

Cross-Curricular Activities Within One Subject?

Modeling Ozone Depletion in 12th Grade

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Abstract: The structural organization of the Danish Gymnasium greatly hinders cross-curricular activities. However, it is possible to integrate other subjects in the mathematics curriculum, not the least due to the existence of the so-called “aspects”. I will discuss a particular course on modeling ozone depletion which was framed by the “model aspect”. The organization and outcome of the course are linked to three types of competencies: mathematical, technological and reflective. I will focus on the reflective competency, in particular the critical evaluation of mathematical models and their use. One conclusion is that modeling furthers all three competencies, and thus should be given more emphasis in mathematics instruction. However, if the reflective competency is to be furthered, the topic must be seen in a broader societal context, and this would be better supported by cross-curricular activities.

Kurzreferat: *Fächerübergreifende Aktivitäten in einem Fach? Modellierung der Ozonzerstörung in einer 12. Klasse.* Die strukturelle Organisation eines dänischen Gymnasiums behindert fächerübergreifende Aktivitäten enorm. Es ist jedoch möglich, andere Fächer in das Mathematikcurriculum zu integrieren, nicht zuletzt wegen der sogenannten “Aspekte”. Im folgenden wird ein spezieller Kurs zur Modellierung der Ozonzerstörung diskutiert, der in den Rahmen des “Modell-Aspekts” gestellt wurde. Organisation und Ergebnis des Kurses waren mit drei Kompetenzen verbunden, nämlich mathematischen, technischen und reflektiven. Die Betonung in diesem Beitrag liegt auf der reflektiven Kompetenz, insbesondere auf der kritischen Bewertung des mathematischen Modells und seiner Anwendung. Unsere Schlußfolgerung ist die, daß Modellbildung alle drei Kompetenzen fördert. Deshalb sollte ihr im Mathematikunterricht ein viel größeres Gewicht beigemessen werden. Soll jedoch reflektive Kompetenz gefördert werden, so muß das Thema in einen breiteren gesellschaftlichen Kontext gestellt werden, was durch fächerübergreifende Aktivitäten besser unterstützt würde.

ZDM-Classification: A40, D30, M10

1. The lack of cross-curricular activities in a Danish Gymnasium

According to the official mathematics curriculum for Danish Gymnasiums (10th-12th grade), students are to achieve

confidence with mathematics as a means of formulating, analyzing and solving problems within different subjects or disciplines. This could be perceived as an encouragement to engage in cross-curricular activities combining different school subjects. However, the structural organization of teaching does not support this type of cross-curricular activity. Several levels of mathematics are taught, and the students can choose various other subjects on different levels, so not all students in a classroom follow the same courses. This is one of the drawbacks of the system.

This does not mean, however, that all sort of cross-curricular activities must be excluded. Claus Michelsen (personal communication) distinguishes between three ways of organizing cross-curricular activities:

- It can be within the subject itself (mathematics or the mathematics lessons), but providing a perspective on the subject, seeing mathematics from outside the field itself, so to speak. Typical examples would be considering the philosophy of mathematics, the history of mathematics, applications, the notion of proof, etc.
- It can be organized as a coordination of subjects, where the same or related topics are treated from several perspectives in different subjects and lessons. An example is working on absorption of ionized radiation in physics while working with exponential growth in mathematics.
- Finally, one can undertake work on an interdisciplinary topic, which goes beyond individual subjects and makes them indistinguishable. The topic could be becoming more familiar with a different culture in a multitude of ways and perspectives, it could be working with the possible conflicts concerning energy resources in the future, etc.

In order to combine mathematics with other subjects in one of the two latter ways, the teachers would have to exhibit a good deal of creativity in maneuvering within the given structures. Instead, the first approach is generally used, where non-mathematical topics are introduced in the mathematics class to the extent it is necessary in order to address a topic which would otherwise have been covered through cross-curricular activities.

The mathematics curriculum does provide some space for this type of activity. According to the centrally determined curriculum, the so-called *aspects* (the model aspect, the historical aspect, and the aspect concerning the internal

*Part 2 will be published in ZDM 30(1998)No. 4.

structure of mathematics) must be addressed.

The *model aspect* must give the students knowledge of the construction of mathematical models as representations of reality and impressions of the possibilities and limitations of applying mathematical models, and also enable students to carry out a modeling process in simple situations (loosely translated from Bekendtgørelse, 1990).

The requirement of working with the aspects forces the teacher to consider mathematics in a broader context. However, the very general and open description of the aspects on a goal level only, sustains the teacher's freedom to organize the instructional space and learning activity according to her own experience, beliefs, values, etc. This methodological freedom of the teacher is highly rated in the Danish educational system. On the other hand, it may be seen as a problem, because the 1989 reform introduced the aspects without installing a parallel change in assessment. This signals a lack of priority of the aspects, as there is no evaluation of the students' ability to, say, perform a modeling process on their own. And together with the methodological freedom, it makes it easy to give the aspects low priority in the instructional activity.

Given that it is required to work with the aspects, they can be treated either integrated with some topic(s) or separately. In the high level mathematics stream, there are 20 lessons set aside for an optional theme, and it is common to cover one or more of the aspects in this connection.

Naturally, cross-curricular activities would serve an important function in the study of mathematical models and modeling, as such models are always models of something – whether already existing or to be constructed. As this is rarely possible due to the structure of the Gymnasium, the teacher will in most cases have to limit herself to draw in competencies from other fields. I will describe an example where this was the case.

2. An example: Modeling ozone depletion in 12th grade

My example dates back to 1992, but I find that it still illustrates several important points. Before I go into more details on this, I will outline the progression of the “course”. The students were in their final year of a Danish Gymnasium, and had all chosen the highest level of mathematics. Modeling ozone depletion covered the modeling aspect and the optional theme. The course was taught by the students' regular mathematics teacher, Børge Rasmussen, together with Iben Maj Christiansen, as part of her doctoral work. In the following, I will refer to either of these as the “teacher”.

The starting point was the students' own suggestion of what important problem in the world they found it worthwhile to consider. The choice of the ozone depletion problem was not surprising, considering the public awareness on ozone depletion over Scandinavia in that very period of 1992. On the basis of this suggestion, a selection of clippings from articles were given to the students. They studied this as part of their homework and used it in formulating a list of questions which were summarized into the following problem statement, generally agreed upon: *How will the ozone depletion develop on the basis of global efforts (especially concerning CFC-gases)?*

With the teacher functioning mainly as chalk holder and chairperson, the factors influencing processes in the stratosphere were listed for four periods of the year. Since it became necessary to describe processes of change as result of these factors, the students were asked for a mathematical notion that encompasses the concept of change. Differential equations were suggested as the first thing, and agreed upon.

From this, it should be clear that the students had already been introduced to differential equations. However, the focus had been on solving ODEs. Furthermore, there were great differences in performance across the classroom. One thing with which the students were not familiar was functions of several variables. But this caused no problems – the students found it obvious that this concept is necessary in describing changes that depend on several factors.

After creating a qualitative overview of processes and their effects, mathematization was undertaken. It was marked by four types of considerations:

- a) The question of what could actually be described mathematically (for instance, some temperature dependency was left out from the model as the temperature is unpredictable).
- b) A method of describing the rate of change resulting from chemical processes was adopted from Solomon, 1990.
- c) Determination of chemical reaction constants.
- d) Some simplifications were made in order to make the modeling within the students' reach. For instance, it was considered too complicated to describe the gradual disintegration of the polar vortex, so instead it was assumed that the vortex disappeared from one day to the next, stopping all depletion processes, and allowing for an instant mixing of the ozone-depleted and the ozone-rich air.

It should be noted that these assumptions did not come from the teacher but were developed through the classroom dialogue.

At this time, the students appeared uncomfortable with the unfamiliarity of a classroom which was not controlled strictly by the teacher. The teachers decided to give them a worksheet on the relation between released amounts of CFC and chlorine in the stratosphere. This was considered to be useful in the students' further understanding of and work with modeling the ozone depletion itself, and it took care of the formal requirement of written homework.

Finally, the model was completed on the class, and the students continued working with it in smaller groups, reformulating it into difference equations which could be programmed directly, so as to perform runs of the model on a computer. Some groups got a bit further, introducing refinements of the model.

The resulting model showed great yearly variations in the ozone abundances over the Polar area, which was very much as expected on the basis of the scientific articles studied. The ozone level in the remaining part of the stratosphere appeared to decrease exponentially as years passed, though rather slowly. The introduction of a ban on CFC could be seen to have a significant effect, but the time de-

lay was evident, and some students were surprised by the extent of ozone depletion reached in the meantime. The one group that had time to introduce an expression for the formation of ozone could inform the class that with a stop for CFC, the amount of ozone would return to the former level, though rather slowly.

The way in which the students related to their results varied a great deal. Some called the teacher over and pointed out that the ozone would be gone in the year so and so. Others expressed their doubt in the results with the generation of every screen picture.

The course was completed by giving the students an evaluation questionnaire on what they thought about their own model, models in general, and the form of the course.

3. Developing different types of competencies in the classroom

In close correspondence with the model aspect, the goal of the course was not simply to engage the students in modeling, but to give them an exemplary insight in the strengths and limitations of applying mathematical modeling to complex problems situated in a social and political context. Thus, I find that working with such an example could (and should) promote three different kinds of competencies.

One competency is the mathematical. A detailed clarification of what I mean by *mathematical competency* requires a careful consideration of what is understood by mathematics and clearly would be out of reach in the present paper. Let it be enough to say that even though our classification is inspired by Skovsmose, I do not completely follow his characterization of mathematical competency. He talks about “Mathematical knowledge, which refers to the competency normally understood as mathematical skills including competencies in reproducing theorems and proofs, as well as mastering a variety of algorithms” (Skovsmose, 1993, p. 99).

I want explicitly to include mathematical activities such as abstracting, generalizing, challenging ideas and notions, formulating conjectures, suggesting and refuting proofs, exemplifying, constructing new concepts, etc. In doing so, I strive to embrace the perception of mathematics argued by recent philosophies of a more social-constructivist nature, with an emphasis on the processes of mathematical activities rather than on the outcome, and with an awareness of the social setting of mathematical activities, including the values connected to mathematics (cf. Ernest, 1991; Bishop, 1988/91).

Technological competency is another. With Skovsmose, 1993, p. 99, I refer to this as the competency to apply mathematics to problems not mathematized before, and as part hereof the competency to construct models. Reflections directed towards obtaining the best possible solution of the problem will be part of putting technological competency into practice.

Finally, *reflective competency* comprises reflecting on the use of mathematics, the link between a mathematical model and what it was intended to do, the effect of using models, etc. It encompasses more than critical perspectives on models, but that is the main point addressed here

(see, however, Christiansen, 1996a). These reflections are directed by a critical interest in recognizing that which is restrictive and oppressive through locating meaning and action in a societal context. They offer an ethical perspective on models and their applications.

As has been indicated through the description given above, the contextualization – or rather imbeddedness in a context – of the notion of functions of several variables helped students in constructing a first understanding of the concept, that is, what has been referred to as basic ideas/Grundvorstellungen (vom Hofe, 1995), on which the more formal mathematical notion can be based and developed. Comparing to the didactical phenomenology of Freudenthal, I find that the authentic topic served to provide phenomena on which to base the development of the Grundvorstellungen necessary to give meaning to the mathematical notions. I see this as an indicative of the fact that bringing applications into the classroom will improve the students’ understanding of mathematics.

This was supported by the students’ performance on solving differential equations in connection with the worksheet and after the course. For one, several students clearly improved their performance in comparison to before the course. It appeared that the imbeddedness in a context had helped some students in developing their understanding and competencies. Some students mentioned this in their evaluation, stating that the connection to reality had made the calculations easier for them. One student found that this connection made it possible to evaluate the “truth” of the result. Thereby, he wrote, the instruction becomes less theoretical than usual, as the introduction of some form of practice creates a parallel illumination of the problem. Several other students wrote that whereas standard mathematics exercises are solved by finding a suitable formula in the book and applying it, there was no given method to solve the worksheet questions. Another student found that he had to evaluate the results repeatedly and that different results and a discussion of the question had been possible. Thus, also a different perception of mathematics as an activity was supported by the course.

I will not go into further details concerning the development of a technological competency with the students in the ozone depletion course. It would take more than one incidence of modeling to say something substantial about technological competency. Rather, I want to focus on the development of reflective competency.

The ozone example could illustrate some important points concerning models and their use (see Christiansen, 1996a, section II.1), but could this potential be maintained if the students were presented with a reduced (and more accessible) version of the problem? In the following, I will describe the ideas behind the course organization, go into more details with the possible content of reflective competency, and finally address the outcome of the course with a particular focus on reflective competency.

4. Course organization

“Owing to the pedagogically well-intended selection of examples, those chosen are generally very misleading. They are too simple, too smooth, giving the student a wrong impression of formal concepts matching reality. The students do not see the

true problem in modeling, in simplification and generalization, in the formulation, analytical treatment and numerical solution of equations, in the interpretation and control of the results – or they see them only in a systematically reduced form.” (Booss-Bavnbek, 1991, p.77)

As one guideline in the organization of the actual course, it was defined that the authenticity of the problem should be upheld to such an extent that the students would see the problem as related to ozone depletion rather than as something introduced as a means to demonstrate or illustrate some mathematics. This would make a discussion of the relevance, consequences, and problems of applying the model feasible. The complexity of the problem should also be maintained to an extent which would require making a choice of simplifications in the system description. By engaging in the performance of such simplifications, the students would not only experience an important element of modeling, they would also have the chance to experience conflicts between the modeler’s and the user’s point of view.

These guidelines concerning content were linked to two pedagogical principles, namely that the work should be problem-centered and participant-directed.

Problem-centered has a special meaning to me (cf. Vithal et al., 1995). The work should be centered around formulating and solving a particular problem, in contrast to working through pre-structured material. This serves a double point. First, in the organization of the content, as the formulation of a problem makes the content operational to what essentially is a research process by goal-orienting the activity. Second, it serves an instructional point because working to generate/formulate a problem forces the students to obtain a preliminary overview of the material and the topic and necessitates analyzing rather than simply comprehending the given information, but also because it clarifies the purpose of the activity and thereby helps to overcome the potential conflicts between the normal requirements, the hidden curriculum, and the students’ expectations.

Participant-directed recognizes both the teacher and the students as participants. This implies that neither party holds complete control over the content. Instead, it must be submitted to negotiation. This makes it more likely that the students’ work will link onto their epistemic interests. Furthermore, the negotiation of the content makes it necessary to consider the purpose of engaging in the activity. This goes well with the problem formulation.

These guidelines were applied in the actual course, as also indicated in the above description. It points to the necessity of carefully considering the topic which is used as a starting point for such activity. Rather than constructing examples to serve instructional purposes, the activity gains from being closely connected to an authentic problem – especially if the goal is to give the students a basis for a critical insight in models and modeling. And this is the very type of insight which should – among others, naturally – be promoted in the future if we want an empowering mathematics education for all.

5. Critique of models in the classroom

If students are to obtain an awareness of the role of mathematics in society – and many reasons can be given why this is desired – they must encounter some authentic models (cf. Hirsberg & Hermann, 1991, p.191; Niss, 1990, p.70). However, the knowledge of the existence of such models is not enough to ensure critical competency. The students must also be able to “see through and evaluate others’ application of mathematics to problems external to mathematics” (Niss, 1984, p.25, my translation).

This implies more than an analysis of the mathematical qualities of the model. It calls also for an investigation of the representational quality of the model and of the possibilities for verification. Ultimately, students should experience that these aspects may vary with the model, and that the issues necessary to address vary with the use of the model in a broader context.

My analyses of the ozone depletion example and similar cases indicate that it is meaningful to the understanding of mathematics in society to let a “critique of models” encompass more than the reliability question (Christiansen, 1996a). It should also concern the fulfillment of the model’s felicity conditions. This implies asking under what circumstances the model is reliable, useful, meaningful, and who is obligated by these conditions in the use of the model.

Furthermore, the acts performed through the introduction of a model to a problem must be considered. One must distinguish between the act of modeling and the act of using the model. This implies a distinction between the intentions behind the construction of the model, the intentions behind its use, and the effects of its use.

The effects of using a model can be addressed in particular. Skovsmose, 1990, recognizes four such effects: an alteration of the interpretation or construction of the problem, a limitation of the group of possible participants in the problem solving procedure, a change in the structure of argumentation, and an influence on the type of solution. Christiansen, 1996a, finds a common effect of using models to be a technocratic transformation by which a political or ethical problem is transformed into one that can be addressed by technological means. The ozone example has the potential to address all these issues in a more or less exemplary way.

These are the important considerations behind striving to maintain the complexity and authenticity of the model, at least to a certain extent, as addressed above. It remains to be addressed whether it is actually feasible to introduce such complex issues in the classroom in such a way that there is a move towards the mentioned goals.

6. Reflections on models exercised by students in the ozone depletion course

The most common type of reflections in the students’ written evaluations concerned the reliability of models as descriptive tools. They had many suggestions to what could be wrong with their own ozone depletion models and how these could be improved.

There was some variation in the students’ confidence in their models. Some thought that it had little connection to

reality or that it had especially many blank spots compared to models in general, while others found that the model showed the tendency of ozone depletion. Many students did not, however, find it trustworthy in this respect, as they had confidence in a positive effect of agreements to reduce CFC emissions. In this sense, the students' attitudes and beliefs made them inclined to disregard the result of their own modeling and calculations. This may well have been different if the students had worked with a topic of which they had more knowledge beforehand – yet another argument in favour of cross-curricular activities.

Several students pointed out that the model's correspondence to reality depends on the level and kind of theory on which it is based. It was noted, however, that in any case the models can show tendencies only, that they are theoretical constructs which cannot be trusted, and that modeling necessitates making assumptions wherefore the model needs to be improved and adjusted. Thus, reliability considerations were central to the students' reflections.

Some students found the models useful in addressing what can be done to prevent further ozone depletion. They expressed that despite the uncertainties of the model, it should be taken as an indication of the range of the ozone depletion under different circumstances and should be used as the basis for regulating the situation. Still, such an approach reflects a technological perspective on the problem – it is assumed that the problem can be controlled through the right initiatives. Undoubtedly a necessary line of pursuit, but nonetheless an approach which ignores the underlying fundamental ethical issues of balancing personal comfort and pollution.

Such issues were raised by some students during the modeling. Thus, a few students opposed, almost aggressively, discussing the details of the ozone depleting processes and the model. They felt that the effect of the CFCs was certain enough, and that instead the focus should be on how to limit CFC emissions immediately. As part hereof, some of the fundamental political and ethical issues were raised – the dilemma between obtaining better living standards with lower consumption of resources, between maintaining standards of living and taking environmental precautions, between reducing production costs and transforming production according to environmental concerns.

However, the technological and the ethical approaches were never combined or connected in reflections on the use of models. I find that one reason for this was the lack of connection to the political and ethical issues in the organization of the course, the organization of which enforced a focus on constructing a model.

The main effects of using models reflected on by the students concerned the possible actions which could be derived from the models. The students seemed to find that the recognition of the ozone depleting effect of CFCs should lead to a complete stop for emissions – an all-or-nothing-view – while they did not recognize the possibility of using the quantifications in arguing for allowing CFC emissions within certain limits.

In general, there appeared to be a recognition of modeling as a useful tool in obtaining more clarity on a problem,

while little consideration was given to the model's possible effects through transformation of the problem – such as the technocratic transformation. Perhaps the recognition of the technocratic transformation and similar uses of models cannot be recognized when the political context of using the model is not sufficiently taken into consideration.

This is yet another indication that a problem submitted to classroom activity must be rather authentic and with a good deal of the original complexity if it is to support the development of a broad range of competencies. And if reflective competency is to be furthered, the problem must not be disconnected from the societal context in which it is originally embedded. Still, it should also be taken into consideration that this was the students' first encounter with modeling and models, and like any other competency, reflective competency does not develop over night.

8. Conclusion

I find that the official mathematics curriculum for the Danish Gymnasium supports some interesting and relevant perspectives through the inclusion of the aspects – though it is somewhat countered by the lack of inclusion in the assessment. It does so without limiting the teachers' methodological freedom. I have discussed a particular incidence of teaching within the model aspect, and I find that this particular way of addressing issues concerning models and modeling have a great potential in developing the three described competencies. It must be recognized as a possible strength in the organization of this particular course that the authenticity and complexity of the problem were maintained to as large an extent as possible, and that the course was problem centered and participant directed. On the other hand, I find that the structure of the Danish Gymnasium inhibits cross-curricular activities and that this confines the development of the competencies in several ways.

In particular, the exclusion of the societal context of a topic may limit the development of certain aspects of reflective competency, especially those concerning the use of models. And this exclusion is hard to overcome without cross-curricular activities – it is hard for the mathematics teacher to create space to include such activities, when other aims must be pursued according to the official curriculum. If the development of all three competencies should be promoted – and I think it should – there must a greater emphasis on modeling, working with authentic and complex problems, etc. rather than on practicing algorithms and reproducing knowledge. In order for this kind of mathematical activity to occur, the curriculum must create space which preferably should encourage cross-curricular activities.

In the present paper, I have touched on the instructional organization only briefly. However, the outcome of such a course is extremely sensitive to the organization and forms of communication supported (see Christiansen, 1996b, 1997, and 1998). I find that the authentic case must be taken seriously, the modeling should be goal-oriented yet open-ended, students must be supported in developing ways of modeling through careful guidance, and communication between teacher and students should support

the students' modeling activity including reflection on the preliminary model at any time. All in all, there must be a breach of the traditional exercise-directed instruction, promoting instead a truly problem-directed approach. In this sense, promoting cross-curricular or modeling activities does not do the job, if the pedagogical organization is not also taken into consideration in close connection to the organization of the content.

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