The Darmstadt Model: A First Step towards a Research Framework for Computer Science Education in Schools

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Abstract. Due to the substantial differences of preconditions, circumstances and influence factors, it is often very difficult to compare or transfer research results in the field of Computer Science Education (CSE) in schools from one country to another. For this purpose we have started the development of a specific framework that, at the end, should reflect all factors that might be relevant for CSE. We collected five extensive case studies from five different countries and performed a qualitative text analysis on those, which was guided by the categories of the well-known Berlin Model as an initial theory. During the coding process we had to realize that this theory was not sufficient in many respects. At first, we noted that we had to deal with three different dimensions. Additionally, we found that we would need more categories, up to 70 at the end. The result of our coding process represents a first step towards the desired framework, that of course, has to be improved still a lot. This will be done by coding further case studies, extending, defining and explicating the categories.

Keywords: Computer sciene education, research framework, qualitative text analysis.

1 Introduction

As recent activities in several countries show, the awareness of the importance of rigorous computer science education (CSE) for a successful, self-responsive and self-deciding life in the modern world seems to grow. In the USA, for example, the *Computer Science Teacher Association* (CSTA) has released a new version of its K-12 curriculum in 2011 [1] that comprises 170 quite ambitious standards, while the 10k initiative "aims to address this fundamental challenge by developing effective and engaging new high school curricula in computing and getting that curricula into courses taught by 10,000 well-prepared teachers in 10,000 high schools" [2]. In the UK, the *Royal Society* has launched its recent initiative "Shutdown or Restart" [3] to improve CSE at schools, while New Zealand has introduced a new subject of Computer Science (CS) recently [4]. On the other hand, there are countries that had implemented such a rigorous CSE already in the 70ies or even earlier and have never stopped this yet, e.g. several eastern European countries [4]. Geographically in-between these two regions, some central European countries (as some German states)

I. Diethelm and R.T. Mittermeir (Eds.): ISSEP 2013, LNCS 7780, pp. 1–14, 2013.

are still sleeping deeply, believing that some funny ICT courses might be sufficient to prepare their students for a live in the information society.

Yet, in my opinion, all decisions of any country that aim to improve CSE should be made on the basis of empirically proven facts instead of personal beliefs or suggestions. After all, there is a mass of evidence, generated by several decades of empirical research in the field of CSE that has been published e.g. by the ACM Special Interest Group on Computer Science Education (SIGCSE) since 1970.

Nevertheless, as already a short glance on any volume of proceedings in this field reveals, those research projects were conducted under very different circumstances. The first problem regarding CSE in schools is that many of those empirical results were obtained at universities or colleges. Many of those might not be applicable to school education at all. As far as the research was conducted at schools, there are many factors that might be relevant for the applicability of the results in a different context. The research might have taken place in very different school systems (see Figure 1), in dedicated CS courses or in other subjects, observing students that have very different cultural or ethnic background.

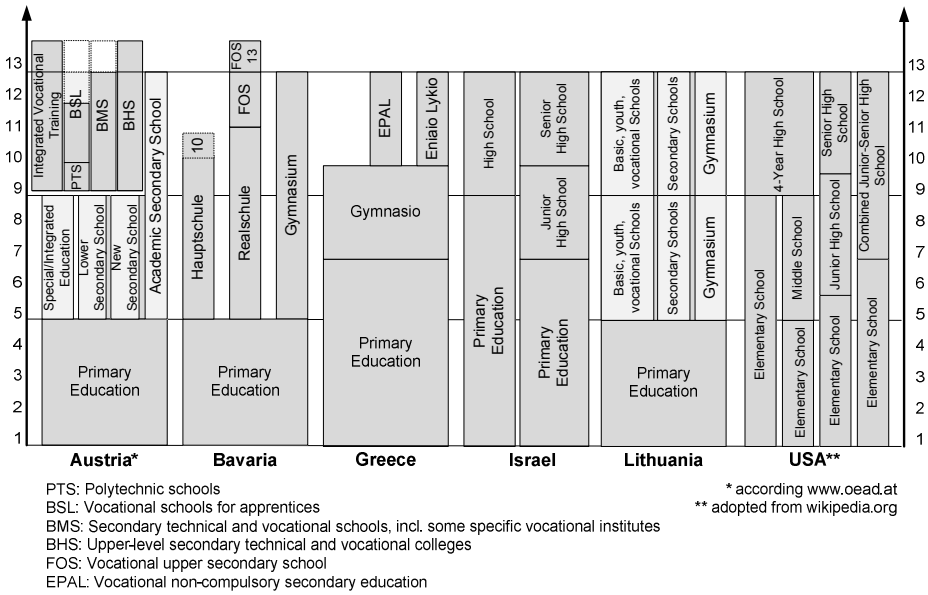

Fig. 1. Differences in the school systems of several countries

The type of school might be attended by all students of a certain age group or only by the "best" 20% (however those are selected). There might have been 10 students in the classroom or 35. The courses might have started with imperative programming, object-oriented modeling or by teaching software skills. The teaching methods might have been quite antiquated or very up to date. The teachers might have had a solid background in CS or none at all. Most importantly, the observed courses might have

had very different goals: preparing for university, teaching key competencies or attracting the most talented students. Regarding the research at university courses that might be applicable to the school context anyway, there are additional deciding factors. The courses might be attended by majors, others by non-majors. The non-majors might have been students of Economy, Medicine, Physics, Engineering or Geography, Some courses might have been dominated by girls, others by boys, some were for freshmen, others for students in the last semester. All this diversity makes it very difficult to transfer or apply any results of empirical research in CSE to a different context, questioning the validity of those results in total at the end.

Driven by these considerations, together with several colleagues I had drawn the conclusion that we would need a suitable framework in the sense of a coordinate system or a roadmap, which would enable us to assess the differences as well as the accordance of the context of any research results in CSE. Thus, I was happy to catch the proposal of former SIGCSE chair Barbara Owens to apply for a working group about CSE in schools at the upcoming ITiCSE conference 2011 in Darmstadt. Together with my German colleagues T. Brinda, J. Magenheim and S. Schubert I submitted a proposal for the working group and was happy to get it accepted. At the end of the conference, this WG had produced the *Darmstadt Model* that might be regarded as a first step towards such a framework [5]. In this paper I want to present the Darmstadt Model in its current preliminary state as well as to make some proposals for its improvement, application, extension and further development.

In order to avoid confusion due to the different meanings of the term *Informatics*, I will use *Computer Science* throughout this paper.

2 From Berlin to Darmstadt

The Darmstadt Model was developed by the working group "Informatics in Secondary Education" (shortly called WG ISE) at the ACM-ITiCSE conference that took place in June 2011 in Darmstadt, Germany. According to the opinion of its members, the WG ISE should be the starting point of a long-term collaboration at an international level. This sections presents a report about the goals, members, working methodology and the first outcomes of this group. More details about the work and the results of the group can be found in the official working group report [5].

2.1 The Goals

There is a variety of very different approaches towards teaching informatics in secondary schools, which differ heavily concerning e.g. learning goals or topics, applied programming paradigms and languages, organizational aspects (e.g. within a mandatory vs. an eligible subject) or teaching methods. In long terms we want to collect and compare research findings from as many different countries as possible about the effects and outcomes of those approaches in different countries. We aim to compare these findings concerning as many relevant variables as possible. For this purpose, we

have to develop a framework that should provide "landmarks" for the comparison of research and at the end for the assessment of applicability of a certain result in another context. Additionally, this framework could reveal, how certain research fields are already covered by existing publications.

The outcomes of the working group might be used e.g. by:

- national stakeholders arguing in favor of (or against) a subject of Informatics,
- curriculum designers deciding which of the investigated approaches a coming national initiative should follow,
- researchers as a stimulation for new projects,
- teacher educators as an orientation guide for the content of their courses,
- teachers and students to stimulate a 'look over the fence' to other countries.

2.2 The Members of the Group

The WG ISE was formed by the following colleagues (in alphabetical order):

- Michal Armoni, Department of Science Teaching, Weizmann Institute of Science, Rehovot, Israel,
- Torsten Brinda, Didactics of Informatics, University of Erlangen-Nuremberg, Erlangen, Germany,
- Valentina Dagiene, Vilnius University, Faculty of Mathematics and Informatics, Vilnius, Lithuania,
- Ira Diethelm, Carl von Ossietzky Universität, Department für Informatik, Oldenburg, Germany,
- Michail N. Giannakos, Ionian University, Corfu, Greece
- Peter Hubwieser, Technische Universität München, Fakultät für Informatik, Garching, Germany,
- Maria Knobelsdorf, University of Potsdam, Potsdam, (currently University of Dortmund), Germany,
- Johannes Magenheim, University of Paderborn, Institute of Computer Science, Paderborn, Germany,
- Roland Mittermeir, Alpen-Adria Universität Klagenfurt, Institut für Informatiksysteme, Klagenfurt, Austria,
- Sigrid Schubert, Universität Siegen, Institut für Didaktik der Informatik, Siegen, Germany.

2.3 The Starting Point

Searching a starting point for our framework, we were looking for a system that provides as most categories as possible to describe teaching projects. As T. Brinda and myself had already applied the Berlin Model (BM) of Paul Heimann [6] in our teacher training courses [7], [8], we convinced the group to use this model as a theoretical point of departure. Nevertheless, as the Berlin Model was developed to help teachers to plan their everyday teaching, we were well aware that this model would not be

sufficient at the end. Paul Heimann had proposed the BM (described in English by [9]) originally as a theoretical framework for the preparation and planning of school lessons [10].

The BM distinguishes between the *preconditions* of learning, several *decision areas*, and finally the *consequences* of learning measures.

The preconditions might be either *anthropogenic* (age and social level of students, gender aspects, prerequisite knowledge) or *socio-cultural* (school system, legal preconditions, outcome definition by curricula or standards, ethnic and traditional aspects, technical and financial resources).

The four decision areas are *intentions* (learning goals, objectives, outcomes, competencies, standards), *content* (topics, subject domain knowledge), *teaching and learning methods* (teaching approaches, typical learning and teaching methods) and *media* (e.g. hard- and software, internet, textbooks, unplugged media).

Corresponding to the preconditions, there are consequences of the teaching and learning process that might be either *anthropogenic* (learning outcomes, acquired skills or competencies) or *socio-cultural* (changed attitude towards data protection, enrollment at major courses at university, increased levels of user skills) again.

2.4 Text Corpus and Coding

In preparation of the work at the ITiCSE conference, five members of the group had produced very detailed case studies about the situation 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).

The goal for the work just before and during the conference (7 days, 8 hours per day) was to perform a theory-guided qualitative text analysis of the 5 case studies, which we hoped would result in an extension and refinement of the BM. We decided to choose the methodology of P. Mayring for this work that combines several techniques for qualitative text analysis [11] to a very systematic process. According to Mayring, the category system might be either derived from a suitable existing theory (deductive category application) or developed during the analysis from the text corpus (inductive category development). The first strategy incorporates also the revision of the existing category system. Both methods can be combined, which we intended to do.

We started with the following category system that was taken directly from the BM:

- *Preconditions: anthropogenic, socio-cultural,*
- *Decision areas*: *Intentions, Content, Teaching and Learning Methods, Media,*
- *Consequences: anthropogenic, socio-cultural.*

The coding and the quantitative exploration of the results was performed by using the software *MaxQDA* (www.maxqda.org), see Figure 2.

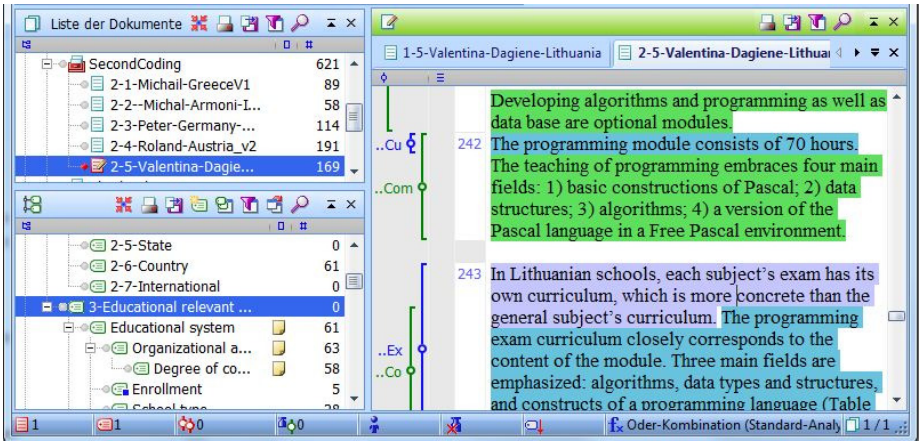

Fig. 2. Codings in MaxQDA

We started by coding the most detailed case study (Bavaria) in a plenary session, by this discovering that several important categories were missing or not suitably located in the hierarchy of the BM. Thus several new categories were included, e.g. the categories *Preconditions/Teacher education* and *Curriculum development*.

In the next step, we coded the remaining four case studies in groups by three members each, including the author of the case study. After this step, each group reported its coding experiences and proposed changes for the category system. Every group had found different new subcategories and had also serious problems with the hierarchy of the BM, particularly with the distinction of *Preconditions* and *Decision area,* which had frequently depended on the professional position of the authors of the studies. At the end several new categories had to be introduced, several others had to be moved in the hierarchy, while most of the categories were refined by adding new subcategories. At the end this step resulted in 70 categories in a five-level-hierarchy system.

Following this, we performed two more coding passes in pairs without the respective author. At the end we had coded 1154 text fragments altogether.

2.5 Shortcomings of the Berlin Model

The most serious deficit of the BM that we had faced was the distinction of *Preconditions* and *Decision Areas.* This distinction turned out to be dependent from the range of influence that the author of the study had. Therefore, in the coded papers different coding results emerged, depending on the author's text and the coder's perspective.

The second critical result was the quite low average percentage of the intercoder agreements of the three coding iterations, which is considered as a crucial measure for the objectivity of coding results. The agreement percentages were calculated automatically by MaxQDA with a threshold of 10% overlapping, which means that two

codings are counted as equal if the coded text fragments overlap at least 10% of one of them. The resulted percentages varied from 13% to 55% percent. In a very close discussion it was supposed that there might be several reasons for the percentages indicating bad agreement, e.g. the problematic distinction of Preconditions and Decision Areas, the lack of time to define the categories exactly, a very different coding granularity in the coding teams and the quite strict strategy of MaxQDA in accepting intercoder agreements.

In order to offer a solution to these intercoder problems for future coding activities, we decided to change the category system considerably, which led to a new model that will be described in the following section. One of the next steps of the group should be a close description of the categories, as far as possible based on definitions from literature. Additionally, we will define the granularity of the codings very carefully, hoping that this would improve the intercoder Agreement.

2.6 The Darmstadt Model

At first we agreed to split the problematic distinction between *Preconditions*, *Decision Areas* and *Consequences* from the original model, forming a new dimension with the draft label *Berlin Model Top Dimension*. Secondly, considering that this new dimension would be appropriate only if a second new dimension would be introduced that would describe the *Range of Influence* respectively the *Level of Responsibility* of the reporting persons. Of course these radical changes of the original model would affect the meaning of all the subcategories also. We called the outcome the *Darmstadt Model* (DM) in honor of the location of the conference.

1. *Berlin Model Top Dimension* (ordinal scale): categories of the first level of the original Berlin Model: *1-Preconditions*, *2-Decision Areas* and *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, and 7-International*.
3. *Educational Relevant Areas* (nominal scale): issues that are directly relevant for educational activities, including the former subcategories of the BM and several other new subcategories that had emerged during the coding work (e.g. *Educational System*). This dimension has the following categories at level 1 and 2:

- *Educational system*: Organizational aspects of subject, Enrollment, School type,
- *Socio-Cultural related Factors*: History of ICT and Informatics in School, Age, Gender, Social and Immigration Background, Family Socialization, Public opinion, Techno-economic development,
- *Policies*: Research and Funding Policies, Education Policies, Quality Management,
- *Teacher Qualification*: Teacher Education, Professional Experience,
- *Motivation*: Student, Teacher
- *Intentions*: Learning Objectives, Competencies, Standards
- *Knowledge*: Computer Science, ICT
- *Curriculum Issues*

- *Examination/Certification*
- *Teaching Methods*, CSE, General Education
- *Extracurricular Activities*: Contest
- *Media*: Technical infrastructure, Textbooks, Tools, Didactical software, Visualization software, Unplugged Media, Haptic media
- *Research.*

The DM can be used in a very flexible way, e.g. by folding respectively unfolding subcategories. For example, it might be sufficient to apply the category hierarchy in some cases down to *Teacher Qualification*, while in other cases it might be suitable to apply the categories of the two lower levels *CSE* and *General Education*. Depending on the specific focus of its application, the DM might be expanded at certain categories by plugging-in other specific category systems or taxonomies: For example the *ACM Computing Classification Scheme* into the category *Educational relevant areas\Knowledge\Computer Science*, the new *CSTA Standards* 2011[1] into the category *Competencies* or the taxonomy for CSE research that was developed recently by [12] into the category *Research*.

After introducing the DM, the codings of the case studies were adapted to the new category system, e.g. the codings of joined categories were also joined into the new category. Afterwards we calculated the intercoder agreement percentages of the new MaxQDA project (that reflected the Darmstadt model). The results showed a clear increase, which indicates that at least some of the worst coding problems were solved by the new model.

3 Improvement Suggestions

As a first application, I decided to write an extensive case study about the genesis, concept and outcomes of the new compulsory subject of CS in my home state Bavaria (Germany) according to the structure and categories of the DM [13]. During the work on the 40 pages of this report, I found the structure and most categories of the DM well-suited, relevant and applicable. Nevertheless, there were two aspects that I faced problems with.

The most serious problem was the category *Research* of dimension 3. As the work of the working group aims to develop a framework for research in CSE, this term is all-embracing in my opinion. After all, we expect that all statements that we consider are based on research. Therefore, research is relevant to all other categories in a certain regard. Consequently, I propose to change the name of this category to *Outcomes/Effects* in order to make it more specific.

The second problem affects the values of the 2nd dimension. I found that there are cases where the relevant person (e.g. the author of a case study) has no influence at all in some of the regarded categories. For example, a teacher who is practicing at school and has no other function beyond that would usually have no influence at all on the school system or on the curricula she/he has to follow. On the other hand, an educational researcher who is investigating the outcomes of a school subject would have no

influence on the teaching methods that are applied in the classrooms. Consequently, I propose to add a "zero"-category to the 2nd dimension of the DM. The name of this category has to be discussed. Regarding the *Level of Responsibility* it might be "None", while this does not fit well regarding the *Range of Influence.* Thus, I will use the label *Zero* throughout this paper as a first approximation.

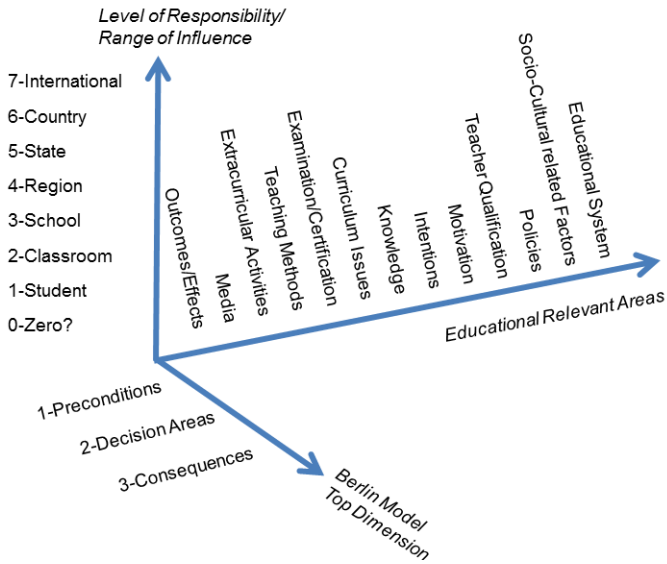

Fig. 3. The proposed Darmstadt Model, Version 0.1

Based on this suggestions, I propose the slightly changed version (Version 0.1) of the DM that is displayed in Figure 3. In the following discussion of the Model I will refer to this proposal.

4 Exemplary Applications

In order to illustrate the meaning and the application of the DM in its macrostructure, I will present two hypothetical cases that demonstrate the different values and the benefit of the three-dimensional structure.

The first case represents a *practicing school teacher* that writes a report about her/his classroom experience. The second case is an expert in CSE that was delegated by the administration of a federal state (e.g. Bavaria in Germany or California in the US) to develop and implement a new curriculum, shortly called a *curriculum designer.* Figure 4 and Figure 5. display the values of dimension 1 respectively dimension 2 that might be assigned to the categories of dimension 3 in both cases. Please note that those are only assumptions by the author of this paper.

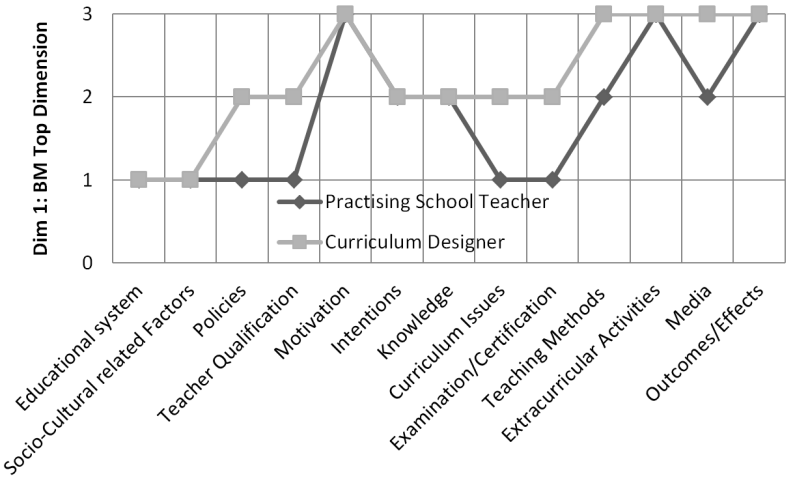

Fig. 4. Exemplary profiles on dimension 1

Nevertheless, it is apparent that the curriculum designer, who might be regarded as "more powerful" at the first glance, might have less influence on several categories compared to the teacher, e.g. on Teaching Methods and Media, which might be applied in the classroom, chosen by the teachers. Also, those categories might be regarded as Consequences of the work of the curriculum designer in the sense that suitable Methods or Media might depend from the *Knowledge* elements that are prescribed by the curriculum.

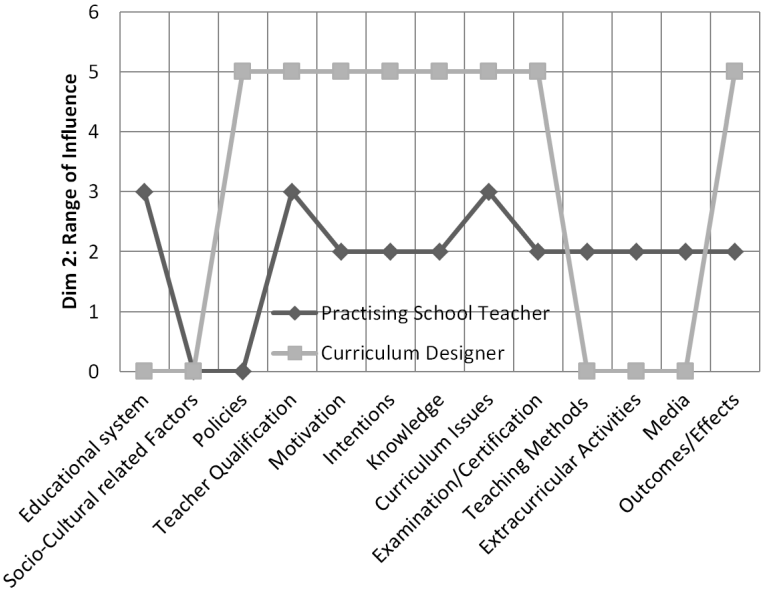

Fig. 5. Exemplary profiles on dimension 2

5 Educational Relevant Categories

As this paper is limited in size, I will list only keywords for the categories of dimension 3 in table 1. Extensive discussions and illustrations of the categories can be found in [5] and [13].

Table 1. Keywords for the remaining categories of dimension 3

Dim. 3: Educational relevant areas	**Keywords**
Educational system Organizational aspects of subject Degree of compulsion Enrollment School type	The type of school: Primary School, High School, Primary School, Gymnasium, Grammar School etc. and its location in the respective school system; compulsory subject, optional subject or course, chosen out of a list of choices, integrated into other subjects, how many years the course comprises, how many lessons per week and time per lesson. Enrollment in the course or subject that is described or as a consequence of the described activity regarding further enrollment in advanced CS courses
Socio-Cultural related Factors History of ICT and Informatics in School Age Gender Social and Immigration Background Family Socialization Public opinion Techno-economic development	Preconditions of that are set by the society, the parents and the students, didactical approaches in the past, limitations of abstraction caused by the cognitive development of the students (e.g. according to the theory of Piaget [14]); diversity aspects, beliefs, attitudes, concerns of the parents, the general opinion towards CS and ICT that is common in the respective social environment, the degree that technology and its usage has made its way into the society, e.g. the percentage of households that are equipped with computers and internet access or the functions or software types that are available to the students at home.
Policies Research and Funding Policies Education Policies Enhancing Cooperation Technical Infrastructure Financing Initiatives Quality Management	Political initiatives and strategies, structural reform projects, experimental school types, influence of industry or universities.

Table 1. (*Continued*)

Teacher Qualification Teacher Education CS Teacher Education Certification Training Professional Experience	Education at universities vs. pedagogical colleges, curricula and standards for teacher education, mandatory degrees in CS or pedagogy, teacher examination, recruitment strategies, percentage of active teachers with such degrees, additional teaching subjects required, in-service training strategies, profile of professional experience of the active teachers.
Motivation Student Teacher	Correspondence between motivation and other factors (gender, age, social or ethnic background), strategies to increase students' and teachers' motivation
Intentions Standards Competencies CSE Interdisciplinary Learning Objectives	Intention of policies and projects vs. intentions of the teaching units; proposals for standards, implementation of those in curricula, competency models, stages, development and definitions, learning objectives, taxonomies, categories.
Knowledge Computer Science ICT	Definition of knowledge, representation forms (e.g. mind maps, concept maps), taxonomies (e.g. factual – conceptual – procedural – metacognitive), measurement, development, prerequisite of competencies.
Curriculum Issues	Curriculum design processes, forms, levels, categories, order and arrangement of knowledge elements, distribution over grades and months, combination and interleaving of knowledge, intentions, methods and media
Examination/Certification	Graduation levels, examination formats, centralization vs. or school autonomous examinations, standards and strategies, certification levels and purposes
Teaching Methods CSE General Education	Suggestions of pedagogical or professional methods, e.g. working methods, learning and teaching methods
Extracurricular Activities Contest	Industry internships, regional, national and international contests (e.g. Informatics Olympiad, Bebra Contest, Bundeswettbewerb Informatik)
Media Technical infrastructure Textbooks Tools Didactical software Visualization software Unplugged Media Haptic media	Electronic or "classical", digital or analogue resources, means, tools, facilities, equipment, aids, auxiliaries, accessories that enhance, leverage or support learning processes, documentations of best practice, examples for CS unplugged, "Abenteuer Informatik", "Informatik im Kontext", programming languages, software systems, hardware applications
Research (Outcomes/Effects)	Results of research project that provide evidence for outcomes, associations, relationships or coherencies between the other categories.

6 Conclusion and Future Work

Apparently, in the current state, the Darmstadt Model must be regarded as a first step towards the intended framework for CSE, which has some serious deficits still. First, the incorporated case studies covered only 4 countries and one of the 16 states of Germany. By coding further studies of more countries, many additional categories or subcategories might show up. Second, the categories presented in this paper are not yet defined clearly, which had caused quite bad intercoder agreements in the coding process. Third, the names of the dimensions should be discussed and improved, in my eyes.

In order to improve the model, we plan the following further work. First, we will code several studies that were published in the meantime, e.g. [3], [4], [15]. Following this, we will discuss the structure, the categories and their definitions in a further working group session, preferably during this conference. The next big step of the group will be the edition of a special issue of the ACM journal Transactions on Computing Education that we are preparing currently. We hope to get many detailed case studies about CSE in Schools that we could code and analyze in order to get the next Version 1.0 of the Darmstadt Model. On the base of this, we might be ready to construct a questionnaire out of our category system that could enable us to conduct an international survey about concepts and situations regarding CSE in Schools. After evaluating and incorporating the results of this study, the Darmstadt Model might be developed to Version 2, which might be regarded as a stable solution of our original goal: to design a research framework for CSE in Schools.

Acknowledgements. At this point I have to express my gratitude to all people that have contributed to the outcomes of the working group: Barbara Owens for the original idea, Guido Rößling, Liz Adams, and Jubo Börstler for accepting, enhancing and editing the ITiCSE working group 2011, all members of the group for their hard and high-class work, native speaker Margot Phillipps for the linguistic assistance. Josh Tenenberg and Robert McCartney for the acceptance of our special issue proposal, Ira Diethelm for organizing this conference and for inviting this keynote and to all others that have supported our work until today in any way.

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