Modeling as a tool for co-operation between physics and other subjects; A course for in-service teachers from upper secondary education

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Abstract
A structural reform of Danish upper secondary education implies that more lessons are set aside for optional subjects organized as subject packages. An important feature of a subject package is that the participating subjects form a coherent program ensured by a closer interaction between the subjects. Some of the subject packages have as their core mathematics, physics, chemistry and biology. To implement the objectives of the reform co-operation across the traditional boundaries between the subjects is required both at the level of subject matter as well as at the level of pedagogy. To prepare the teachers for the reform the University of Southern Denmark developed the course "Modeling as a tool for cooperation between the subjects of the natural sciences". In the course the teachers are introduced to a didactical framework for co-ordination and mutual interaction of the subjects of mathematics, physics, chemistry and biology. As a part of the course the teachers develop and implement integrated modeling instructional units, which are presented at a seminar for teachers.

Introduction

In Denmark a structural reform has been introduced into upper secondary education. The reform implies that students choose among subject packages where the participating subjects form a coherent program. To prepare students for studies in science, mathematics and technology in tertiary education some of the packages have as their core the subjects of physics, chemistry, biology and mathematics. To implement the objectives of the reform co-operation is required across the traditional boundaries between the subjects both at the level of subject matter as well as at the level of pedagogy. Future mathematics and science teachers will need thorough and interconnected knowledge of their subjects. This calls for an in-service teacher training program with the aim of producing teachers who are committed to an increasing understanding of the connections between science, mathematics, and technology.

1 Modeling as a tool for co-operation between the subjects of mathematics and natural sciences

Many mathematics and science educators are in favor of a more realistic education where modeling activities are used to treat concepts in realistic, everyday life contexts [1], [2]. As a rule modeling activities take place in an interdisciplinary context and are therefore a promising frame for elucidation of the relations between mathematics and science. Based on the assumption that models for making sense of complex systems are some of the most important components of knowledge of mathematics and science a team of science and educational researchers from the University of Southern Denmark and teachers from upper secondary schools have developed the course "Modeling as a tool for co-operation between the subjects of natural sciences" for in-service teachers from upper secondary education.

1.1 A didactical model for co-operation between subjects

One of the great challenges of the reform of Danish upper secondary education is the development of integrated learning environments across mathematics and science. Although it's a common view among many teachers in upper secondary schools that closer relations

between mathematics and science should help the students to grasp both mathematics and the subjects of the natural sciences, a better co-ordination and mutual interaction of the subjects is far from being a trivial task. What is needed is a didactical model for integrating productive ideas from a variety of theoretical and practical perspectives on the relations between mathematics and science.
During the course the teachers are introduced to a didactical model for co-ordination and mutual interaction between mathematics and science. The model consists of two phases: *horizontal linking* and *vertical structuring*. In the horizontal phase thematic integration is used to connect concept and process skills of mathematics and science by modeling activities. Also in this phase explicit connections are established between the process skills of mathematics and science. The vertical phase is characterized by a conceptual anchoring of the concepts and process skills from the horizontal phase by creating languages and symbol systems that allow the students to move about logically and analytically within mathematics and science without reference back into the contextual phase. The shift from the horizontal to the vertical phase thus might concur with a shift from integrated instruction to subject-oriented instruction. It should be stressed that the didactical model is iterative. Once the concepts and skills are conceptually anchored in the respective subjects, they can evolve in a new interdisciplinary context, as part of a horizontal linking [3].

1.2 A System Dynamics approach to modeling

In science education it is often accentuated that many phenomena and their patterns of interaction are best described in the language of mathematics, which then becomes a bridge between the students' verbal language and the scientific meaning we seek to express. In the course mathematics plays a central role. In our view the importance of school mathematics should be justified by the fact that it provides the students with powerful tools for dealing with the quantitative aspects of the world. This role is brought about predominantly through the building, employment, and assessment of mathematical models.
When students are involved in modeling activities in an interdisciplinary context they are confronted with information from multiple sources that is presented and communicated in different forms. To avoid the problems brought about by the differences in terminology and notational systems and create a common domain for mathematics and science a System Dynamics approach to modeling is introduced in the course. A system dynamics model integrates and runs all the variables of the system in a dynamic way, which means that students involved in a modeling activity gain practice in identifying and representing variables across the boundaries between subjects.

2 The modeling course

It is the core idea of the course to involve teachers in design, implementation and evaluation of innovative instructional sequences, which deals with a wide range of aspects of mathematics and science. The educational reconstruction model developed by Kattmann et al [4] provides a framework for designing, implementation and validating the instructional sequences. The model consists of three main components which mutually interact: First, analysis of the content structure (including the educational viewpoint); second, the execution of empirical investigations which at first have explorative character; and third the construction of instructional units. These three components are supposed to stimulate each other in an interactive and cyclic process.
The development of the modeling course was initiated in the autumn of 2004 where 12 teachers participated in a pilot study funded by the Danish Ministry of Education. Based on the experiences from the pilot study the first version of the course was developed in the autumn of 2005. The course's objectives were

- to develop prototypes of interdisciplinary instructional units centered on modeling activities and including at least two subjects,
- to encourage the creation of communication between the subjects of biology, chemistry, mathematics and physics, and
- to introduce the teachers to the System Dynamics approach to modeling in an interdisciplinary context.

In the spring of 2006 14 teachers with several years of teaching experience participated in the course, which was structured as three sessions: a 3-days workshop, a 2-days workshop and an open seminar. During the two workshops the teachers were accommodated in a hostel. All the sessions included inspiration lessons by modeling experts from The Faculty of Science at University of Southern Denmark.

2.1 The modeling workshops

The first workshop began with a presentation of the didactical model of horizontal linking and vertical structuring, and the model of educational reconstruction. Then the software Powersim was introduced. Powersim is a tool for System Dynamics modeling. During the workshop the teachers were shown examples of modeling with Powersim and worked in groups with the program.

To effectively create interdisciplinary teaching units teachers from different subjects need to collaborate. Therefore the first workshop was ended with creating 7 interdisciplinary teams of 2 – 3 teachers representing different subjects. Once the teams were established the members faced the challenging task of designing a scenario for an interdisciplinary instructional unit centered on modeling activities and including at least 2 of the subjects of physics, chemistry, biology and mathematics.

The second workshop was held 1 month after the first. Each of the teams gave a preliminary report about their instructional unit and got comments from the other teams. The participants were also introduced to a guide for reporting on their project. Then the teams had 1½ month for writing a report with a description of their interdisciplinary instructional unit, preparing a presentation of the unit at a seminar, and implementation of some of their ideas in the classroom.

2.2 The modeling seminar for teachers

A factor relevant to successful innovations is the degree to which it is perceived better than the existing program it hopes to supersede. Lesh & Sriraman [5] introduce the main law survival of the useful law that determines the continuing existence of innovative programs and curriculum materials. Usefulness involves going beyond being powerful in a specific situation and for a specific purposes to also be sharable with other people and re-usuable in other situations. It is therefore of great importance to make the improvements available to a larger community of teachers. To meet this challenge the teams presented at the final session their interdisciplinary projects for discussion at an open seminar at University of Southern Denmark attended by 32 upper secondary school teachers. Table 1 below shows the projects presented:

Project:	Subjects:
• Mathematical modeling with Powersim	• Mathematics and biology
• Models – interplay between reality and simulation	• Mathematics and physics
• Data sampling and modeling	• Mathematics, chemistry and biology
• Modeling an inclined throw	• Mathematics and physics
• Traffic and kinematics	• Mathematics and physics
• Mathematical modeling and enzyme kinematics	• Mathematics, biology and chemistry
• Modeling with dynamic diagrams	• Mathematics and physics

TABEL 1: Interdisciplinary instructional units presented at the open seminar for teachers

The table shows that there were different approaches to projects ranging from a focus on the software to a focus on the modeling process. Looking at Table 1it is not unfair to say, that the topics of the projects are ones that belong in the traditional content of the subjects. Therefore it is obvious to include a more up-to-date interdisciplinary content including technological and socio-scientific issues in the next version of the modeling course.

After the seminar reports, presentation and lecture notes from the teams were made accessible on a website [6].

Conclusions

Modeling provides a generic methodology that can serve as a common denominator for learning subjects such as physics, biology, chemistry, and mathematics. The teachers welcomed the opportunity to explore new ways to engage students in interdisciplinary modeling activities. There were among the teachers agreement on that the course supported active innovation and intervention in classrooms. The System Dynamics approach was according to the teachers a new way to enhance students' understanding of complex systems and formal thinking. But the integration of System Dynamics into teaching is also challenging and time consuming.

From our experience the course structure with workshops and an open seminar made it possible for the teachers to share their ideas and experiences with their colleagues and having contacts with academic experts in the fields of modeling and educational research. However, to get full profit of interdisciplinary modeling activities further research on the constraints and possibilities of the cooperation between the subjects of physics, chemistry, biology and mathematics is needed.

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