Informatics to Foster Scientific Culture

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Abstract: The paper gives a résumé of the research project INEL. We describe an educational approach to promote competences about Internetworking and its realization in classroom practice as example how the general public can be engaged in discussions of science and technology. According to the method of Didactic Systems learner-centred scenarios can be implemented to improve the responsible-minded communication and retrieval of information on the Internet. Thus, enhancing scientific culture by informatics provides the prerequisites to realize educational standards in the practice of teaching and learning.

Keywords: Classroom Teaching/Practice, Secondary Education, Internet

1. Research Objectives

Informatics has influenced the cultural development through the last decades enormously. “Web researchers have discovered new social behaviours and ways of computing by using the entire Web as their laboratory” (Denning, 2007, p. 14). The Web refers to a phenomenon with global dimensions. This phenomenon is called the digital media upheaval, i.e., a comprehensive sociocultural and technical change of the whole media system. Informatics promoted the digital media upheaval providing new media and has to cope with connected educational requirements. Thus, the digital media upheaval motivated a research project that lead to conclusions which influence Didactics of Informatics at international level.

The project “INEL – Informatics Education and E-Learning for Active Participation in the Digital Media Upheaval” was designed to explore the role of informatics as content and medium in education. The project (2005-2009) is promoted by the German Research Foundation. Four research questions were identified:

1. Which contributions of informatics were recommended by international curricula to enable a mature citizen to react consciously and emphatically facing problems of the digital media upheaval?
2. Which educational model is appropriate to support an understanding of Internet structures, communication, and information security on the Internet?
3. How is the successful concept Didactic System, composed of knowledge network, exercise classes, and exploration modules, applicable to contribute to developing the recognised levels of competences (results from questions 1 and 2)?

4. Which classroom practice will meet the educational requirements (results from question 3) in upper secondary education?

2. Research Methodology

Our research methodology consists of six phases (see Figure 1). **Phase1.** We analysed international curricula and recommendations for informatics and ICT education to describe educational demands and to determine necessary competences. **Phase2.** We proposed research questions and created a hypothetical solution which connects informatics and educational science. The framework for a course concept was developed as Didactic System Internetworking\(^1\). A Didactic System comprises structuring of learning objectives \(S\), called knowledge networks, exercise classes \(E_C\), and learning software \(E_M\) supporting learner activity within the learning process (Schubert, 2005). **Phase3.** We developed an educational model and lessons which led to an understanding of Internet structures (A), communication on the Internet (B), and information security on the Internet (C). We used the theories to construct a learner-centred and application-oriented approach. **Phase4.** In 2006, 2007, and 2008 the classroom intervention based upon Didactics of Informatics took place at secondary level with student teachers. We aimed at qual-

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\(^1\) The term Internetworking is made up of internetwork and networking, i.e., networking as the establishment and use of internetworks.
tative studies and discovered demands for learners’ activities and new learning aids, which had to be developed. We got results with respect to acceptability by learners and general feasibility. **Phase 5.** For the evaluation learners had to fill in a questionnaire and to take a test and we interviewed the teachers of the informatics courses. We achieved a set of empirical data which we reflected and discussed in teacher education. **Phase 6.** The Didactic System Internetworking was published to improve the theory of Didactics of Informatics and to get new research questions on a higher level.

3. Theoretical Basis for Innovation in Informatics Lessons

3.1 Visualisation of Didactic Meta-Knowledge

As starting point for the theoretical foundation we used the approach of Didactic Systems. The component knowledge network is used to explicate didactic knowledge about the structure of knowledge in informatics. An exemplary knowledge network which was used during the research project is shown in Figure 2. The vertices represent knowledge elements which are connected by learning activities. We assign three functions to them: (1) Knowledge networks describe necessary previous knowledge and possible sequences in learning processes. (2) They facilitate determining the current degree of knowledge attainment. (3) They allow the comparison of different variants of learning processes. Thus, knowledge networks support teacher and learner before, during, and after lessons and courses. In INEL knowledge networks have been used to encourage communication about learning.

![Figure 2: Exemplary knowledge network](image-url)
strategies between teacher and learners. This was essential for the learner-centred approach. The learners could improve the level of responsibility for their learning process.

These functions result in concrete requirements of constructing and representing knowledge networks. Learners’ prerequisites have to be considered describing adequate sequences of knowledge elements in learning processes. Meaningful learning requires that new knowledge is related to already available knowledge. Moreover, a learning sequence depends on whether there exist adequate learning activities. This shows the relation to the exercise classes and learning software which describe respectively facilitate activities for learning. Furthermore, the description of the degree of knowledge attainment requires that concrete learning outcomes are specified. Furthermore, facilitation of comparing variants of learning processes demands the possibility to abstract from specific details to create a clear and thus comparable representation. Depending on the didactic function the structure of the knowledge elements is discussed by means of differently detailed representations. For example, subject-inherent logical relations can be discussed by means of relations between knowledge elements while learning objectives have to be considered regarding aspects that are specific for a target group. The comparison of different knowledge networks demands a comprehensible representation. Therefore, the knowledge elements have to be refined and the relations have to be explained. Thus, the theory of knowledge networks must be enhanced.

3.2 Approachability in Learning Processes

Structures of the subject are used to disclose relations between knowledge elements. The knowledge about these relations must be considered when designing learning processes because they describe necessary previous knowledge. But it is not possible to derive learning processes in secondary education just from the structure of the subject. A basis for the analysis of the subject-specific structure is to identify superordinate, subordinate, and combinatorial relations between knowledge elements. These relations have to be disclosed to make meaningful learning possible. Meaningful learning requires substantive learning and that new knowledge is nonarbitrarily related to what the learner already knows. We discern meaningful learning from rote learning to describe the difference. The anchoring ideas, i.e., what the learner already knows, are necessary prerequisites for building relations to new knowledge. It is not possible to establish nonarbitrary relations in learning processes without anchoring ideas.

The didactic meta-knowledge describes structures of the development of new knowledge. Based on the theory, that knowledge is composed of concepts as the basic elements, learning means to attain propositions which are chains of concepts. Propositions comprise factual, conceptual, and procedural knowledge. Thus, the knowledge of concepts is the prerequisite for learning propositions, i.e., to
attain the linkage between the concepts. For example, the concepts client and server are the basic components of the proposition client-server model which describe the principle that a client requests a service from the server by a network connection. Furthermore, there are two types of relations between propositions which have to be discerned. Logical relations indicate commonness and peculiarities of an issue which is described by a proposition. Psychological relations describe assumptions about the necessity to learn one or more propositions before another one. Thus, it is possible to describe the path from concepts taking logical and psychological relations towards the learning objective as one or more propositions. The described knowledge attainment is the prerequisite for problem solving as application of propositions.

It is not enough to consider the subject-inherent logical structure to describe didactical knowledge about appropriate learning paths and to structure learning processes. Further prerequisites respectively experiences and attitudes have to be regarded. That is described by the term approachability which decisively affects the planning of course sequences in terms of contents. Hence, the structure of the contents is not finally given. Both, logical and psychological aspects have to be considered. It is necessary to define which approaches, learning tasks, and applicability of the knowledge are appropriate to make the contents accessible respectively to make learners willing to assimilate the knowledge. Only the linkage between didactic and subject-specific knowledge as well as the consideration of characteristics of the target group allow to structure contents for learning processes. The approachability is concerned about the question of appropriate learning paths. Bennedsen and Schulte (2007) analyse different approaches to object-oriented programmming. Integral part of each approach is an appropriate learning activity. Hence, it is necessary that for each relation between knowledge elements within the knowledge network at least one adequate learning activity exists.

### 3.3 Different Stages of the Visual Representation

The definition of learning objectives is an essential element for planning learning processes and for designing tests. In this section we analyse the relation between learning objectives and knowledge networks. Didactic meta-knowledge for defining the current state of learning outcome has to be also described with knowledge networks. Steinert (2007) describes a similar approach to represent learning objectives for assessment. In the graph vertices represent operationalised learning objectives. Directed edges between learning objectives represent two types of relations which indicate prerequisites. First, vertices are related to each other because of the subject-inherent structure. Second, learning objectives are assessed according to their rising knowledge and process category (cf. Fuller et al., 2007). Within the graph of learning objectives logical, and therefore, objective relations between content and behavioural components are described. But the limitation to generally valid relations of prerequisites is not appropriate as we have explained in the pre-
ceeding section. Otherwise, the important aspect approachability would not be considered.

Educational taxonomies discern levels of learning objectives (Fuller et al., 2007). The topmost level comprises global objectives which are broadly stated and allow different interpretations. Educational objectives make concrete global objectives. But they are still too vague to use them for defining suitable assessment procedures. The most specific level of objectives is the level of instructional objectives. They define the learning outcome as concrete behaviour of learners. Objectives at the different levels are used in different phases of planning learning processes. The objectives at the different levels are related to each other. Decisions about objectives, contents, and methods are interdependent throughout planning of learning processes. Hence, objectives at the lower level cannot be logically derived from an objective at a higher level. Therefore, knowledge networks can be described at different levels. The representation at different levels supports the description of different aspects. This meets the requirements which are derived from the application of knowledge networks in the planning process and from the design of assessments, i.e., to assure its lucidity and its precision. Knowledge networks are considered to be just partially adequate to represent the current state of learning outcomes. To reach one vertex does not implicitly mean that a learner also has reached previous vertices. That is contrary to graphs of learning objectives. Otherwise knowledge networks had to be definite and generally valid. This is not possible because they comprise logic and psychological relations. The level of educational objectives has proved to be adequate to describe these relations. A sound verification of knowledge networks requires also an empirical test of adequate learning activities. The relations between knowledge elements within the knowledge networks have to be traceable to support the didactic discussion about the structure of learning objectives. On the one hand, this requires that contents have to be made concrete by extension of examples respectively analogies which are used during the learning process. On the other hand, relations have to be specified more precisely. We identified different types of relations referring to the example Internetworking (Freischlad, 2008a).

4. Classroom-Based Learning about Internetworking

4.1 Empirical Studies: Three Classroom Projects

The evaluation of relations between knowledge elements as described by knowledge networks, objectives of learning processes, and learning activities require empirical studies. We have implemented the Didactic System in cooperation with schools in upper secondary education. Three classroom projects were conducted from 2006 to 2008. The results of these studies were used to refine and extend the theory-based approach. The first project took seven weeks and was completed by a written test. Pupils learned that it is possible to identify persons who exchange
data on the Internet by considering the principle of packet switching. This knowledge is the basis to understand the issue “anonymity on the Internet”. Furthermore, they learned about security risks that are assigned to e-mail exchange and how it is possible to protect oneself from these risks by reconstruction of the e-mail transfer path and by encrypting and signing messages. The third issue was about protection of personal data and web-cookies. During this classroom project we found out that the topic Internetworking – that was not established in schools so far – is accepted by learners and teachers. Emerging difficulties could be traced to the fact that the functionality of the Internet is not directly observable. Although learners had already got experiences in programming they were not able to solve programming tasks concerning functionality of the Internet. Therefore, the exercises’ level of difficulty was revised. Thus, requirements of new learning material that supports an appropriate approach had to be theoretically explained and implemented.

The second classroom project was conducted as a course for eight weeks with an additional test. The course was extended by the issues “information retrieval on the Internet” (cf. Iding, 2007) and “exchange of confidential messages” as well as the concepts about the Internet layer model. For this, we could base upon experiences from a scientific attended trial the year before. The results of this classroom project comprised knowledge about the design of exercises and test items (Freischlad, 2008b) which contribute to the development of media competences. The third classroom project in 2008 was conducted by the course teachers while the first two were conducted by student teachers who were attended by the course teacher and the researcher. The last project lasted four weeks. Thus, the integration of the didactic concept into school practice was completed. The research focus during the last classroom project was on the evaluation of new learning software for Internetworking which was developed in the scope of this research project.

4.2 From Structured Exercise Classes to Exercises and Test Items

An exercise class is the abstraction of a set of exercises or test items which are characterised by the same knowledge necessary to solve them. We refer to this knowledge as the informatics core of an exercise. Exercise classes are used to enable learners to apply informatics concepts in different situations (Habermann et al. 2008). Therefore, learners have to find and apply an appropriate strategy to solve the exercise that is related to one or more exercise classes. The classification of exercises and the structuring of exercise classes support learners and teachers in selecting exercises for concrete learning processes. Furthermore, teachers can use exercise classes as templates to design new exercises. These two functions of exercises result in requirements for the hierarchical structure of exercise classes. First, the hierarchy has to show how exercises can be connected. Thus, dependencies between the necessary knowledge assigned to exercise classes have to be considered. Second, the application of exercises must be understandable for teachers.
and learners. Therefore, the characteristics which are used for the structuring must be transparent. Learning processes have to be varied. Basic types and variations of exercises have to be illustrated. Exercise classes are used as templates to design new exercises if there is no exercise assigned to yet. Thus, only necessary characteristics of exercises have to be defined by exercise classes.

There are different possibilities to develop the structure of exercise classes. Brinda (2007) has analysed exercises in textbooks about object-oriented programming to get exercise classes by abstracting from the context. To proceed this way means that the identification of an exercise class depends on the existence of associated exercises. Prerequisite to achieving sustainable results is that there are enough exercises. The available exercises have to be representative. Another possibility is to define exercise classes from the subject-area and in a second step to assign existing exercises. There are not enough exercises about Internetworking. Therefore, we analysed textbooks with regard to fundamental concepts and their relations to each other. Thus, we defined a regulative structure of exercise classes. The structure was defined according to the following characteristics: At the first level we discern subareas of Internetworking with as few connections as possible. The second level is composed of the fundamental concepts which describe the subarea. And at the third level we discern factual, conceptual, and procedural knowledge. Besides combining exercise classes in one test item the knowledge type is another attribute to adjust the level of difficulty. Our approach for the description of exercise classes included analysing five textbooks. Different approaches for structuring the area were identified and evaluated regarding their suitability for informatics in secondary education (Freischlad and Schubert 2007).

4.3 Learning Software to Foster Exploratory Learning

The classroom projects disclosed that there is a need for learning material that supports exploratory learning activities. The evaluation of the projects was composed of teacher interview, questionnaire for the learners, observations during the lessons, and a final test. The evaluation led to concrete requirements for learning material. Without appropriate learning material, the structures of the Internet are concealed from learners. We introduced this topic by analysing the local network at school. But important aspects are not represented by this computer network. First, the functionality of routers that connect local networks is not considered. It is not possible to illustrate forwarding of IP packets by the target address in the header. Second, the hierarchical organisation of the connected networks is not approachable. Local networks are connected to the network of an Internet service provider (ISP). The networks of local ISPs are connected by regional ISPs and so on. We used the tool Traceroute to show transfer paths. Thus, it is possible to show cycles and alternative routes. But the hierarchical structure remains hidden.

The observations during the lessons and the evaluation of test results revealed learning barriers. The reduction of the complexity of the real infrastructure may
lead to cognitive models that are not viable. Learners sent and received e-mails using the text-based protocols Simple Mail Transfer Protocol (SMTP) and Post Office Protocol (POP). The e-mail exchange was processed between the personal computers of the learners and a separate computer in the computer lab within the local network. In reality, the transfer of an e-mail to the recipient’s mailbox is processed by more than one mail-server. This knowledge is a necessary prerequisite to understand why it is not possible to avoid spoofing mails. But the learners were not able to apply their knowledge about the functionality of the protocols to the more complex real-world situation during the following talk in the classroom. The learning software which copes with these requirements was developed by a team of student teachers. We implemented four views of the Internet regarding the requirements: The Network View allows to build up virtual internetworks composed of computers, switches, routers, and modems connected by cables. The Application View offers a virtual desktop for every computer and is used to start applications like web-server and web-browser to initiate data transfer on the simulated virtual internetwork. The Message View displays the messages which are exchanged between the computers respectively programmes. The Source Code View enables learners to add or modify their own network applications by means of the programming language (see also www.die.informatik.uni-siegen.de/pgfilius).

Several classroom projects were realised and the theoretical approach based on knowledge networks has been refined. Concrete requirements which were derived from the case studies have been taken into account to describe the approach for designing exercises and test items as well as to the development of the learning software. The integration of the concept derived from required competencies into classroom practice has been successfully concluded.

5. Conclusion

The paper has shown how informatics, in this special case Internetworking, is fostering scientific culture. This is one example how the general public can be engaged in discussions of science and technology. Secondary education in Informatics must at least be capable of assessing the relevance of arguments put forward by experts and understanding the possible consequences of the authorities’ proposed measures on the society. Since 2006 the classroom practice has met the objectives every year and has created a new learning tradition not only in school partnerships of Germany (see Section 4) but also in other European schools as result of the research cooperation through IFIP conferences (see also www.die.informatik.uni-siegen.de/lehrstuhl/freischlad/internetworking/en.html).
The Didactic System Internetworking has been systematically improved by this classroom practice and now provides a collection of well-coordinated teaching-and-learning-materials:

- a knowledge network (see Section 3),
- a set of exercise classes (Freischlad and Schubert, 2007),
- software to support exploratory learning (see Section 4.3).

This allows connecting two theories, the system oriented approach and the concept of Didactic Systems, and to realize educational standards in the practice of teaching and learning.

The next task is to structure a model of competences with dimensions and levels that will be accepted by an international community of teachers and researchers.

References


