their students (what teaching approaches do they use, and what curricular areas do they emphasize)" (Martin, 1996, p. 1-5). In contrast, the processive models in Figs. 4 and 5 emphasize the adherence (or deviation) of the implemented curriculum to the intended curriculum, both as the teachers perceive it and teach it. Using this perspective, teachers' affective factors are implicit. We saw the need to further extend the model presented in Figure 5, so it would explicitly address affective aspects, such as self-efficacy, motivation, and attitudes, which we find very important, potentially influencing the success of every curriculum.

For example, consistent with Bandura's framework of self-efficacy, teachers' self-efficacy regarding their understanding of the curriculum might affect their performance as teachers who teach it, namely, their in-class practice (Bandura, 1986, 1997; Pajares, 1997), and hence also the curriculum's learning outcomes. Other teacher-related affective factors (such as motivation and attitudes) may affect the teachers' future professional decisions, and hence also the future of the curriculum. We believe that the teacher-related affective aspects are especially relevant in the context of primary-school CS, since, as noted above (see Section 1), primary-school teachers are often generalist teachers who teach several subjects and most of these teachers lack CS knowledge. Hence, they may face a substantial challenge when required to teach a CS curriculum, thus amplifying affective impacts. Similarly, student-related affective factors may lead to undesired affective effects, such as low self-esteem.

The model in Figure 5 can accommodate student-related affective factors in the attained experiential layer. However, an explicit extension is required for the teacher-related affective factors. To this end, we chose to partition the implemented perceived layer into two parts: the implemented perceived cognitive part, addressing the teachers' perceived knowledge, and the implemented perceived affective part.

Last, we wanted to explicitly express the processive perspective by clarifying the order relations between the components of the model, when such relations exist. To this end, we first added arrows between the intended layer and the processed layer, between the processed layer and the implemented layer, and between the implemented layer and the attained layer (similar to Figure 2(a)-(c)). Within layers, the order relation is depicted by the vertical spatial order of appearance. In line with this and since by definition there is no order relation between the attained experiential curriculum and the attained learned curriculum, we chose to modify the graphic representation of the attained layer, depicting two parts side-by-side, similar to the graphic representation of the implemented perceived layer. The resulting model is depicted in Figure 6. We also chose to change the name of the model entirely, to a name that expresses the change of perspective to a processive one, the 4-layer processive model for curriculum evolution (the 4LPCE model). The complete definition of all layers is as follows:

The intended ideal layer: The vision of the policymakers regarding the curriculum, including any educational goals they set.

The intended formal written layer: The curriculum as published in formal documents, including official syllabi, curricular guides, and content-related information.

The processed perceived layer: The curriculum as perceived by the teachers' trainers.

The processed operational layer: The actual implementation of the teacher training.

The implemented perceived layer:

1. The cognitive part: Teachers' perceptions and interpretations of the curriculum.
2. The affective part: Teachers' motivation, self-efficacy, attitudes, and intentions regarding the curriculum.

The implemented operational layer: The actual in-school implementation of the curriculum.

The attained layer:

- 1. The experiential part: The students’ learning experience of the curriculum, including their own perception of their knowledge, their motivation, attitudes, and intentions regarding the curriculum.
- 2. The learned part: The actual cognitive learning outcomes.

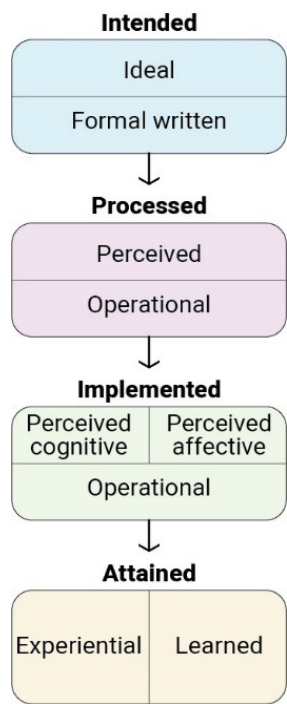


Figure 6. The 4-layer processive model for curriculum evolution (the 4LPCE model)

Taken together, the development of the 4LPCE model can be characterized as a selective, reflective synthesis of established perspectives on curriculum representations. We selected predecessor models according to the aspects of curricular evolution that were relevant to our research context: the IEA tripartite model provided the basic distinction between intended, implemented, and attained curricula; its extension in the TIMSS-related literature highlighted the mediating role of organized curricular resources; and the typology of curriculum representations provided a finer-grained distinction between representations within the intended, implemented, and attained levels that is consistent with a processive, evolving perspective instead of the former perspective that emphasized variability. We then made several conceptual operations in response to features that emerged from our research context: introduced an explicit teacher-training layer as a mediating stage between the formal curriculum and teachers; further differentiated teacher-related cognitive

and affective representations and the two attained facets; and specified the order relations between the layers and sub-layers. Thus, the 4LPCE model is an elaboration of established curriculum-representation approaches, shaped through their reflective synthesis with the requirements of the research context, rather than a claim that curriculum interpretation, mediation, or development were previously unrecognized.

Next, we will describe how the new model naturally induces a flexible generic framework that allows for an analysis of the entire evolution of a new curriculum and fosters the identification of potential gaps or deviations from the curricular goals in the transitions between the layers and sub-layers.

5. The framework for evaluating K-12 CS curricula

The framework for evaluating K-12 CS curricula is based on the 4LPCE model and includes adequate research questions and research approaches. The key research question for a study that aims to fully evaluate a CS curriculum is: How is the evolution of the curriculum, from the ideal intended level to the attained level, exhibited by each of its players? The players are the policymakers, trainers, teachers, and students. In line with the 4LPCE model (Figure 6), this complex research question consists of the following sub-questions, which together form a chain that starts with the policymakers' vision, namely, the learning goals set by them, and ends with the learning outcomes (cognitive and affective).

The Intended layer:

1. (The Ideal layer) What is the policymakers' vision regarding the curriculum? Which educational goals do they set?
2. (The Formal written layer) How do the formal published curriculum documents reflect the policymakers' vision and educational goals?

The Processed layer:

3. (The Perceived layer) How do the teachers' trainers perceive the formal written curriculum? How does their perception reflect the content of the formal written curriculum?
4. (The Operational layer) How do the teachers' training content and materials reflect the trainers' perception of the curriculum?

The Implemented layer:

5. (The Perceived cognitive part) In what ways do the teachers understand, perceive, and interpret the curriculum following their training?
6. (The Perceived affective part) What are the teachers' motivation, self-efficacy, attitudes, and intentions regarding CS and the teaching of CS?
7. (The Operational layer) To what extent does the teachers' in-class implementation of the curriculum reflect the curriculum as they perceived it following their training? How do school- and teacher-related characteristics interfere with or support in-class practice?

The Attained layer:

8. (The Experiential part) What is the students' learning experience of CS as it was taught in class (their own perception of their CS knowledge, as well as their motivation, attitudes, or other affective aspects of their learning experience)?
9. (The Learned part) How do the students' learning outcomes reflect the curriculum as it was taught in class?

This is a flexible series that can be easily adapted to specific research goals and interests. First, although it was developed with an entire curricular evolution in mind, researchers can focus on partial phases by using only some of the layers and making some straightforward adaptations to the questions. Second, researchers may narrow the width of the investigation by modifying certain questions. For example, Research Question 6 can be modified by deleting the aspect of teachers' attitudes. Similarly, Research Question 7 can be modified by specifying certain school- or teacher-related characteristics. Third, researchers may extend the width of their investigation by adding additional questions to certain layers. For example, by adding a new question to the Attained layer, one can examine the students' backgrounds and their relationship with other student-related factors (e.g., attitudes or learning outcomes).

The above series of research questions, together with specific research contexts, naturally lead to research approaches and tools. In general, the Intended ideal layer is investigated through qualitative content analysis of any data that present the policymakers' vision (which can be collected through interviews, questionnaires, and document search); the Intended formal written layer is investigated through qualitative content analysis of the formal curricular documents. The Processed perceived layer is investigated by analyzing data that concern the teachers' trainers (which can be collected by means of interviews and questionnaires). The corresponding research approach may vary, depending on the number of teachers' trainers. The Processed operational layer is investigated by analyzing data concerning the implementation of the teachers' training program (collected via questionnaires, observations, or recordings of training sessions). Again, the corresponding research approach may vary, depending on the nature and volume of the data. For the Implemented layers (perceived and operational), one can take a qualitative, quantitative, or a mixed-method approach, depending on the size of the group of participating teachers and the choice of tools (qualitative tools such as interviews and class observations, or quantitative tools, such as questionnaires). Last, for the Attained layer a quantitative approach is appropriate (using affective and knowledge questionnaires for the experiential and learned parts, respectively) or a mixed-method approach, augmenting the data using qualitative tools such as interviews.

In our research project on the new primary-school CS curriculum, to obtain information on the vision of the policymakers, we turned to the three policymakers' statements that were included in the formal written curriculum as introductory essays (written by the head of the Joint Administration for Computerization, Technology and Information Systems (CTIS) in the Ministry of Education, the chair of the Ministry of Education's CS Committee, and the inspectorate of K-12 CS Studies). In addition, following the three essays, the formal

published curriculum included an introduction by the formal-written curriculum author, presenting his perspective on the rationale, principles, and goals of the curriculum. Taking a qualitative approach, the four essays constituted our data for the Intended ideal layer. We treated the three policymakers' statements as the primary source for identifying the policymakers' educational goals, while considering the author's introduction separately as an interpretation of the curriculum's rationale, principles, and goals. Themes appearing only in the author's account were not attributed to the policymakers. An alternative tool could be interviews with the policymakers, but we preferred the written statements, since in our case these interviews would necessarily have been retrospective, potentially affected by the actual implementation of the new curriculum, whereas the essays were written before the implementation started. We used a thematic inductive analysis, separately examining the policymakers' statements and the author's introduction.

For the Intended formal written layer, we also utilized the qualitative approach and used the published formal document of the curriculum, specifically the 90-page part of the 4th grade. Since the research question in this layer refers to the vision and goals of the policymakers, the qualitative analysis of the 90-page document had to refer to the themes that were found regarding the first question and thus consisted of several sub-analyses. For example, one of the themes found in the policymakers' statements was abstraction. Specifically, the policymakers presented the development of abstraction abilities as one of the learning goals. Hence, the document analysis of the formal-written layer explicitly referred to this theme. Based on the research literature, we defined a suitable deductive category system, which was then inductively extended, yielding a set of categories used for analyzing the reflection of abstraction in the formal written curriculum (Friebroon-Yesharim et al., 2023b). Our findings indicated that the formal written curriculum emphasized the level of programming, whereas the more abstract concept of an algorithm was not sufficiently stressed. Our analysis method captures the essence of algorithmic abstraction and can be easily used to analyze other elaborate formal written versions of K-12 curricula as well as accompanying textbooks. Similarly, the analysis of the policymakers' statements also revealed the theme of problem solving, as a central practice of CS. Hence, another component of the document analysis of the formal-written layer examined the reflection of problem solving (Friebroon-Yesharim et al., 2023a). Our findings indicated that CS problem solving was mostly interpreted as programming, thus potentially leading to an inaccurate image of CS. In this case too, the analysis method we developed can be used in the context of other K-12 CS curricula to characterize the treatment of CS problem solving in their elaborate formal written representation or any accompanying textbooks.

To examine the Processed layer, namely, the teacher training (Friebroon-Yesharim & Armoni, in preparation), we again used the qualitative approach. For the Processed perceived layer, we focused on one trainer, an experienced educator who was responsible for teacher training in the central part of the country covering about 70% of the schools that implemented the 4th-grade curriculum at the time of the research. We employed the clinical interview tool, aiming to investigate the perception of this teacher trainer regarding the content and goals of the formal curriculum, theme by theme. For the Processed opera-

tional layer, the data encompassed the slides and notes of six presentations, constituting all the training materials of the teacher training designed by the interviewee of the previous phase. These materials provide evidence of the content and emphases that the training was designed to cover, but they do not by themselves establish everything that was delivered, discussed, or experienced during the training sessions. We therefore used these materials as a documentary proxy for the operational layer and limited our interpretation accordingly.

For the Implemented perceived layer, when examining the teachers' understanding, perceptions, and interpretations of the curriculum, as well as their attitudes, motivation, and intentions, we again decided to use the qualitative approach, focusing on a relatively small number of teachers. We employed the qualitative clinical interview tool, conducting interviews with the teachers who participated in our study. Another possibility could be to use questionnaires to assess the teacher-related affective factors and the teachers' understanding of the curriculum. We preferred interviews over questionnaires, since we thought that the latter could be perceived by the teachers as tests and therefore would be too intimidating, especially for teachers who are new to the subject and whose self-efficacy may thus be lower. For the Implemented operational layer, examining the actual in-class implementation, we used the qualitative tool of class observations, conducted throughout the school year. Last, for the attained, student-related layer, the experiential and learned parts, we used both the qualitative and quantitative approaches, employing the tools of clinical interviews and questionnaires, respectively. For the experiential curriculum we used attitude questionnaires, whereas knowledge questionnaires were designed for the learned curriculum, operationalizing the themes that were found regarding the first layer, the Intended ideal layer, namely, the policymakers' vision.

In our research, the themes found in the first layer accompanied the study further throughout the layers, acting as a horizontal axis. They constituted the results of the first layer, whereas for all other layers they served as prisms, through which the entire educational process was examined. In line with this, the analysis of the first layer was fully inductive, starting with an empty set of categories, whereas in other parts the themes served as the basis of deductive analyses (inductively extended when appropriate) or as categories guiding the design of interviews and questionnaires. The set of themes included the themes of abstraction and problem solving mentioned above, as well as the following five themes:

- The conceptual knowledge: This theme included the development of algorithmic thinking and the learning of CS concepts.
- Interdisciplinary: The Policymakers highlighted the role of CS in enhancing the understanding of other scientific subjects such as mathematics, physics, and chemistry.
- Skills: skills such as peer learning, collaboration, decision-making, and critical thinking were mentioned, as well as creative thinking, communication, and meta-cognitive skills.
- The nature of CS: Exposing the students to the principles of CS, which constitute the scientific foundation of the discipline.
- Affective Factors: The policymakers aimed to make the first exposure to CS enjoyable and engaging, fostering curiosity and motivation for learning CS.

6. The end

We presented a framework that supports a multi-level investigation of K-12 CS curricula. This framework is built around a 4-layer processive model (the 4LPCE model, Figure 6). That is, our view of a curriculum is based on the framework of curriculum representations and the tripartite model (van den Akker, 2003), but extends it by incorporating a processive view. In this view, a curriculum is an evolving process that starts with the policymakers' vision and ends with the students who are learning according to the curriculum. In line with this view, this process is affected by mediating agents that have their own representations of the curriculum and whose representations act as media through which the curriculum passes, media that may support or hinder the achievement of the policymakers' vision. The framework starts by identifying the policymakers' vision, namely, the educational goals, and then follows these goals as they evolve through the media introduced by the mediating agents, identifying stumbling blocks, inconsistencies or gaps that may cause the curriculum to get off track regarding certain goals or make some goals unreachable by damaging paths that could lead to them. Thus, research that employs this framework is 2-dimensional, as themes identified in the research's first phase act as lenses that cut across the layers of the model.

In applying this framework, a difference between two successive representations should not in itself be interpreted as a failure of the curriculum. Such a difference may reflect a loss, a justified adaptation to a particular context, or an unresolved discrepancy; its educational significance requires additional contextual evidence. Likewise, the arrows in Figure 6 represent the processive order and possible mediation between representations and organize the corresponding research questions; they do not by themselves establish causal effects.

This framework addresses three mediating agents: (1) formal documentation of the curriculum, which may include elaborate content items and teaching resources; (2) trainers who plan and teach training sessions for teachers; and (3) teachers who implement the curriculum in their classrooms. Our own study of the primary-school CS curriculum introduced in our country, which employed this framework, identified how the formal written curriculum reflected a partial treatment of algorithmic abstraction and algorithmic problem solving, two aspects that were included in the policymakers' vision. That is, the two respective educational goals were interfered with, already in the first medium that they crossed.

Both the trainers and the teachers can affect the evolution of the curriculum by their own perceptions and interpretations of it and by their actual implementation of the curriculum. Specifically, one of the key points raised in the article is the significance of teachers' professional training in shaping the curriculum's evolution. It recognizes that trainers' perspectives and understanding of the subject matter play a crucial role in curriculum development. By extending known models and including a layer dedicated to teacher training in the proposed model, the 4LPCE model acknowledges the transformative impact of training on teachers' perception of the curriculum. This highlights the importance of investing in and developing comprehensive and effective teacher training programs to ensure the successful implementation of computer science curricula.

Based on the 4LPCE model, the framework induces a series of research questions (concerning cognitive as well as affective factors) that guide the exploration of the curriculum through its layers and sub-layers, from the policymakers' vision to the outcomes as they are reflected by the students' experiential and learned facets. However, the framework is flexible, and enables researchers to add, delete, or modify research questions. In addition, as we demonstrated above, the nature of the series of research questions calls for a variety of data collection tools and analysis methods, both qualitative and quantitative. For example, interviews, document analysis, observations, and questionnaires are proposed methods for collecting data from policymakers, curriculum planners, teacher trainers, teachers, and students. This comprehensive approach to data collection and analysis ensures a holistic understanding of the curriculum's impact on various stakeholders.

In the current global reality, in which K-12 CS education is a highly active arena that is increasingly present in more countries and spans wider age groups, this framework offers a valuable contribution. It can flexibly support K-12 CS curricular research, and specifically the assessment of K-12 CS curricula, examining the entire process of curricular evolution or some of its components. This framework can also accommodate comparative research, which compares different K-12 CS curricula of various contexts and across various countries.

Author statements

Acknowledgements and funding: This work was funded by Israel Science Foundation, Grant 556/18.

Ethics approval and consent: This manuscript does not report primary research involving human participants or identifiable personal data; ethics approval and informed consent were not required.

Data/materials availability: No empirical data or research materials were generated or analyzed for this paper.

Generative AI disclosure: ChatGPT was used to assist with language editing and refinement of selected paragraphs. The authors remain fully responsible for the content, accuracy, and integrity of the manuscript.

Author contributions: Both authors contributed equally to the theoretical development of the paper and to the preparation and revision of the manuscript. Both authors read and approved the final version of the manuscript.

References

- Armoni, M., & Gal-Ezer, J. (2014). Early computing education: Why? What? When? Who? *ACM Inroads*, 5(4), 54–59. <https://doi.org/10.1145/2684721.2684734>
- Australian Curriculum, Assessment and Reporting Authority. (2022). Digital technologies: F–10 curriculum (Version 9.0). <https://www.australiancurriculum.edu.au/>
- Ball, S. J., & Bowe, R. (1992). Subject departments and the ‘implementation’ of National Curriculum policy: An overview of the issues. *Journal of Curriculum Studies*, 24(2), 97–115. <https://doi.org/10.1080/0022027920240201>
- Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Prentice-Hall.
- Bandura, A. (1997). Self-efficacy: The exercise of control. W. H. Freeman.
- Barendsen, E., Grgurina, N., & Tolboom, J. (2016). A new informatics curriculum for secondary education in the Netherlands. In A. Brodnik & F. Tort (Eds.), *Informatics in schools: Improvement of informatics knowledge and perception* (pp. 105–117). Springer. https://doi.org/10.1007/978-3-319-46747-4_9
- Barendsen, E., Mannila, L., Demo, B., Grgurina, N., Izu, C., Mirolo, C., Sentance, S., Settle, A., & Stupurienė, G. (2015). Concepts in K–9 computer science education. In *Proceedings of the 2015 ITiCSE on Working Group Reports* (pp. 85–116). ACM. <https://doi.org/10.1145/2858796.2858800>
- Baron, G.-L., Drot-Delange, B., Grandbastien, M., & Tort, F. (2014). Computer science education in French secondary schools: Historical and didactical perspectives. *ACM Transactions on Computing Education*, 14(2), Article 11. <https://doi.org/10.1145/2602486>
- Bell, T., Andreae, P., & Lambert, L. (2010). Computer science in New Zealand high schools. In *Proceedings of the Twelfth Australasian Conference on Computing Education (ACE 2010)* (pp. 15–22). Australian Computer Society.
- Bers, M. U., Strawhacker, A., & Sullivan, A. (2022). The state of the field of computational thinking in early childhood education (OECD Education Working Papers No. 274). OECD Publishing. <https://doi.org/10.1787/3354387a-en>
- Brown, N. C. C., Sentance, S., Crick, T., & Humphreys, S. (2014). Restart: The resurgence of computer science in UK schools. *ACM Transactions on Computing Education*, 14(2), Article 9. <https://doi.org/10.1145/2602484>
- Burstein, L. (Ed.). (1992). *The IEA study of mathematics III: Student growth and classroom processes*. Pergamon Press.
- Canada Learning Code. (2020). Learning for the digital future: A pan-Canadian K–12 computer science education framework. https://k12csframework.ca/wp-content/uploads/Learning-for-the-Digital-Future_Framework_Final.pdf
- Caspersen, M. E., Gal-Ezer, J., McGettrick, A., & Nardelli, E. (2018). Informatics for all: The strategy. Informatics Europe & ACM Europe Council. <https://doi.org/10.1145/3185594>
- Choi, J., An, S., & Lee, Y. (2015). Computing education in Korea—Current issues and endeavors. *ACM Transactions on Computing Education*, 15(2), Article 8. <https://doi.org/10.1145/2716311>
- Code.org. (2021). 2021 annual report. <https://code.org/about/2021>
- Code.org. (2023). 2023 state of computer science education. https://code.org/assets/advocacy/stateofcs/2023_state_of_cs.pdf
- Code.org. (2024). 2024 state of computer science education. https://code.org/assets/advocacy/stateofcs/2024_state_of_cs.pdf

- Combéfis, S., & Stupurienė, G. (2020). Bebras based activities for computer science education: Review and perspectives. In K. Kori & M. Laanpere (Eds.), *Informatics in schools: Engaging learners in computational thinking* (pp. 15–29). Springer. https://doi.org/10.1007/978-3-030-63212-0_2
- Committee on European Computing Education. (2017). *Informatics education in Europe: Are we all in the same boat?* ACM. <https://doi.org/10.1145/3106077>
- Council of the European Union. (2024). Council recommendation of 23 November 2023 on improving the provision of digital skills and competences in education and training. *C/2024/1030*.
- Dagienė, V., Hromkovič, J., & Lacher, R. (2021). Designing informatics curriculum for K–12 education: From concepts to implementations. *Informatics in Education*, 20(3), 333–360. <https://doi.org/10.15388/infedu.2021.22>
- Dagienė, V., Jevsikova, T., Schulte, C., Sentance, S., & Thota, N. (2013). A comparison of current trends within computer science teaching in school in Germany and the UK. In *Informatics in schools: Local proceedings of the 6th International Conference ISSEP 2013* (p. 63). <https://d-nb.info/1218695722/34#page=65>
- Duncan, C., & Bell, T. (2015). A pilot computer science and programming course for primary school students. In *Proceedings of the Workshop in Primary and Secondary Computing Education (WiP-SCE '15)* (pp. 39–48). ACM. <https://doi.org/10.1145/2818314.2818328>
- El-Hamamsy, L., Chessel-Lazzarotto, F., Bruno, B., Roy, D., Cahlikova, T., Chevalier, M., Parriaux, G., Pellet, J.-P., Lanarès, J., Dehler Zufferey, J., & Mondada, F. (2021). A computer science and robotics integration model for primary school: Evaluation of a large-scale in-service K–4 teacher-training program. *Education and Information Technologies*, 26(3), 2445–2475. <https://doi.org/10.1007/s10639-020-10355-5>
- European Education and Culture Executive Agency. (2022). *Informatics education at school in Europe*. Publications Office of the European Union. <https://data.europa.eu/doi/10.2797/268406>
- Falkner, K., Sentance, S., Vivian, R., Barksdale, S., Busuttil, L., Cole, E., Liebe, C., Maiorana, F., McGill, M. M., & Quille, K. (2019a). An international comparison of K–12 computer science education intended and enacted curricula. In *Proceedings of the 19th Koli Calling International Conference on Computing Education Research* (pp. 1–10). ACM. <https://doi.org/10.1145/3364510.3364517>
- Falkner, K., Sentance, S., Vivian, R., Barksdale, S., Busuttil, L., Cole, E., Liebe, C., Maiorana, F., McGill, M. M., & Quille, K. (2019b). An international study piloting the MEasuring Teacher Enacted Computing Curriculum (METRECC) instrument. In *Proceedings of the Working Group Reports on Innovation and Technology in Computer Science Education (ITiCSE-WGR '19)* (pp. 111–142). ACM. <https://doi.org/10.1145/3344429.3372505>
- Falkner, K., Vivian, R., & Falkner, N. (2014). The Australian digital technologies curriculum: Challenge and opportunity. In *Proceedings of the Sixteenth Australasian Computing Education Conference (ACE '14)* (pp. 3–12). Australian Computer Society.
- Forlizzi, L., Lodi, M., Lonati, V., Mirolo, C., Monga, M., Montresor, A., Morpurgo, A., & Nardelli, E. (2018). A core informatics curriculum for Italian compulsory education. In S. N. Pozdniakov & V. Dagienė (Eds.), *Informatics in schools: Fundamentals of computer science and software engineering* (pp. 141–153). Springer. https://doi.org/10.1007/978-3-030-02750-6_11
- Fowler, B., & Vegas, E. (2021). How England implemented its computer science education program. Brookings Institution. <https://www.brookings.edu/wp-content/uploads/2021/01/How-England-implemented-its-computer-science-education-program.pdf>
- Friebroon-Yesharim, M., & Armoni, M. (in preparation). From the formal curriculum to the training room: The processed layer of a primary-school computer science curriculum. Manuscript in preparation.

- Friebronn-Yesharim, M., Ben-Bassat Levy, R., & Armoni, M. (2023a). Abstraction and problem solving in a CS curriculum for 4th grade. In *Proceedings of the 7th APSCE International Conference on Computational Thinking and STEM Education (CTE-STEM 2023)* (pp. 19–24). Asia-Pacific Society for Computers in Education.
- Friebronn-Yesharim, M., Ben-Bassat Levy, R., & Armoni, M. (2023b). Algorithmic abstraction in computer science curricula for primary schools: The case of a national curriculum for 4th grade. In *Proceedings of the 2023 Conference on United Kingdom & Ireland Computing Education Research (UKICER '23)* (pp. 1–7). ACM. <https://doi.org/10.1145/3610969.3611154>
- Gal-Ezer, J., Beeri, C., Harel, D., & Yehudai, A. (1995). A high school program in computer science. *Computer*, 28(10), 73–80. <https://doi.org/10.1109/2.467599>
- Gal-Ezer, J., & Harel, D. (1999). Curriculum and course syllabi for a high-school CS program. *Computer Science Education*, 9(2), 114–147. <https://doi.org/10.1076/csed.9.2.114.3807>
- Gamoran, A., Porter, A. C., Smithson, J., & White, P. A. (1997). Upgrading high school mathematics instruction: Improving learning opportunities for low-achieving, low-income youth. *Educational Evaluation and Policy Analysis*, 19(4), 325–338. <https://doi.org/10.3102/01623737019004325>
- Goodlad, J. I., & Associates. (1979). *Curriculum inquiry: The study of curriculum practice*. McGraw-Hill.
- Guzdial, M., Ericson, B., McKlin, T., & Engelman, S. (2014). Georgia Computes! An intervention in a US state, with formal and informal education in a policy context. *ACM Transactions on Computing Education*, 14(2), Article 13. <https://doi.org/10.1145/2602488>
- Hubwieser, P. (2012). Computer science education in secondary schools—The introduction of a new compulsory subject. *ACM Transactions on Computing Education*, 12(4), Article 16. <https://doi.org/10.1145/2382564.2382568>
- Hubwieser, P., Armoni, M., Brinda, T., Dagienė, V., Diethelm, I., Giannakos, M. N., Knobelsdorf, M., Magenheimer, J., Mittermeir, R., & Schubert, S. (2011). Computer science/informatics in secondary education. In *Proceedings of the 16th Annual Conference Reports on Innovation and Technology in Computer Science Education – Working Group Reports (ITiCSE-WGR '11)* (pp. 19–38). ACM. <https://doi.org/10.1145/2078856.2078859>
- Hubwieser, P., Giannakos, M. N., Berges, M., Brinda, T., Diethelm, I., Magenheimer, J., Pal, Y., Jackova, J., & Jasute, E. (2015). A global snapshot of computer science education in K–12 schools. In *Proceedings of the 2015 ITiCSE on Working Group Reports* (pp. 65–83). ACM. <https://doi.org/10.1145/2858796.2858799>
- Husén, T. (Ed.). (1967a). *International study of achievement in mathematics: A comparison of twelve countries* (Vol. 1). Wiley.
- Husén, T. (Ed.). (1967b). *International study of achievement in mathematics: A comparison of twelve countries* (Vol. 2). Wiley. <https://eric.ed.gov/?id=ED015130>
- Knobelsdorf, M., Magenheimer, J., Brinda, T., Engbring, D., Humbert, L., Pasternak, A., Schroeder, U., Thomas, M., & Vahrenhold, J. (2015). Computer science education in North-Rhine Westphalia, Germany—A case study. *ACM Transactions on Computing Education*, 15(2), Article 9. <https://doi.org/10.1145/2716313>
- Kurz, A., Elliott, S. N., Wehby, J. H., & Smithson, J. L. (2010). Alignment of the intended, planned, and enacted curriculum in general and special education and its relation to student achievement. *The Journal of Special Education*, 44(3), 131–145. <https://doi.org/10.1177/0022466909341196>
- Larke, L. R. (2019). Agentic neglect: Teachers as gatekeepers of England's national computing curriculum. *British Journal of Educational Technology*, 50(3), 1137–1150. <https://doi.org/10.1111/bjet.12744>

- Maiorana, F., Csizmadia, A. P., & Richards, G. M. (2020). P12 computing in Italy, England and Alabama, USA. In *Proceedings of the 21st Annual Conference on Information Technology Education (SIGITE '20)* (pp. 242–247). ACM. <https://doi.org/10.1145/3368308.3415376>
- Martin, M. O. (1996). Third international mathematics and science study: An overview. In M. O. Martin & D. L. Kelly (Eds.), *Third international mathematics and science study (TIMSS) technical report: Vol. 1. Design and development*. Boston College. <https://eric.ed.gov/?id=ED406418>
- Martin, M. O., & Kelly, D. L. (Eds.). (1996). *Third international mathematics and science study (TIMSS) technical report: Vol. 1. Design and development*. Boston College.
- McKnight, C. C. (1979). Model for the second study of mathematics (Bulletin 4). IEA.
- Neethipudi, B., Fares, K., Fowler, B., & Vegas, E. (2021). How South Korea implemented its computer science education program. Brookings Institution. https://www.brookings.edu/wp-content/uploads/2021/10/How-S-Korea-implemented-its-CS-program_FINAL.pdf
- Ni, L., Bausch, G., & Benjamin, R. (2023). Computer science teacher professional development and professional learning communities: A review of the research literature. *Computer Science Education*, 33(1), 29–60. <https://doi.org/10.1080/08993408.2021.1993666>
- Oda, M., Noborimoto, Y., & Horita, T. (2021). International trends in K–12 computer science curricula through comparative analysis: Implications for the primary curricula. *International Journal of Computer Science Education in Schools*, 4(4), 24–58. <https://doi.org/10.21585/ijcses.v4i4.102>
- Pajares, F. (1997). Current directions in self-efficacy research. In M. L. Maehr & P. R. Pintrich (Eds.), *Advances in motivation and achievement* (Vol. 10, pp. 1–49). JAI Press.
- Partanen, T., Niemelä, P., Mannila, L., & Poranen, T. (2017). Educating computer science educators online – A Racket MOOC for elementary math teachers of Finland. In *Proceedings of the 9th International Conference on Computer Supported Education (CSEDU 2017)* (Vol. 1, pp. 47–58). SCITEPRESS.
- Pasterk, S., & Bollin, A. (2017). Graph-based analysis of computer science curricula for primary education. In *2017 IEEE Frontiers in Education Conference (FIE)* (pp. 1–9). IEEE. <https://doi.org/10.1109/FIE.2017.8190610>
- Purves, A. C. (1989). Foreword. In K. J. Travers & I. Westbury, *The IEA study of mathematics I: Analysis of mathematics curricula* (pp. v–vi). Pergamon Press.
- Raman, R., Venkatasubramanian, S., Achuthan, K., & Nedungadi, P. (2015). Computer science (CS) education in Indian schools: Situation analysis using Darmstadt model. *ACM Transactions on Computing Education*, 15(2), Article 7. <https://doi.org/10.1145/2716325>
- Ribeiro, L., Foss, L., Da Costa Cavalheiro, S. A., Kniphoff Da Cruz, M. E. J., & De França, R. S. (2023). The Brazilian school computing standard. In *Proceedings of the 54th ACM Technical Symposium on Computer Science Education V. 1 (SIGCSE 2023)* (pp. 53–58). ACM. <https://doi.org/10.1145/3545945.3569863>
- Robitaille, D. F., Schmidt, W. H., Raizen, S. A., McKnight, C. C., Britton, E. D., & Nicol, C. (1993). *Curriculum frameworks for mathematics and science (TIMSS Monograph No. 1)*. Pacific Educational Press.
- The Royal Society. (2017). After the reboot: Computing education in UK schools. <https://royalsociety.org/computing-education/>
- Rutstein, D. W., Xu, Y., McElhaney, K., & Bienkowski, M. (2019). Developing implementation measures for K–12 computer science curriculum materials. In *Proceedings of the 50th ACM Technical Symposium on Computer Science Education (SIGCSE '19)* (pp. 321–327). ACM. <https://doi.org/10.1145/3287324.3287424>

- Schmidt, W. H. (1992). The distribution of instructional time to mathematical content: One aspect of opportunity to learn. In L. Burstein (Ed.), *The IEA study of mathematics III: Student growth and classroom processes* (pp. 129–145). Pergamon Press. <https://www.sciencedirect.com/science/article/pii/B9780080413716500146>
- Schmidt, W. H., & Cogan, L. S. (1996). Development of the TIMSS context questionnaires. In M. O. Martin & D. L. Kelly (Eds.), *Third international mathematics and science study (TIMSS) technical report: Vol. 1. Design and development*. Boston College. <https://timss.bc.edu/timss1995i/TIMSSPDF/TRall.pdf#page=101>
- Schmidt, W. H., & Houang, R. T. (2003). Cross-national curriculum evaluation. In T. Kellaghan & D. L. Stufflebeam (Eds.), *International handbook of educational evaluation* (pp. 979–995). Springer Netherlands. https://doi.org/10.1007/978-94-010-0309-4_54
- Schmidt, W. H., Houang, R. T., Cogan, L. S., & Solorio, M. L. (2018). *Schooling across the globe: What we have learned from 60 years of mathematics and science international assessments*. Cambridge University Press.
- Schmidt, W. H., McKnight, C. C., Valverde, G. A., Houang, R. T., & Wiley, D. E. (1997). *Many visions, many aims: A cross-national investigation of curricular intentions in school mathematics*. Vol.1. Kluwer Academic Publishers.
- Schulte, C., Hornung, M., Sentance, S., Dagienė, V., Jevsikova, T., Thota, N., Eckerdal, A., & Peters, A.-K. (2012). Computer science at school/CS teacher education: Koli working-group report on CS at school. In *Proceedings of the 12th Koli Calling International Conference on Computing Education Research* (pp. 29–38). ACM. <https://doi.org/10.1145/2401796.2401800>
- Sentance, S. (2024). Building a national center for K–12 computing education. *ACM Inroads*, 15(3), 29–41. <https://doi.org/10.1145/3679023>
- Sentance, S., & Csizmadia, A. (2017). Computing in the curriculum: Challenges and strategies from a teacher's perspective. *Education and Information Technologies*, 22(2), 469–495. <https://doi.org/10.1007/s10639-016-9482-0>
- Shah, V. (2018). CSpathshala: Computational thinking curriculum for K–12. <https://cspathshala.org/curriculum/>
- Sprenger, M., Leonhardt, T., Bergner, N., & Yamamoto, R. (2024). Computer science education – What can we learn from Japan? In *Proceedings of the 55th ACM Technical Symposium on Computer Science Education V. 1 (SIGCSE 2024)* (pp. 1279–1285). ACM. <https://doi.org/10.1145/3626252.3630810>
- Sysło, M. M., & Kwiatkowska, A. B. (2015). Introducing a new computer science curriculum for all school levels in Poland. In A. Brodnik & J. Vahrenhold (Eds.), *Informatics in schools: Curricula, competences, and competitions* (pp. 141–154). Springer. https://doi.org/10.1007/978-3-319-25396-1_13
- Travers, K. J., & Westbury, I. (1989). *The IEA study of mathematics I: Analysis of mathematics curricula*. Pergamon Press.
- Tshukudu, E., Sentance, S., Adelakun-Adeyemo, O., Nyaringita, B., Quille, K., & Zhong, Z. (2023). Investigating K–12 computing education in four African countries (Botswana, Kenya, Nigeria, and Uganda). *ACM Transactions on Computing Education*, 23(1), Article 9. <https://doi.org/10.1145/3554924>
- Uljens, M. (1997). *School didactics and learning: A school didactic model framing an analysis of pedagogical implications of learning theory*. Psychology Press.

- Valverde, G. A., Bianchi, L. J., Wolfe, R. G., Schmidt, W. H., & Houang, R. T. (2002). According to the book: Using TIMSS to investigate the translation of policy into practice through the world of textbooks. Kluwer Academic Publishers.
- van den Akker, J. (2003). Curriculum perspectives: an introduction. In J. van den Akker, W. Kuiper, & U. Hameyer, (Eds.), *Curriculum landscapes and trends* (pp. 1–10). Springer Netherlands. <https://doi.org/10.1007/978-94-017-1205-7>
- van den Akker, J. (2013). Curricular development research as a specimen of educational design research. In T. Plomp & N. Nieveen (Eds.), *Educational design research, part A: an introduction* (pp. 52–71). SLO.
- Vezis, V., & Krumins, O. (2019). New competencies-based curriculum of computing in general basic education schools in Latvia and its testing. *Baltic Journal of Modern Computing*, 7(3), 364–379. https://www.bjmc.lu.lv/fileadmin/user_upload/lu_portal/projekti/bjmc/Contents/7_3_04_Vezis.pdf
- Vinikienė, L., Dagienė, V., & Stupurienė, G. (2023). Introducing programming concepts through the Bebras tasks in the primary education. In T. Keane & A. E. Fluck (Eds.), *Teaching coding in K–12 schools* (pp. 145–156). Springer. https://doi.org/10.1007/978-3-031-21970-2_10
- Vivian, R., Quille, K., McGill, M. M., Falkner, K., Sentance, S., Barksdale, S., Busuttil, L., Cole, E., Liebe, C., & Maiorana, F. (2020). An international pilot study of K–12 teachers' computer science self-esteem. In *Proceedings of the 2020 ACM Conference on Innovation and Technology in Computer Science Education (ITiCSE '20)* (pp. 117–123). ACM. <https://doi.org/10.1145/3341525.3387418>
- Webb, M., Davis, N., Bell, T., Katz, Y. J., Reynolds, N., Chambers, D. P., & Sysło, M. M. (2017). Computer science in K-12 school curricula of the 21st century: Why, what and when? *Education and Information Technologies*, 22(2), 445–468. <https://doi.org/10.1007/s10639-016-9493-x>
- Zur Bargury, I. (2012). A new curriculum for junior-high in computer science. In *Proceedings of the 17th ACM Annual Conference on Innovation and Technology in Computer Science Education (ITiCSE '12)* (pp. 204–208). ACM. <https://doi.org/10.1145/2325296.2325347>
- Zur-Bargury, I., Pârv, B., & Lanzberg, D. (2013). A nationwide exam as a tool for improving a new curriculum. In *Proceedings of the 18th ACM Conference on Innovation and Technology in Computer Science Education (ITiCSE '13)* (pp. 267–272). ACM. <https://doi.org/10.1145/2462476.2462479>