Perspectives on an integrated computer learning environment

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Summary

This thesis is about my research and development work in the last decade that aimed at improving the contribution of information and communication technology (ICT) to inquiry-oriented mathematics and science education at secondary school level. On the one hand, I aimed to contribute to the perspectives on the role of ICT in quantitative mathematical modeling, pragmatically defined as exploration of mathematical models with the support of ICT tools in order to come to grips with natural phenomena and to interpret real data. On the other hand, I aimed to contribute to the development of an open activity-based computer working environment that offers its users a versatile set of integrated tools for the study of natural phenomena, mathematics, science and technology. More specifically, I aimed at contributing to the development of an integrated computer learning environment by making recommendations about the functional design on the basis of classroom experiments and sample activities, and by exploration and analysis of educational needs and possibilities, especially regarding inquiry activities. The second purpose of the classroom experiments was to explore how ICT can contribute to the realization of students' practical work that resembles applied mathematics and science practice. This is how I mainly interpreted the authentic nature of students' practical work: activities in which they do research in much the same way scientists and practitioners do and in which they use high-quality tools that are similar to professional tools, but that have been designed for educational purposes.

The scope of my study was limited to pedagogical and software design perspectives on ICT use in inquiry activities in which students develop mathematical and scientific literacy. Its main focus was on ICT-supported practical investigations and research projects at pre-university level in which students learned to apply and deepen their mathematical and scientific knowledge and worked in manners that resemble the ways in which scientists and practitioners explore phenomena. Driving questions were:

- How can the use of ICT and in particular of an integrated computer learning environment contribute to the realization of challenging, cross-disciplinary practical work of good quality, in which pre-university students can work with real data, apply mathematical methods and techniques in concrete problem situations, improve their mathematical and scientific knowledge and skills, and increase their mathematical and scientific literacy?

- What integrated tools should the computer learning environment provide for inquiry-oriented mathematics and science education? What are the requirements for the computer learning environment from a mathematical point of view and do they link up with requirements coming from science fields?

In other words, the two main results at which I aimed in my study were: (1) better understanding of how, why, and to what extent ICT tools can support students in their learning and practice of scientific inquiry; and (2) more insight in what it takes to develop an integrated computer environment for learning mathematics and science in the context of inquiry-oriented approach, the usability of which is explored within educational practice. In both explored perspectives, I used a specific computer learning environment, namely, Coach, to learn lessons from developing ICT tools that are integrated in an open, activity-based, multimedia authoring environment for mathematics and science education, and to learn lessons from exploring their usability in specific practical investigations for upper secondary students, in sample activities, and in usability studies.

In my thesis work, research and development were intertwined. Focus was on students' working with real data and on the design of supportive tools. The intention was to bridge the gap between mathematics and science education at school on the one side and modern research carried out by professionals on the other side, through provision of a suitable computer learning environment for inquiry-oriented mathematics and science education. The framework for my research and development work was formed by elements of design research, case-based design of educational software, frameworks on using multiple representations, frameworks on evaluating inquiry activities of students, and of models of modeling.

Chapter 1, in which I introduce the thesis work, is organized as follows. Regarding the motivation and scope of my research and development work, I describe the main components of the multiform context of my study. To this end, I present in the first section the educational context, and especially changes in the Dutch curricula for pre-university mathematics and science education in the last decade. In the second section I go briefly into previous research and development work at AMSTEL (Amsterdam Mathematics Science and Technology Education Laboratory) that laid the foundations for my study. In the third section I point at the multiformity of ICT tools for secondary mathematics and science education and at the differences between ICT usage in these disciplines, which called for an investigation into the possibilities of an integrated computer environment for learning and doing both mathematics and science. In the fourth section I describe the aims and set-up of my research and development work. Finally I outline the structure of this thesis.

Chapter 2, in which I report on the results of classroom studies on ICT-supported practical investigations, is organized as follows. In the first introductory section I explain how the reports in subsequent sections have been compiled from papers published in conference proceedings and journals. These papers, together with corresponding instructional materials, can be found on the CD-ROM that is part of the presented research and development work. Because the research settings and methods applied in the case studies had much in common I also briefly discuss these aspects of the case studies in the introduction. The classroom studies have been grouped on the basis of the subject of the students' investigations and on the characteristics of the ICT use. This led to the following categorization: (1) student work with real data, tables, and graphs in the context of human growth; (2) investigation of shapes of real objects through digital image analysis and mathematical modeling; (3) video analysis of human locomotion. (4) video-based practical work at pre-vocational secondary school level; (5) spreadsheet-based investigation in the context of survival analysis of clinical data and in the context of handling weather data; (6) computer-based modeling in the context of quantitative pharmacology, and particularly in the context of alcohol metabolism; and (7) combination of video analysis and computer-based modeling in a study of bouncing balls. I mainly report on the student work and the use of ICT in the practical investigation tasks listed above.

In Chapter 3 I present exploratory case studies on working with real data in practical investigation tasks using the versatile computer learning environment COACH 6. The presented case studies are field experiments and usability studies that were part of my development work on the design and implementation of an integrated computer environment for learning mathematics and science in an inquiry-oriented approach. These studies served in fact many goals: (1) They were meant to gain insight in the needs of secondary school students for doing authentic inquiry work. (2) They helped me specify requirements for an integrated computer learning environment from a mathematical point of view. (3) They served to test the usability and scope of (prototypical) implementations of particular tools for collecting, processing and analyzing data. (4) They gave an impression of the potential of ICT regarding the realization of challenging, cross-disciplinary practical work in which secondary school students were engaged in activities such as experimenting, data collection, and data analysis in much the same way as scientists and practitioners. In Chapter 3 I have selected some of my papers and briefly describe their contents. Although most papers contain examples of integrated use of more than one tool, they have been categorized according to the most eye-catching tool part. This led to the following sectioning of the chapter: (1) overview of activity types; (2) digital image and video analysis; (3) modeling; (4) combination of measurement with sensors, control of experiments, and video; and (5) combination of video analysis and modeling.

In Chapter 4 I recap and discuss the results and conclusions of the reported research and development work, that is, I go into the main aspects of scientific inquiry and authenticity addressed in the case studies and into the tool design of an integrated computer environment for inquiry-oriented mathematics and science education. Thus, my reflection on the outcomes of the exploratory case studies is to a large extent oriented toward answering the two questions that were driving my research and development work. Finally, I reflect on my work as a whole and go into possible implications for future research and development.