Perspectives and Visions of Computer Science Education in Primary and Secondary (K-12) Schools

PETER HUBWIESER, Technische Universität München, Germany
MICHAL ARMONI, Weizmann Institute of Science, Israel
MICHAEL N. GIANNAKOS, Norwegian University of Science and Technology, Norway & Old Dominion University, VA, USA
ROLAND T. MITTERMEIR, Alpen-Adria-Universität Klagenfurt, Austria

In view of the recent developments in many countries, for example in the USA or in the UK, it seems that computer science education (CSE) in primary or secondary schools (shortly K-12) would have reached a significant turning point, shifting its focus from ICT-oriented to rigorous computer science concepts. The goal of this special issue is to offer a publication platform for soundly based in-depth experiences that have been made around the world with concepts, approaches or initiatives that aim at supporting this shift. For this purpose, the paper format was kept as large as possible, enabling the authors to explain many facets of their concepts and experiences in detail. Regarding the structure of the papers, we had encouraged the authors to lean on the Darmstadt Model, a category system that was developed to support the development, improvement, and investigation of K-12 CSE across regional or national boundaries. This model could serve as a unifying framework that might provide a proper structure for a well-founded critical discussion about the future of K-12 CSE. Curriculum designers or policy stakeholders, who have to decide, which approach an upcoming national initiative should follow, could benefit from this discussion as well as researchers who are investigating K12 CSE in any regard. With this goal in mind, we have selected six extensive and two short case-studies from the UK, New Zealand, USA/Israel, France, Sweden, Georgia/USA, Russia and Italy which provide an in-depth analysis of K-12 CSE in their respective country or state.

Categories and Subject Descriptors:
K.3.2 [Computer and Information Science Education]: Computer science education

General Terms: Human Factors

Additional Key Words and Phrases: Schools, Curricula, CS Education, K-12 Education

ACM Reference Format:

DOI:http://dx.doi.org/10.1145/0000000.0000000

1. INTRODUCTION

During the last few years, the focus of computer science education (CSE) in primary and secondary schools (shortly K-12) was shifted from computer and ICT applications towards rigorous academic computing in several countries or states, see e.g. (Bell, Andreae, & Lambert, 2010), (Brown et al., 2013), (Hubwieser, 2012). Accordingly, the students should learn basic concepts of computer science like algorithms or data structures instead of mere
user skills. In many places, initiatives and projects were launched to foster this change. For example in US, the activities of the CSTA yielded quite ambitious standards in 2011 (Tucker et al., 2011) and a disclosing comparison of CSE over the 50 states in 2010 (Wilson, Sudol, Stephenson, & Stehlík, 2010). The 10K Initiative aims at educating a substantial number of formally educated CS teachers, (Forbes, 2012), while the recent approaches of “Computational Thinking” (Wing, 2006), “(Astrachan & Briggs, 2012)” and “Exploring CS” (Goode & Margolis, 2011) aim at fostering the consolidation of K-12 CSE. Simultaneously, the British Royal Society has published its reveling report “(The Royal Society, 2012)”, which has inspired the broad and promising initiative “Computing at Schools” (Brown et al., 2013), while in New Zealand brand new computer science standards for schools were introduced from 2011 to 2013 (Bell et al., 2010). In contrary to these current activities, Israel (Gal-Ezer, Beeri, Harel, & Yehudai, 1995) and many eastern-European countries (Syslo, 2011), (Dagiene, 2008) were offering rigorous CS courses at schools for several decades already.

Obviously, these numerous and different initiatives produce many interesting ideas and amazing outcomes. Unfortunately, the respective publications are distributed over a broad variety of conference proceedings (e.g. SIGCSE, ITiCSE, ICER, ACE, KOLI, WiPCSE, and ISSEP) or journals (e.g. Computer Science Education, ACM Transactions on Computing Education, and Informatics in Education). Additionally, due to the comparably short paper format of most of the proceedings, the majority of those papers contain only a small part of the information about the respective initiative. Therefore, we have proposed this special issue theme to the editors-in-chief of TOCE in order to collect and present as much information as possible. For this purpose, we have invited extensive, detailed case studies about the situation and perspectives of CSE in a certain country or state. We aimed at a coherent issue, bringing forward concepts, approaches, strategies, experiences, or outcomes to improve the current K-12 computer science education. Additionally, we hope to bring the different communities together, triggering new dialogues and enabling the countries to learn from each other. The studies included in this issue could be used, for example, by national stakeholders arguing in favor of a subject of CS, by curriculum designers that have to decide which approach a coming national initiative should follow, by researchers developing a framework for further studies about computer science education in primary and secondary schools, or by teacher educators as a ‘look over the fence’.

2. THE STORY OF THIS SPECIAL ISSUE

The prologue of this special issue started in 2010 on a bus trip from the ICER conference in Aarhus, Denmark back to the Billund Airport, when Barbara Owens, former chair of SIGCSE, encouraged the associate editor of this issue to apply for a working group about K-12 CSE at the upcoming ITiCSE 2011 conference in Darmstadt. After getting the working group
“Computer Science/Informatics in Secondary Education” approved by the conference chairs, several colleagues that have been very active in this field for a long time gathered in Darmstadt in June 2011: Michal Armoni (Israel), Valentina Dagiene (Lithuania), Michail N. Giannakos (Greece), Roland Mittermeir (Austria), Torsten Brinda, Ira Diethelm, Maria Knobelsdorf, Johannes Magenheim, and Sigrid Schubert (all from Germany). The group was chaired by its initiator, Peter Hubwieser (Germany).

In preparation of the work at the conference, five members of the group had produced very detailed case studies about the situation and perspective of CSE in their respective country or state, covering 57 pages of text all together: Roland Mittermeir (Austria), Peter Hubwieser (Bavaria, a federal state of Germany), Michail N. Giannakos (Greece), Michal Armoni (Israel) and Valentina Dagiene (Lithuania).

Comparing those studies, the group found significant differences between the conception and the context of CSE from country to country, e.g. pertaining to organizational issues (e.g. mandatory, elective, orientation course), learning objectives (e.g. programming, data bases, HCI), teaching methods (e.g. traditional, project-based, collaborative) and several other more or less important aspects. The presumably most relevant of these differences was the amazing variety of K-12 school systems (see Fig 1).

![Fig. 1. Differences in the school systems of several countries (Hubwieser, 2013)](image)

Fig. 1. Differences in the school systems of several countries (Hubwieser, 2013)

Apparently, these substantial differences in many facets made it very difficult to transfer or even compare experiences from one country to another. Driven by these considerations, the group decided to develop a draft
framework for guiding further research and development in the field. This could enable the K-12 CS education community to assess the differences as well as the accordance of the conception, outcomes or context of any research in CSE in the future. As a first step towards this direction, the working group condensed the information of the five detailed case studies and developed a category system based on this, which was considered to comprise all factors that might be relevant for K-12 CSE across all regional or national boundaries. As a starting point, the group had chosen the Berlin Model of P. Heimann (originally published in German Heimann, Otto, & Schulz, 1965, in English by Uljens, 1997). The outcome of our work was a three-dimensional category system, called Darmstadt Model (DM) in honor of the location of the conference:

1. BerlinModel Top Dimension (ordinal scale):
   1. Preconditions,
   2. Decision Areas,
   3. Consequences

2. Level of Responsibility/Range of Influence (ordinal scale): the decision level of the regarded stakeholders with the following values:
   1. Student/Pupil,
   2. Class-room,
   3. School,
   4. Region,
   5. State,
   6. Country,

3. Educational Relevant Areas (nominal scale): issues that are directly relevant for educational activities. The categories of level 1 and level 2 of this dimension are listed in table 1.

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educational system</td>
<td>Organizational aspects of subject</td>
</tr>
<tr>
<td></td>
<td>Enrollment</td>
</tr>
<tr>
<td></td>
<td>School type</td>
</tr>
<tr>
<td>Socio-Cultural related Factors</td>
<td>History of ICT and Informatics in School</td>
</tr>
<tr>
<td></td>
<td>Age</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
</tr>
<tr>
<td></td>
<td>Social and Immigration Background</td>
</tr>
<tr>
<td></td>
<td>Family Socialization</td>
</tr>
<tr>
<td></td>
<td>Public opinion</td>
</tr>
<tr>
<td></td>
<td>Techno-economic development</td>
</tr>
<tr>
<td>Policies</td>
<td>Research and Funding Policies</td>
</tr>
<tr>
<td></td>
<td>Education Policies</td>
</tr>
<tr>
<td></td>
<td>Quality Management</td>
</tr>
<tr>
<td>Teacher Qualification</td>
<td>Teacher Education</td>
</tr>
<tr>
<td></td>
<td>Professional Experience</td>
</tr>
<tr>
<td>Motivation</td>
<td>Students</td>
</tr>
<tr>
<td></td>
<td>Teacher</td>
</tr>
</tbody>
</table>
Perspectives and Visions of Computer Science Education in Schools

<table>
<thead>
<tr>
<th>Intentions</th>
<th>Learning Objectives</th>
<th>Competencies</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>Computer Science</td>
<td>ICT</td>
<td></td>
</tr>
<tr>
<td>Curriculum Issues</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Examination/Certification</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teaching Methods</td>
<td></td>
<td>CSE</td>
<td>General Education</td>
</tr>
<tr>
<td>Extracurricular Activities:</td>
<td></td>
<td>Contests</td>
<td></td>
</tr>
<tr>
<td>Media</td>
<td>Technical infrastructure</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Textbooks</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tools</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Didactical software</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visualization software</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unplugged Media</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Haptic media</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The three dimensions of the model indicate and emphasize the complexity one has to deal with. For example, in a certain country students’ assessment policy (dimension 3) can be a constraint (dimension 1) in the school level (dimension 2), while in the region level (dimension 2) decisions (dimension 1) regarding students’ assessment can be taken. The model and the methodology of its derivation were described in detail in the working group report of the conference (Hubwieser et al., 2011). Later on, a slight adoption of the categories was proposed by (Hubwieser, 2013), see Fig. 1.
As soon as this model was constituted, the group realized that there would be a need for more case studies to validate, expand, or differentiate its categories. This motivated the idea of a special issue in which multiple, extended case studies could be published together. After elaborately confering with the editors-in-chief of TOCE, Josh Tenenberg and Robert McCartney, one such case study, exemplifying the kind of case studies we had in mind, was published in TOCE (Hubwieser, 2012). The author of this study was chosen to act as associate editor on behalf of the editors-in-chief, while Michal Armoni, Michail Giannakos and Roland Mittermeir agreed to join the editorial team as guest editors.

All together, we aimed at gathering the research community of this field, in order to brainstorm about the future of K-12 CS education and to learn from each other. Specifically, this issue should provide a platform where the CS education community could exchange experiences and ideas from national initiatives on K-12 CS education around the world.

The actual work on the special issue started with dissemination of the call for extended abstracts in February 2013. In response, many interesting proposals from 22 countries have been submitted, witnessing to the wide interest of the CS education community regarding K-12 CS education, and the worldwide extent of K-12 CS activities. A careful review process
resulted in a fine selection of papers, large enough to allow two special issues on this important subject. Six full and two short papers are included in this issue. Hopefully, a second issue is due to appear later this year.

3. THE PAPERS
The eight papers included in this special issue form together a rich and diverse collection of cases studies, representing a variety of countries (and continents), with various perspectives, various needs and constraints, and various CSE history.

3.1 United States and Israel
The first paper A Tale of two Countries: Successes and Challenges in K-12 Computer Science Education in Israel and the United States by Gal-Ezer and Stephenson compares the development and the current situation of K-12 computing curricula and standards in Israel and the United States. Although these two countries have substantial differences, such as the level of centralization of their educational system and pedagogical approaches, they share a number of challenges that the authors believe are likely to be encountered by other countries as well. The main challenges identified by the authors, include issues related to

1. the perceptions that respective actors (e.g., students, educators, policy makers) have of CS,
2. ways to improve and update CS curricula, and
3. how to ensure CS teachers’ knowledge and schools’ resources in order to better support the curriculum.

In particular, the authors summarized that both Israel and U.S. face the following challenges in K-12 computing education:

- the lack of understanding of CS as a scientific discipline,
- a curriculum that must be constantly reviewed and revised and being able to engage all students,
- ensuring that teachers have the technical, content, and pedagogical knowledge needed to teach CS, by providing ways for teachers to continually refresh and upgrade their knowledge,
- providing schools with access to the hardware, software, and resources they require in order to teach a rigorous, up-to-date computer science curriculum.

3.2 United Kingdom and New Zealand
The following block comprises two papers from Commonwealth that describe similar, country-wide initiatives that are driven by the academic community.
The first paper of this block, *Restart: The Resurgence of Computer Science in UK Schools* written by Brown, Sentence, Crick, and Humphreys, focuses specifically on Computing Education in *England* with brief descriptions of the similarity and divergence of the educational systems in Wales and in Scotland.

The history section explains that computing related instruction at school started in the eighties with a broad spectrum of computer related topics. Opposed to the situation in Eastern Europe (see the paper by Khenner and Semakin from Russia), and in line with the situation in many more affluent Western European countries (see the paper by Baron et al. from France), Computing declined to low-level educational goals such as making pupils or students Computer Literate. Presumably, this was caused by the relative inexpensive advent of PCs as well as by the deficiencies in the subject specific skills of teachers. As the related courses outcomes weren’t either intellectually challenging for good students nor did they qualify for admission to university, students’ interest and motivation declined.

The groundbreaking report (The Royal Society, 2012) caused significant political awareness and lead to initiatives of reintroducing Computing in schools with rigorous contents of Computer Science. The paper then describes the curriculum review 2012-2014 and the prescribed subject content for different age groups. The article describes in detail the issue of teacher qualifications and the recruitment of new teachers, as well as approaches for raising the competence levels of in-service teachers and the obstacles those are facing.

The third paper *A case study of the Introduction of Computer Science in NZ schools* by Bell, Andreae, and Robins describes the case of *New Zealand* – a country with a centralized education system, which has only recently modified its high school program to include rigorous computer science (as opposed to computer applications). The readers get the chance to learn about a rapid, still on-going process, and about the driving factors that initiated this process, influenced the system to embrace it, and enabled it. Such a rapid change poses significant challenges to all involved parties, notably curriculum designers, teachers and students, in all aspects (teaching, assessment, teacher preparation, etc.).

### 3.3 France and Sweden

On the other hand, the following two papers enjoy a perspective of more than 40 years. In France, as well as in Sweden, CS, at least in its narrowed form of computer programming, was present in secondary education since the 1960's. In both countries, these forty years or so have witnessed changes, in terms of the identity of the school subject of computing – progression, as well as regression. These two papers examine the identity of CS, as reflected in their national high school curricula. The tension be-
tween rigorous CSE and ICT-based courses is in the center of both case studies.

The paper about *Informatics Education in French Secondary Schools* by Baron, Drot-Delange, Grandbastien, and Tort describes a pendulum – swinging back and forth between CS (informatics) and ICT in France. Such a progressing-regressing process raises many interesting questions: what were the factors driving these swings? What were the effects of these swings on teachers, students and the place of the school subject in the national curriculum? After explaining the volatile history, the authors present a concept for a new CS course and preliminary research results.

The paper *Programming in School – look back to move forward* by Rolandsson and Skogh goes deep into the tension between rigorous CSE and ICT-based courses. In order to get deeper it narrows its focus on three decades – the 1970s, 1980s, and 1990s. What happened in Sweden during that period that has caused the shift from the programming school subject to the school subject of computer applications? The authors use lenses of curriculum theory, for delving into these historical processes. They use multiple sources, carefully analyzed historical sources – archived documents of various sorts – as well as interviews, to learn lessons from the past that can lead into future progress. The research illuminates the need to deeply understand the interplay between the different stakeholders and emphasizes the important role of teachers, specifically of teachers' knowledge.

### 3.4 Georgia, USA

The following paper *Georgia Computes! An Intervention in a US State, with Formal and Informal Education in a Policy Context* by Guzdial et al. presents the development and the outcome of a large six-year (2006-2012) project called “Georgia Computes!” (GaComputes), aiming mainly at broadening participation among women and minorities. This paper differs from the preceding ones in this issue regarding two aspects. First, it describes an initiative that is not focused primarily on the design of formal education or curriculum and second, it may not be considered as a case study in the narrower sense. However, we included the paper since the well-described project was designed and conducted aiming at improving Georgia’s K-12 CSE. Additionally, its outcomes have had direct effects on the K-12 CSE curriculum. Finally, the reported experiences might help other countries or states that intend to broaden participation in CSE.

The goal of GaComputes was to investigate the impact of early CS interventions on “pipeline” that is formed by the subsequent educational stages from Kindergarten to high school graduation. Based on quantitative evidence provided by a statewide survey, authors found that teachers receiving GaComputes professional development were more successful at motivating students to pursue computing into their undergraduate career. This was particularly the case for female students and members of un-
derrepresented groups. Although it turned out to be difficult to specify the influence of the interventions by GaComputes, the qualitative findings support the hypothesis that the interventions by GaComputes, located early in the pipeline, would have had a long-term impact.

In addition to the impact of those early interventions, GaComputes revealed certain particular challenges related with the K-12 CSE penetration regarding female and underrepresented minorities.

3.5 Short papers from Russia and Italy

At the end of this special issue, two short papers provide an overview over the situation in two countries that both played an outstanding role in the history of Europe for many centuries.

The short paper School subject “Informatics” (“Computer Science”) in Russia: Educational Relevant Areas by Khenner and Semakin summarizes the situation of K-12 CSE in Russia. Similar to other Eastern Europe countries, Russia introduced CS courses into K-12 education under the term “Informatics”. This short paper focuses on the 'third dimension' of the Darmstadt Model and describes CSE in Russia through the lens of the evolution of the subject, the regulatory norms formed by the Russian Federal Educational Standards, the learning objectives, the required learning outcomes, and the Unified National Examination in Informatics. To provide a comprehensible picture of K-12 CSE in Russia, the authors compared the required outcomes of “Informatics” courses with the recent K-12 CS Standards of the CSTA (Tucker et al., 2011). Interestingly, authors identified a strong correspondence between the intended learning outcomes of Informatics in Russian schools and these standards. Informatics courses belong to the core disciplines of Russian K-12 education. In addition, a state-sponsored system of education trains CS teachers and guarantees their knowledge and competences. It is noteworthy that the relatively high level of K-12 CSE in Russia is determined by a well-established system with a 30-year history.

The concluding short paper Informatics Education in Italian Secondary School by Bellettini, Lonati, Malchiodi, Monga, Morpurgo, Torelli, and Zecca provides a brief introduction to informatics-related education in Italian secondary schools. It focuses specifically on differences between the contents prescribed by ministerial decrees on the aim of Informatics education in different types of secondary schools (Lyceums, technical schools focusing on economics and those focusing on technology, vocational schools) and the reality one finds in classrooms. The reasons for those differences, manifested in a strong focus on ICT and ECDL-training can be found in the qualification of teachers, that may have obtained their degree in a broad spectrum of disciplines, Informatics/Computer Science being only one of them. The authors attempt to remove the resulting misconception by extra-curricular activities.
4. CONCLUSIONS

Despite the apparent differences, there are several topics that are addressed by the majority of those papers. First, proper teacher education in substantial extent and depth seems to be one of the most critical factors for the success of rigorous computer science education on the one hand and also one of the hardest goals to achieve on the other. Second, there is a convergence towards computational thinking as a core idea of the K-12 curricula. Third, programming in one form or another, seems to be absolutely necessary for a future oriented CSE.

Despite the fact that there have been several and important developments in K-12 CS education during the last years, there is still much that can be done, especially in K-12 educational systems with low CS subject integration. The contribution of this issue might foster this by exchanging experiences among countries and assisting national stakeholders and curriculum designers on their future decisions and plans. In this endeavor, the DM could be used as a common ground and allow researchers to better understand, compare and improve the value of their K-12 CS curriculum.

5. ACKNOWLEDGEMENTS

We would like to thank all members of the ITiCSE working group for their engagement and their hard work, as well as the TOCE editors-in-chief, Josh Tenenberg and Robert McCartney for their support and guidance throughout the special issue processes and Barbara Owen for the idea of the working group. We gratefully acknowledge the work of all our reviewers. Without their assistance this special issue would not have been possible.

6. REFERENCES


