Computer Science Education and Key Competencies

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Abstract: This article intends to accentuate the contribution of Computer Science Education (CSE) fostering key competencies. Besides an outline of its contribution to convey general education a first approach of a competence model will be presented. It is elaborated within the project MoKoM granted by the German Research Foundation (DFG), which is proposed to cover competence aspects concerning informatics modeling and system comprehension. Another chapter will present relevant key competencies according to the OECD’s Definition and Selection of Competencies Project (DeSeCo). Finally it will be shown, how the competence components covered by the competence model contribute to the development of key competencies within the scope of CSE.

Keywords: General Education, Lifelong Learning, Informatics Modeling Competencies, Secondary Education, System Comprehension, Key Competencies

1. Motivation

Due to OECD Programme for International Student Assessment (PISA), the German education system is faced with an outcome oriented reformation movement \cite{1}, \cite{2}. In this context, educational standards are developed for all grades of school up to university level. These are closely linked to competencies learners should achieve. Concerning this trend actions were taken to develop educational standards in informatics secondary education. \cite{3}. An important foundation to systematically derive such standards is the development of an empirically proofed competence model. This is needed to plan educational objectives and informatics learning and to measure competence development. Perceiving Weinert'\textquotesingle s understanding of competence, such kind of models should describe relevant dimensions and components as well as a grading of competence components, which corresponds to different levels of learners’ cognitive skills \cite{4}. According to this approach four competence dimensions were developed for CSE emphasizing informatics modeling and system comprehension within the project MoKoM. These contain competence components addressing basic competencies,
perspective towards an informatics system, complexity of an informatics system and non cognitive skills. The grading of the competence dimensions relates to the way of knowledge usage (apply, comprehend and develop informatics systems) and the complexity of the informatics systems and tasks.

The development of a competence model for CSE though should not only consider informatics specific knowledge and ability demands but also general education aspects. According to this perspective the question arises, how the mentioned competence model of informatics modeling and system comprehension could contribute to the development of key competencies in terms of using tools interactively, interacting in heterogeneous groups and acting autonomously [10]. In the first instance it is convenient to take a closer look at the potential of CSE encouraging general education.

2. CSE and General Education

Due to its origin in engineering science, CSE is the most important subject, which can impart ICT related knowledge in secondary education. With respect to the exceedingly growing relevance of ICT in everyday life (i.e. in home-, school-, and job related environment) CSE has to foster appropriate competencies concerning the handling of ICT in different social environments [5], [6], [7].

In order to take a closer look at respective educational objectives, subject matters and teaching methods and to examine the contribution of CSE to impart general education, it is expedient to take some theoretical background into consideration. Students need to understand and to handle informatics systems to act as a mature citizen in the information society. Thus, dealing with informatics modeling and system comprehension in particular, it is essential to define the term informatics system.

By socio technical informatics systems (IS) we understand the unity of software including graphical user interface (GUI), hardware and the associated social action system of persons, who are interacting among each other and with the technical part of the informatics system. This term roots both in computer science and in sociology of technique [8].

Particularly - concerning software development processes - modeling is a highly communicative and interactive activity, which demands close cooperation between developers and customers. In this context developers create a model of parts of the future functionality of the software and its integration into working environment and social context [6].

With regard to this theoretical background, there are implications concerning the analysis of informatics systems. While observing technical aspects of such a system (i.e. hardware and software) one also has to take social aspects and effects into consideration [6].
In order to foster general education in CSE, in our opinion system comprehension and system development should be central topics. Presenting system development as a process, which depends on several different interests, the learner has to develop a process perspective which points out various social influences touching an informatics system. This comprises interests of different roles acting cooperatively (e.g. developers, users and contractors), their objectives as well as the decisions made concerning the software design. By emphasizing these social and complex interrelated aspects and effects of system development and system comprehension, CSE is able to foster the development of key competencies with regard to using technology tools interactively. Conducting CSE in such a system oriented way it can also contribute to general education of learners according to Klafki's epochal typical problems [9]. According to Klafki the teaching of subject matter has to be legitimated concerning its relevance in past-, presence- and future context. This can be achieved by emphasizing epochal typical problems e.g. risks and chances of ICT. In the next chapter it is discussed, which key competencies learners have to acquire in CSE.

3. Key Competencies

Due to the increasing demands of everyday life, global economy and the information society key competencies are of prime importance. Key competencies are in this respect more than knowledge and skills. They rather involve abilities to meet complex demands, by drawing on and mobilizing psychosocial resources (including skills and attitudes). General or key competencies are not only important for specialists but for all individuals. They help to meet important demands in a variety of contexts and contribute to valued outcomes for societies and individuals [10]. Key competencies can also be obtained by learning and they are a precondition of lifelong learning. According to these characteristics they can be understood as central topics of general education.

With reference to the DeSeCo-approach key competencies can be categorized in three groups i.e. using tools interactively, interacting in heterogeneous groups and acting autonomously [10].

The first group “using tools interactively” concerns the ability to use language, symbols and texts interactively, to use knowledge and information interactively and to use technology interactively as well. Interactive use of technology requires knowledge and especially an awareness of contemporary ways in which persons can use technology in their everyday lives. Fostering the respective usage of ICT can transform the way people work together (e.g. in a location independent way), access information (e.g. making vast amounts of information resources available) and interact with others (e.g. facilitating relationships and networks of people around the world). Using tools interactively can also be realized as an opportunity
to include persons who are deprived with regard to technology and to assure gender equality.

The second group “interacting in heterogeneous groups” contains key competencies which are related to interpersonal relationships. Thus this group of key competencies is decisive in pluralistic societies and in situations characterized by complex demands. It consists of relating well to others, cooperating and working in teams and finally managing and resolving conflicts. Relating well to others denotes the ability to initiate, maintain and manage personal relationships with other persons having different careers, professions, backgrounds etc. They enable individuals to communicate with others appropriately, to discourse and to “take the role of the other person and imagine the situation from his or her perspective” [10, p. 12].

The third group of key competencies “acting autonomously” consists of the ability to act within the big picture, form and conduct personal projects and to defend and assert rights, interests, limits and needs. Human beings have to act autonomously in order to participate actively in various projects, in different spheres of life including the workplace and the social life. The ability to act within the big picture requires individuals to understand patterns, have an idea of the system to which they belong. Moreover persons must detect direct (and indirect) consequences of their actions. Thus this ability addresses decision-making and taking responsibility. In consideration of these aspects key competencies are decisive for self-reliance and employability.

Adequate educational environments have to be arranged in order to teach and to acquire key competencies, wherein not only subject matter skills are taught but also competence development is fostered.

4. System Comprehension and Modeling Competencies in Computer Science Secondary Education

As mentioned before, a prototypical competence model is proposed to cover several competence facets concerning the domain of CSE in terms of informatics modeling and system comprehension as well as learners’ non-cognitive skills. In the following, two dimensions of the competence model will be introduced representatively. Furthermore it will be shown, which key competencies are related to the presented competence dimensions.

4.1 Basic Competencies

Learners have to acquire several basic competencies concerning informatics modeling and system comprehension. These can be allocated to the competence components system application, system comprehension and the process of system development.
The competence component **system application** represents the competence facets to utilize an informatics system.

It empowers learners to use technology interactively as a key competency. It is necessary to foster an awareness of current potentials to incorporate technology in their daily lives. Therefore they have to relate possibilities embedded in technological tools to their own circumstances and goals instead of simply using them in a non-reflective manner [10].

For this purpose learners have to develop the ability to use an informatics system as a tool or as a learning medium consciously. In this context they have to choose adequate user applications and are obligated to perform appropriate inputs. Furthermore they have to react to the output of the informatics system.

Dealing with typical informatics systems as a central topic in CSE, teaching can help learners to use respective systems in a reflective and purposive way. At the same time the accentuation of system failures can provide learners with opportunities to recognize inconsistencies of their mental models [11]. In order to develop these mental models and to correct them, informatical models have to be taken into consideration. Use case diagrams as well as object-oriented models (e.g. by perceiving documents, passages and characters as objects) support learners’ comprehension of standard software.

The competence component **system comprehension** emphasizes the understanding of elements of an informatics system and the informatics principles they are based on. Besides the application of an informatics system this is an important precondition to form skills concerning the interactive utilization of technology as key competency. Therefore learners have to comprehend the nature of technology before they can estimate how it can be utilized and adapted to their own purposes [10].

In order to develop informatics system comprehension it is crucial to analyze the internal structure and the recognizable outer behavior of such a system [12]. To restrain learners from applying the “trial and error” method, they have to be provided with procedures to explore an informatics system in a methodical manner. Hence they must be supported to experiment with the system in a reflective way, i.e., to prove reasonable hypotheses. This course of action might be oriented to methods and principles of computer science but has to be reduced for didactic purposes. Computer science offers two different kinds of tests i.e. white box test (implementation and internal structure are known) and black box test. In this context learners should be able to formulate own hypotheses in order to combine perspective, behavior and structure of an informatics system.

The competence component **system development** represents the ability to construct an informatics system or to perform reverse engineering on it. It is subdivided into several phases of the Rational Unified Process (RUP). RUP is a potential approach (among others) to establish many successfully exercised principles of software engineering in one comprehensive process. It is broadly used and can be adapted to various application scenarios [13].
The subcomponents of system development are oriented towards the process workflows of the Rational Unified Process. These describe sequences of numerous activities as well as communication between relevant persons developing software. Additionally RUP illustrates appropriate models of Unified Modeling Language (UML) according to a specific workflow.

RUP sticks to principles of iterative Software Engineering and relies on component based architectures, which contain already existing components and new ones alike.

Because of the extensive comprehensiveness of RUP, it has to be adapted in order to fit in a specific application scenario.

Especially in educational environment RUP has to be reduced according to the complexity of school related software projects and learners’ skills.

As illustrated in the following subsection, the capability to develop an informatics system (e.g. by modeling the system’s architecture) is closely linked to several non cognitive skills, which could be allocated to key competencies in terms of interacting in heterogeneous groups and acting autonomously [10].

### 4.2 Non Cognitive Competencies

This dimension emphasizes the learners’ non cognitive abilities concerning their attitude towards the subject matter, social communicative and motivational competencies.

In the following it will be discussed, how these competence components can be distinguished in matters of informatics modeling and system comprehension and how they contribute to general education by fostering key competencies.

The competence component attitude towards the subject matter comprises the perception of an informatics system in addition to a prospective view on such a system. Furthermore it contains the learners’ expectations concerning the handling of an informatics system.

A recurrent consideration of the concept of socio technical informatics system and the implications following from this, show the relevance of having the ability to perceive an informatics system in context and to anticipate it during the modeling process.

The reason to integrate the expectation concerning the handling of an informatics system into the competence model is derived from an empirical study of Schulte and Magenheim. In this context they emphasized the importance of being aware of students’ expectations concerning CSE. So, expectation of the subject matter is an important condition for successful and effective teaching and learning with reference to this domain [15].

Particularly fostering the key competency interactive utilization of tools (e.g. by embedding technology in daily life) requires an awareness of learners’ expectations concerning subject matters of CSE.
As mentioned before, it is essential to look at social aspects and effects while regarding socio technical informatics systems. This perspective, which follows from the definition of an informatics system, highlights the relevance of social communicative skills when analyzing the interests and demands of the different stakeholders and roles involved in the development of informatics system and informatics modeling. In this context learners also have to develop team competencies to act as a part of a social action system (e.g. in cooperative e-learning environments or developing software cooperatively).

Learners also have to develop empathy in order to comprehend different roles in informatics system development (e.g. users, software developers, contractors) and their different points of view. Nygaard affirms that there are highly differing perceptions of an informatics system which are often coherent nevertheless [16]. This shows the enormous importance of developing such a kind of empathy [6].

In secondary education students are often involved in project oriented CSE. In this context students act in the roles of developers, users and contractors. This fact shows the relevance of forming empathy even in school environment.

According to these demands they get the chance to learn how to interact in heterogeneous groups by acquiring key competencies in terms of relating well to others, working in teams and managing conflicts [10].

Furthermore the students are provided with opportunities in developing the key competency to act autonomously. Creating software in project groups can help them to realize their identity while acting as a part of an informatics system. In this context learners have to develop an awareness concerning their environment, social dynamics and the specific role they act within the software development process. This also includes an awareness of the social compliance of their acting and possible effects their action might implicate [10].

In addition to attitude and social communicative competencies learners have to develop motivational competencies. These motivational competencies are closely connected to processes of self-regulation and are preconditions of acting autonomously and pursuing difficult goals persistently.

Learners have to be encouraged to develop willingness to learn and to form openness to new ideas and demands and to develop willingness to engage in informatics. The degree of motivation reveals the purposefulness of acting, decision-making and taking responsibility. Thus, having adequate motivational (and self-regulatory) skills is highly relevant for achieving aims and having success in so far as persons with superior motivational competencies are less distracted by task-irrelevant thoughts and cognitions. Hence by developing these competencies in school projects they will be able to apply them in complex application scenarios in daily life.
5. CSE and Key Competencies

In the following we give a review how the key competencies are related to the competence components. In the third column, additional examples of ICT-learning processes related to key competencies are delineated.

Therefore, we refer to the educational model for comprehension of informatics systems and of reengineering and developing informatics systems [12]. The behavior of an informatics system is analyzed with respect to fundamental ideas of informatics. The internal structure of the informatics system has been investigated, because it is a representation of fundamental ideas. One typical exercise was to experiment with and to modify an informatics system realizing access control.

<table>
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<tr>
<th>Competence component</th>
<th>Key competency</th>
<th>ICT-related learning processes</th>
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<tbody>
<tr>
<td>System application</td>
<td>Using tools interactively</td>
<td>Documentation and examination of the observed data and identifying informatics concepts [12].</td>
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<td></td>
<td>Acting autonomously</td>
<td>Anticipation of system failures and unexpected behavior of systems in the learning process.</td>
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<tr>
<td>System comprehension</td>
<td>Using tools interactively</td>
<td>Experiment with and explore informatics systems systematically helps relying behavior to internal structure of systems. Establishing a set of special cases to be tested and evaluated; create a series of hypotheses for using the informatics [12].</td>
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<td></td>
<td>Interacting in heterogeneous groups</td>
<td>Knowing internal structure and appropriate terminology to describe informatics systems enables students to cooperate with others.</td>
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<tr>
<td></td>
<td>Acting autonomously</td>
<td>Strategies to explore informatics systems enable students to understand unknown systems and to act autonomously. Systems can be adapted to a new context.</td>
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<tr>
<td>System development</td>
<td>Interacting in heterogeneous groups</td>
<td>Software development involves communication between persons. Students developing software have to share leadership and to establish different roles. Students examine class diagrams in groups and identify how informatics concepts are implemented; check special cases and test for internal inconsistencies; plan to reorganize and reuse the internal structure for a different application [12].</td>
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<td></td>
<td>Acting autonomously</td>
<td>Analyzing problems and modeling new solutions for unknown problems. Listing</td>
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involved classes and objects for access control; classifying operations and classes; arranging the correct relations between the participating classes [12]. Modifying programs to adapt the application to a new context.

Coping with different software applications. Understanding how computers and basic operating systems work; demonstrating that the computer is under control [7]; subdividing typical representatives of informatics systems into system software and application software [12].

Students with knowledge in programming often overestimate their own abilities and lack of cooperation. Whereas students without previous knowledge want to understand function of informatics systems and guidance. Meeting these demands to bridge digital divide and gender-specific differences, e.g. by conducting experiments: Answering questions about the intended behavior of an informatics system and outlining the procedure.

Solving problems with informatics means in interdisciplinary school projects. Learning to define the project and set the own goals.

Successful application of informatics systems to solve problems motivates students to use them.

Explaining behavior of informatics systems to other students is motivating.

Table 1: Review of relations between competence dimensions and key competencies and examples how to foster them in ICT-learning processes

6. Conclusions

In our approach we tried to demonstrate how key competencies as central components of general education can be integrated in selected dimensions and facets of a competence model concerning informatics modeling and system comprehension. Specifically the DeSeCo-approach has shown to be appropriate for this purpose. The integration of key competencies in the described CSE competence model has implications for the derivation of educational standards and
learning objectives and also the design of related learning processes and measurement instruments to evaluate competence development. To develop and to evaluate respective standards, objectives, learning processes and measurement instruments are objectives of further research steps in the project MoKoM.

References


