TOWARDS A COMPETENCE MODEL FOR EDUCATIONAL STANDARDS OF INFORMATICS

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ABSTRACT

First the article in consideration of processes in other subject areas will outline the relation between core curricula, their implicit standards and the needs for assessment and quality assurance in the area of informatics education. There is also placed emphasis on the importance of educational standards in the area of informatics education for general education and the acquisition of knowledge. A short analysis of existing international ICT-Curricula and some approaches of educational ICT-Standards will follow. The necessity of evaluation of the mainly not approved and empirically not verified educational standards will be shown. Then, as the most important part of the paper, a model of ICT competence classes will be deduced based on fundamental aspects of software development and basic media functions of informatics systems. Finally, some requirements on evaluation concepts of educational standards and aspects of further work will be discussed.
This article is either of the two introductory contributions to the workshop 'Educational Standards of Informatics for International Student Assessment' to be held at the WCCE2005, and it is closely linked to the second introductory paper of Sigrid Schubert 'From Didactic Systems to Educational Standards'.

1. STANDARDS, COMPETENCIES AND CORE CURRICULUM

Due to the economic importance of a nation's educational system the focus on education has partly shifted from its content and methods to the outcomes of learning processes and the assessment of their cost-value ratio. Changes in teaching methods, learning theories and learning styles of students as well as an increasing support of learning processes by computer based media suggest taking care about the results and the quality of learning processes. This outcome oriented view on education leads to the definition of subject related educational standards which are oriented on educational objectives. Educational standards are closely linked with competencies students should achieve. They can be empirically measured by standardized tests and indicate a students' knowledge and his or her abilities related to a specific knowledge domain e.g. ICT. Competencies are concerned as well with factual knowledge (knowing that and knowing how) as with inferential knowledge which is based on reasoning and theory.

In order to gain empirical proofed results of students ICT-competencies and the effects of ICT-related learning processes there is a need of a competence model in different subject areas of ICT. The model should describe relevant dimensions and the grading of competencies as well as patterns of progress in achieving them. Standards allow to establish a culture of evaluation and they are an important instrument of quality assurance with regard to learning processes. They also foster international comparative trials and enable educational organisations to define nationwide core curricula in order to guarantee an approved and binding set of content and methods that will be suitable to the standards.

Extensively approved curricula and sophisticated educational standards have been revealed by traditional academics and school related subjects during their relatively long lasting phase of development, e.g. the NCTM Standards in Mathematics [7]. The contribution of the subjects to general education is not questioned although sometimes vague. Internationally harmonized tests like the PISA study for the educational outcome within different subject areas have been carried out [8].

The situation in ICT-related education, especially in the area of informatics education is due to its relatively short time of existence much different. Although there are also recommendations, curricula, and demanding tuition concepts, they are mostly not approved and not empirically verified at all. In addition, comparative data for informatics standards and students competencies are missing. In order to retrace the development in other subjects informatics education has to develop an approved competence model and define international approved educational standards. Intensive analysis and following discussions about existing curricula on different levels of demand have to be made. For the needs for empirical evaluation of educational standards within informatics education comparable teaching-and-learning-materials are necessary as well. In this way a contribution to the development of a core curriculum will be created simultaneously. Thus, informatics education will be able to outline its contribution to general education and guarantee a sustainable development of the subject in school related education.

2. INTERNATIONAL ICT-CURRICULA AND CONCEPTS OF EDUCATIONAL STANDARDS

2.1 Learning from Mathematical Competence Models and Studies?

First we will have a short look at the efforts in mathematics defining standards and developing a competence model within the context of the PISA study. Differences between the mathematical and an informatics model of competencies to be developed will be worked out. Then a short overview of some important approaches in the area of informatics curricula and their implicit educational standards will be given in order to draw conclusions for the concept of standards to be developed. In doing so I will consider ICT related curricula of secondary level as well as those of higher education and also take care of ICT-skills related evaluation concepts.

Modelling in mathematics education is of comparable importance as in informatics. Although we have to deal with different methods and concepts in both subject areas it might be useful to tackle with the mathematical competence concept. The PISA assessment in mathematics is concerned with students' knowledge and skills which indicate their capacity "to identify and understand the role that mathematics play in the world, to make well-founded judgements and to use ...mathematics in ways that meets the needs of that individual's life as a constructive, concerned and reflective citizen." [8] p. 15. The PISA study is defining a three dimensional model of mathematical competencies. The content related dimension is mainly defined in terms of 'overarching ideas' like quantity, space and shape, change and relationships, uncertainty, numbers and algebra. Basic competencies are: Thinking and reasoning; argumentation; communication; modelling, problem posing and solving; representations; using symbolic, formal and technical language and operations; use of aids and tools. Different levels of cognitive activities are described in the PISA model as competency clusters: reproduction, connections and reflection. The situations in which mathematics is used is finally defined as a kind of forth dimension, where competencies have to be applied. They are based on their distance to the students' real world experiences: personal, educational, occupational, public and scientific [8] pp 24.

These definitions may also partly meet the demands of informatical competencies and the use and the development of informatics systems by the students. But we also have to diagnose essential differences, not only in the subject area but also in the methods applied. Informatics systems, the subject matter of informatics, are not only artefacts with media functions and cognitive tool abilities. They have in addition a specific quality as a universal machine for symbolic code transformations and can be used as problem solving machines. Therefore, informatics competencies must represent the handling of the product software as well as the process of its development. We also have to take into consideration the process of the systems' construction and it's modelling as well as the process of its deconstruction and it's re-engineering. Informatical modelling does not only have the task to describe or predict real-world scenarios but in contrast to mathematical modelling also requires the ability to anticipate a future socio-technical scenario that will be created during the implementation of the socio-technical informatics system. This aspect is rooted to the engineering tradition of informatics which is transcending pure mathematical calculations [5]. From that point of view the mathematical competence model is not completely meeting the demands of an informatical one and it will be insufficient if we only replace mathematics related terms by informatics specific expressions.

Resulting from that argumentation the PISA ICT Feasibility Study [9] concerning the ICT-competencies of students is to be classified as completely insufficient. It covers only the smallest range of students' competencies related to specific application areas of informatics systems and does not take into consideration most of the construction skills and the knowledge ICT-competencies should include. It indicates a complete lack of understanding in regard to ICT or informatics education. Other concepts or curricula give more suitable clues to the construction of an informatics education related competence model.

2.2 ICT-related Standards and Curricula

Some general aspects of ICT-literacy and the use of ICT in educational contexts can be found at an OECD- ICT-Curriculum for Schools and Programme for Teacher Development [10]. The analysis of their implicit standards may also contribute to exploit dimensions of an ICT-related competence model. Standards in regard to ICT-competencies of students and their abilities to use technology in educational contexts are also presented by the National Educational Technology Standards (NETS) from International Society for Technology in Education (ISTE) [2]. Students' skills are described with categories like 'Basic operations and concepts' , 'Social, ethical, and human issues', 'Technology productivity tools', 'Technology communications tools', 'Technology research tools', 'Technology problem-solving and decision-making tools'.

Sources of highest importance for the rationale of an ICT-competence model are the ACM and IFIP curricula for computer science [3] [12] in general and for school related education in particular. The ACM Model High School Computer Science Curriculum, for example [11] defines seven topics in which students should be qualified: Algorithms, Programming Languages, Operating Systems and User Support, Computer Architecture, Social, Ethical, and Professional Context, Computer Applications, Additional Topics.

The IFIP-Curriculum, [12] which performs the task to foster ICT-related progression with regards to students as well as to teachers and the educational institutions, contains different levels of ICT competencies: ICT Literacy - ICT as a separate subject; Application of ICT in Subject Areas - ICT as a tool to work within a subject; Integration of ICT across the Curriculum - ICT as method to work across subjects; ICT specialisation - ICT as a profession. Especially, the modules last mentioned cover the use of advanced tools and techniques for ICT professionals. The related topics include: basic and advancing programming, planning information systems, designing process control systems, and project management.

Denning defines 'Great Principles of Computing' scaffolding a curriculum [1]. They consist of 'Design Principles' (complexity, performance, reliability, security) and 'Computing Mechanics' (computation, communication, coordination, automation, recollection). They are also including application domains: 'Computing Practices' (programming, engineering systems, modelling, innovating and applying) and 'Core Technologies' (architecture, algorithms, databases, networks …).

ACM computing curricula also stress the importance of distinguishing between different levels of knowledge and skill complexity, e.g. 'Knowledge', 'Comprehension' and 'Application' [4] p20. Discussions at the Dagstuhl meeting [6] lead to a standards model for school informatics that contains a process line (problem solving, modelling; interpreting and reasoning; communication; connections; representation) and a content line (information and data; algorithms, informatics systems; technology; theory; society).

Another model that emphasizes modelling and knowledge skill in regard to formal techniques is presented by Humbert / Puhlmann [in 6]. Further references are given in the corresponding article of Schubert mentioned above. Recapitulating the essentials of the presented approaches a competence model should take into account the following aspects: complexity of the students' knowledge and skills, topics, type of using an informatics system as a media and finally complexity of the applied system.

3. A MODEL OF ICT-COMPETENCE CLASSES

3.1 The Model's Dimensions

According to the informatics concepts discussed above a general model of ICT-competence will be presented. It is a first draft and has to be discussed intensively and improved further on. It has to be adapted to the needs for evaluation and assessment on different levels of informatics education. The model is based on three fundamental skills and knowledge dimensions. Each of them can be differentiated into several categories.

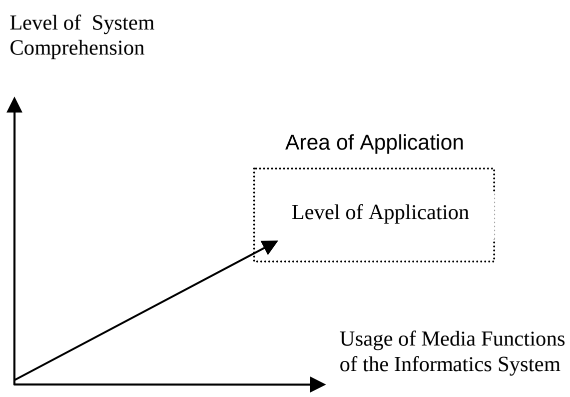

Figure 1: Model of ICT – Competence Dimensions

The model presented is related to the types of usage of an informatics system (IS), to the process of its construction and the degree of comprehension of informatics concepts that users have on their disposals. By socio-technical informatics systems we may understand the unity of software including the graphical user interface (GUI), the hardware, embedded systems for control and regulation of peripherally technical processes and for communication with other IS and, last but not least, the associated social action system of people, who are interacting with the IS and with one another [5]. Most of the dimensions of the competence model mainly cover the software and technical parts of an IS.

Let's have a closer look on the dimensions of the competence model.

USAGE OF MEDIA FUNCTIONS OF THE INFORMATICS SYSTEM

- Domain Specific Application
- Cognitive Tools with Generic Functions
- Communication / Co-operation Tools
- Exploration and Evaluation Tools
- Development Tools

LEVEL OF APPLICATION

- Guided Use of Selected Basic Functions of the IS
- Scenario-related Free Choice of Selected Basic Functions of the IS
- Usage of Selected More Complex Functions of the IS
- Competent Extensive Use of Systems Functions
- Combined Co-ordinated Use of different IS

LEVEL OF SYSTEM COMPREHENSION

- *Knowledge*
  - Understanding of Basic System Functions and Basic Concepts of Systems Hardware
  - Knowledge of Selected Views of the Informatics System (Algorithms, Source Code, GUI, Models, Protocols, Theory…)
  - Comprehension of Fundamental Informatics Principles and Abstract Concepts (Meta-Models)
- *Transfer of Knowledge*
  - Ability to Use ICT-Knowledge in Familiar Application Scenarios
  - Ability to Transfer ICT- Knowledge to a New Context
- *Complexity of Construction*
  - Comprehension of a System's Coherence (Ability of Re-engineering)
  - Using Information, Methods, Concepts and Theories in New Context to Build Systems (e.g. Design Pattern)
- *Assessment*
  - Assessment of System Design and its Functionality in Socio -Technical Context
  - Evaluation of IS Current Social Impact and IS in Historical Perspective

3.2 Usage of Media Functions of the Informatics System'

The first dimension '*Usage of Media Functions of the Informatics System*' is based on the assumption that informatics related skills and knowledge are closely linked to the use of an informatics system. The use of an IS enables us to enhance our cognitive abilities and our opportunities to communicate or co-operate. They help us to explore and to evaluate knowledge domains or application areas. We will be enabled to predict future developments on the basis of a simulation. Last but not least we may use an IS as a tool to develop new informatics systems.

The category 'Domain Specific Application' describes the use of specific software in a special knowledge domain or specific limited area of application and includes the use of learning software. This type of software is characterized by strong user guidance and a low level of possibilities for scenario specific adaptations.

'Cognitive Tools with Generic Functions' are software tools which support us in generating, structuring, recomposing, presenting or visualising data in order to gain information in any application area.

'Communication / Co-operation Tools' are generic software tools which enables us to communicate and co-operate which each other via an IS. This includes the organisation of common data access by transmitting data; arranging accessibility and synchronizing the process of exchange.

'Exploration and Evaluation Tools' serve the purpose of complex data analysis, simulations and assessment. They also indicate corresponding skills of people who use them. Whereas the first four categories are mainly related to the manipulation of data for purposes of individual or collaborative knowledge acquirement, the following deal with the adaptation of existing or the construction of new informatics systems.

The use of 'Development Tools' including the use of Macro-tools indicates the ability of a person to adapt an existing IS for personal needs in a given application scenario. It also implies the use of a script language or programming language tool to develop software or rather an IS for specific purposes. Finally, the use of a development tool indicates the ability of developing software in an extensive way.

3.3 Level of Application

The dimension '*Level of Application'* measures the complexity of the functions of an informatics system which are used in a given scenario of application. The category 'Guided Use of Selected Basic Functions of the IS', for instance, is often realized in a learning software. 'Scenario Adequate Free Choice of Selected Basic Functions of the IS' is mainly linked to cognitive tools. The other categories of the dimension 'Usage of Selected More Complex Functions of the IS', 'Competent Extensive Use of Systems Functions' and 'Combined Co-ordinated Use of different IS' are representing an increasing complexity of the usage of the system.

3.4 Level of System Comprehension

The dimension '*Level of System Comprehension'* provides us with a system of measurement for the degree of comprehension of the IS functionality and of its implicit informatics concepts. The model distinguishes between four levels of comprehension. Each of them is subdivided into further levels. They are concerned with informatics systems related aspects. They also deal with the cognitive ability of a person to reproduce given facts or to transfer experiences in other application scenarios and to assess them.

The sub-dimension 'Knowledge' first of all describes a person's ability 'to Understand Basic System Functions and Basic Concepts of Systems Hardware' of an available IS or an IS to be developed. The 'Knowledge of Selected Views of the Informatics System' describes the ability of a person to deal competently with relevant informatics concepts a given system consists of. This includes knowledge and skills in the subject areas of algorithms, source code and programming language, human computer interaction and graphical user interfaces, design models, protocols, informatics theory, hardware etc. The category 'Comprehension of Fundamental Informatics Principles und Abstract Concepts' indicates that a person is able to deal with abstract meta models of informatics systems like design patterns or theoretical models like the 'Turing Machine'.

The sub-dimension 'Transfer of Knowledge' consists of two categories. The category 'Ability to Use ICT-Knowledge in Familiar Application Scenarios' may be assigned to a person, who has the ability of domain specific knowledge transfer by using information in familiar application scenarios. A higher level of knowledge transfer is represented by the category 'Ability to Transfer ICT- Knowledge to a New Context' Students classified as belonging to the second sublevel of this category are expected to be capable of using information, methods, concepts and theories in new contexts to solve problems. Thus, this category sublevel indicates problem transfer skills that exceed domain specific scenarios.

The sub-dimension 'Complexity of Construction' deals with the students' abilities of re-engineering and software-development. The category 'Comprehension of a System's Coherence (Ability of Re-engineering)' characterises a person who comprehends the informatics systems coherence and who is capable of performing the systems re-engineering. Persons who are assigned to the second sub-level 'Using Information, Methods, Concepts and Theories in New Context to Build Systems' are supposed to be extensively qualified for software development.

Finally, the sub-dimension 'Assessment' first of all characterises a person, who is capable of doing assessment and evaluation of an informatics system in an all-embracing way. This category is particularly suitable to indicate the capability of system analysis that includes assessment of system design and the system's functionality in its direct socio-technical context. Further on, the second category 'Evaluation of IS Current Social Impact and IS in Historical Perspective' implies the ability to evaluate the general societal impact of an informatics system and its significance from a historical perspective.

With regard to the competence model we have to take into consideration the ambiguous character of the categories. They are related to the application area of software (e. g. cognitive tools) as well as to the process of software development (e.g. construction tools).This deliberately intended concept takes into consideration both relevant aspects of software and informatics systems to be a product with specific properties as well as the result of a construction process. Furthermore, we have to pay attention to the contents the competencies are related to. When constructing items for empirical studies on the basis of this concept the students' real world experiences like personal, educational, occupational, public and scientific application areas should be incorporated, similar to the PISA concept.

4. CONCLUSION AND FURTHER WORK

The presented competence model can provide us with a theoretical concept for further discussions and empirical research in the area of informatics education. Its explanatory statement requires without doubt more theoretical argumentation and refinement of the categories. It has to be improved during further discussions with regard to reliability, validity and the discriminatory power of its categories. As an aftermath of this discussion a lot of test items concerning the various competency clusters of the model have to be designed and empirical studies should be carried out. It would be eligible if this took place on an international level. Thus, students' competencies in different knowledge areas corresponding to the IFIP / UNESCO curriculum could be tested. In this way the contribution of ICT-education to general education and the development status of informatics education in different regions could be clarified.

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