A Nanoscience Course for Upper Secondary Students

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Abstract: The Organization for Economic Co-Operation and Development (OECD) suggests (Palmberg, Dernis & Miguet, 2009) that the number of jobs involving Nanoscience will increase by 2 million by the year 2015 and that the market value of Nanoscience products will be over 1000 billion dollars by 2015. In the ROSE study on student motivation (Lavonen, Byman, Juuti, Meisalo & Uitto, 2005), girls expressed interest in interdisciplinary items and boys in studying implementations of technology. Both areas are fundamental in Nanoscience education.

These opportunities in mind, we offered physics teacher students a task to design a Nanoscience- and technology-oriented course for upper secondary pupils. The course was constructed from Nanoscience expert lectures and experimental lessons. The major topics of the course were Forces and Interactions (via surface tension and surfactants), Tools and Instrumentation (via DNA electrophoresis and Atomic Force Microscopy) and Size-Dependent Properties (via thin films).

A co-operation between the physics teacher trainees and the scientists in the Nanoscience Center in Jyväskylä was a starting point for this course. The teacher trainees were instructed to design the learning units from ideas and discussions on Nanoscale topics, using educational reconstruction (Duit, Gropengiesser & Kattmann, 2005) to define meaningful and precise learning goals for each unit. In doing this, they received assistance from the scientists. This design procedure was developed for our pilot course in 2007. The new course took place in May 2010 in the Teacher training school of Jyväskylä. We present an overview of the course and one of the learning units as a case in educational reconstruction in physics teacher training as well as a school inquiry.

Keywords: Science Education, Nanoscience, Nanotechnology, Educational Reconstruction, Teacher Training

1. Introduction

Nanoscience can be thought of as the united effort of physics, chemistry and biology at the scale where all three sciences overlap: the nanoscale, or $10^{-9}$ m. The so-called “Big Ideas of Nanoscience” (Stevens & Krajcik, 2009) are shared throughout the field and are often thought to form the foundations of Nanoscience Education. These ideas include e.g. development of new measuring techniques, size-dependent properties of matter and self-organizing of molecules.

In the next few years, Nanoscience is expected to present significant new work positions and to increase its market value worldwide (Palmberg et al., 2009). This presents a challenge to educate both the future designer and the consumer in Nanoscience. Fortunately, there is evidence that including Nanoscience as an interdisciplinary and technology-oriented topic in the classroom is beneficial for student motivation (Lavonen et al., 2005), especially if it is approached with experiments (Hutchinson et al., 2007).
Design as a research paradigm was chosen for this study to tie it in with an ongoing work of developing educational materials in Nanoscience. Design research is a cycle that includes assessment at every stage; assessment of the science content, the pupils’ learning, the developed materials, and a final evaluation at the end of the process. The demanding part is that the development cycle must also result in theoretical understanding of learning that comes from the research (Design-Based Research Collective, 2003). For assessing the science content and designing the particular learning units for the Nanoscience course, Educational Reconstruction (e.g. Duit et al., 2005) was introduced to bring balance where there is inclination to focus on only the science content or the educational practices.

1.1. Research Questions

In the following chapters we clarify

1) to what extent the pupils learned to apply Nanoscience specific thinking to problems, and
2) to what extent the student teachers followed the instructed Educational Reconstruction approach in planning the course.

Both questions are looked shortly into from the general standpoint and more closely in the case of one learning unit, DNA Identification.

2. Methods

2.1. The Nanoscience Course and Participants

In late 2009 the development of a Nanoscience course for upper secondary pupils was started. It was entered into the city school system as an optional Physics course and registration was open to pupils from all schools in the city. The duration was 18 hours of class time (1/2 course credits in the Finnish system). The topics of the course addressed in experimental work were Forces and Interactions, Tools and Instrumentation and Size-Dependent Properties. The other “big ideas” were included in three expert lectures given by researchers from the Nanoscience Center of Jyväskylä. An outline of the course is shown in Table 1.

Table 1. Contents of the Nanoscience course in chronological order.

<table>
<thead>
<tr>
<th>Lesson topic</th>
<th>Duration (h)</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>First meeting</td>
<td>2</td>
<td>Contents and timetable of course, pre-questionnaire on Nanoscience ideas</td>
</tr>
<tr>
<td>Magic Sand</td>
<td>3</td>
<td>Teflon-coated sand as a Nanotechnology product, surface tension and dominant forces</td>
</tr>
<tr>
<td>Lecture 1</td>
<td>1</td>
<td>Cellular biology in the Nanoscale</td>
</tr>
<tr>
<td>Lecture 2</td>
<td>1</td>
<td>Computational methods in Nanosciences</td>
</tr>
<tr>
<td>DNA Identification</td>
<td>3</td>
<td>How does DNA identification work, electrophoresis as a method in Nanoscience</td>
</tr>
<tr>
<td>Lecture 3</td>
<td>1</td>
<td>Self-Organized Molecular Electronics</td>
</tr>
</tbody>
</table>
In the beginning, the course had 20 participants from ages 16-19. By the end of the course there were 17 pupils left, 9 girls and 8 boys. 14 of those who completed the course had only taken two previous courses (36 h class time each) in Physics, and the remaining three had a varying number of courses between 5 and 10.

2.2. The Pre- and Post-Questionnaires

The pre-questionnaire (Table 2) was developed with the student teachers. There were questions targeted at each of the experiments in the course as well as some other areas of Nanoscience, to see if they are known to pupils. Answers of the pre-questionnaire were graded on a scale 0-1 on whether the answer showed insight and understanding of Nanoscience concepts. Full marks were given to any answer properly motivated by Nanoscience principles.

Table 1. The items in the Pre-Questionnaire on the first lesson.

<table>
<thead>
<tr>
<th>Pre-Questionnaire Questions</th>
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<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

1 A popular item in winter 2010. See e.g. http://www.goodnewsfinland.com/archive/karhus-nano-ski-well-suited-for-wet-and-warm-skiing-conditions/
a) What is DNA Identification? b) How is it connected to Nanoscience?

Give examples of Nanotechnology products.

The post-questionnaire (Table 3) was designed during the course. It included more specific questions on each of the experiments and a question on the lectures. It was graded on the same principle as the pre-questionnaire, but with stricter demand for evidence of understanding Nanoscience concepts.

Table 3. The items in the Post-Questionnaire on the last lesson.

<table>
<thead>
<tr>
<th>Post-Questionnaire Questions</th>
</tr>
</thead>
</table>
| 1 | Surface-modified sand.  
  a) describe shortly how the moist-repelling coating in e.g. windows works.  
  b) Come up with liquids that would wet the Magic Sand. How do they differ from water? |
| 2 | DNA investigation.  
  a) How do the DNA of different people differ from each other?  
  b) Give an example of how the difference can be observed. |
| 3 | Atomic force microscopy.  
  a) Why is an accurate atomic force microscope built on a bottom plate separate from the rest of the building?  
  b) Describe shortly how atomic force microscopes can be used to study endurance of a molecular bond. |
| 4 | A thin film of oil floats on water.  
  a) Why do we see colors in the film? b) How would you find out the thickness of the film? |
| 5 | Lectures.  
  a) Which research methods can you remember mentioned on the lectures? Name or idea is enough.  
  b) What about applications? |
| 6 | Feedback.  
  a) What was the most useful thing in the course?  
  b) What would you hope was done different next time? |
2.3. Student Teacher Assignment

The course design was done in co-operation between seven volunteer student teachers of Physics, a graduate student and the lecturer of Physics Education. All of the student teachers had at least 60 ECTS of Physics studies before entering the Physics Education courses.

The student teachers were instructed in Educational Reconstruction (ER) as a tool in designing the learning unit from science content new to them. The steps of content analysis were the following:

a) scientific knowledge is analyzed and its core ideas are carefully extracted, and
b) pedagogical content knowledge (PCK) is built from the core ideas with the support of educational research and the audience in mind.

Data from the student teachers’ content analyses was collected from discussions during the planning stage, watching the lessons, the pupil instruction forms, and a teacher guide that they were required to turn in for Physics Education class.

3. Results

3.1. Pupils’ Learning of Nanoscience Concepts

The results of the pre-questionnaire were mostly very meager; the average score for the class was 44% of the maximum. The pupils had difficulties in explaining macro scale properties – such as stickiness or slipperiness – with reference to properties of the molecules. Instead, most offered states of matter or additives as the reason for different behaviors. The best understood phenomenon before the course was surface tension; the pupils were able to motivate their answer to a nanoscale question with their understanding of surface tension. The average grades for each pre-question are listed in Table 4.

Table 4. Average grades per question in Pre-Questionnaire

<table>
<thead>
<tr>
<th>Question</th>
<th>Average grade (0-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sticky or slippery water</td>
<td>0.21</td>
</tr>
<tr>
<td>2. Nano Skis</td>
<td>0.29</td>
</tr>
<tr>
<td>3. Sticky nanoscale</td>
<td>0.47</td>
</tr>
<tr>
<td>4. Oil film</td>
<td>0.26</td>
</tr>
<tr>
<td>5. Surface tension</td>
<td>0.79</td>
</tr>
<tr>
<td>6. DNA identification</td>
<td>0.41</td>
</tr>
<tr>
<td>7. Nano-products</td>
<td>0.68</td>
</tr>
</tbody>
</table>

After the course, the average score was 66% of the maximum. The pupils were able to use scientific terminology where appropriate. Their understanding of the underlying idea rather than memorizing tidbits was affirmed in answering questions that had not directly been discussed in class, e.g. 1b and 3a in Table 3. Especially the oil film question, which was the
same as in the pre-questionnaire, showed considerable improvement. The DNA identification question proved surprisingly difficult and it is discussed further in section 3.2. All of the grades are shown in Table 5.

Table 5. Average grades per question in Post-Questionnaire

<table>
<thead>
<tr>
<th>Question</th>
<th>Average grade (0-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Surface-modified sand</td>
<td>0.76</td>
</tr>
<tr>
<td>2. DNA identification</td>
<td>0.35</td>
</tr>
<tr>
<td>3. Atomic force microscopy</td>
<td>0.66</td>
</tr>
<tr>
<td>4. Oil film</td>
<td>0.76</td>
</tr>
<tr>
<td>5. Lectures</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Finally, the distribution of pupil scores in the pre- and post-questionnaires is shown in Figure 1. It clearly shows how the score distribution has shifted towards the higher end of the scale.

![Figure 1. Distribution of pupil test scores in the Pre- and Post-questionnaires.](image_url)

3.2. Case: Pupil Learning of DNA Identification

The Pre-questionnaire question was “What is DNA Identification? How is it connected to Nanoscience?” (average grade 0.41).

The answers reveal that even though pupils had a good understanding of what DNA is (demonstrated by use of words such as “base pairs”, “amino acids” and “protein formation” in their answers), their ideas of how DNA is identified were very vague. Only one pupil described “measuring the distances of certain sequences in the DNA”, evidently already understanding the procedure in general, whereas the rest offered generic explanations such as “identifying a person” (30% of answers). The pupils were also unclear on whether such
identification would identify differences between persons, identify two persons as relatives, or identify certain properties of a single person.

The post-questionnaire question was “How do the DNA of different people differ? Give an example of how the difference can be observed.” (average grade 0.35).

Interestingly, the post-questionnaire average for this question was worse than the pre-questionnaire average; taking into account that they were different questions and the post-questionnaire question required deeper understanding of the DNA identification process, it does not mean they knew less than when they came in. As in the other post-questionnaire items, the questions were more difficult. Here, the pupils had trouble explaining the procedure of observing the difference in required depth to gain points.

However, the pupils gave coherent answers indicating that the differences in DNA are related to the ordering of base pairs or differences in the lengths of DNA chain between the repeated sequences.

The DNA experimental work was interesting to the pupils and a couple nominated it as the most useful content of the course (see question 6 in Table 3).

### 3.3. Student Teachers’ Educational Reconstruction approach

The student teachers together chose topics from Nanoscience-related products, news and publications. The preliminary topics were honed into lesson plans centered on one or two “big ideas” of Nanoscience.

Student teachers in general were receptive to the approach. Some of them had background in working at the Nanoscience Center (for Bachelors’ or Masters’ theses) and in discussions on how their projects were developing, they were excited to use their knowledge and to obtain new knowledge for themselves. Throughout the procedure they remained very motivated and serious about the Nano-course.

The use of information resources such as Internet guides and scientists at the Nanoscience center were soon automatic and did not require much outside guidance. Towards the end of the course, it became evident that the student teachers would have required help in using educational research knowledge in their work. The hints and sources for information given at the beginning of the project were not used and often forgotten throughout the project. The most pressing concern of the student teachers was getting their experiment “to work” and overcome practical issues, such as whether to use paper or plastic cups for a procedure.

### 3.4. Case: Designing a Learning Unit in DNA Identification

Student teachers Sami and Tomi (pseudonyms) chose DNA Identification as a topic for their 3-hour learning unit. They began by studying the basics of the system using some internet resources and links suggested. The goal at this point was simply to plan an experimental work for upper secondary school pupils that would be a hands-on experience on manipulating DNA.

The internet resources used were e.g. the Learn.Genetics site (Genetic Science Learning Center, 2010) and the General Biology Program for Teachers site (University of Arizona, 2002) that both gave us ideas for using DNA investigations on a lesson. In addition, Sami and
Tomi used textbooks and searched for scientific knowledge online to build an understanding of the DNA Identification process.

As a second step, the student teachers worked in collaboration with a Nanoscientist on their lesson topic. Sami and Tomi had several discussions with Teemu Ihalainen, a nanobiology PhD, and were able to self make a DNA electrophoresis experiment in the lab at the Nanoscience Center in University of Jyväskylä. Gathered from the teacher package and the lesson outline, the ER process is outlined in Figure 2.

Figure 2. Application of Educational Reconstruction to knowledge in DNA Identification

The Pre-questionnaire findings led Sami and Tomi into putting more weight on the properties of DNA that are used for identification and the way that the results are interpret in an experiment, rather than focusing on the principles of electrophoresis.

The changes and simplifications in the actual, scientific experimental procedure were due to practical reasons rather than pedagogical. The original goal had been to reproduce the electrophoretic method as faithfully as possible. Thus, choice between more expensive and hard-to-obtain substances, such as agar and agarose powders for the gel, was made on the basis of whether they noticed a difference in the experimental results. The decision to use food colorings rather than real DNA for the experiment was because of the difficulties and poisonous substances required in staining the DNA and viewing it under UV light.

However, when forced to abandon the original method, the student teachers did communicate the similarities and differences with the pupils. In their teacher guide, they wrote: “Food colorings can be used to visualize the DNA study by mixing several colorings into one sample. The electrophoresis separates the colorings from each other, just as the different [length] DNA chains would be separated.” The poor post-questionnaire results in
understanding the procedure of DNA electrophoresis suggest this comparison had deserved more attention in class.

4. Discussion and Conclusion

An overarching goal of the course was to be able to explain macro-world phenomena with micro-world concepts. Initially, this was very difficult for the pupils. Despite the use of different questionnaires at the beginning and the end, it was clear that pupils’ understanding of Nanoscience concepts was greatly enhanced during the course. The feedback from pupils was mainly positive; they complained about difficulty of topics and timetable issues. The construction of the course from lectures and experiments proved to be a good choice, as seven pupils found the lectures to be the best part and ten preferred experiments – a very even result.

Student teachers in general followed the ER model up to extracting key ideas. In Sami and Tomi’s work it was clear that they worked through the steps of acquiring scientific knowledge and broke it into key points for themselves; they tried out the experiments and discussed the content from the scientific point of view with staff members. This was essential in gaining expertise over the topic they had chosen and understanding the difficulties in the actual experimental work.

Unfortunately the student teachers were unable to use education research findings or specific knowledge of learning in doing the final reconstruction. This problem is likely connected to the biggest pupil complaint about the course: the explanations were too difficult for the pupils. With more attention to understanding how new content is learnt, the student teachers could have prepared different constructions of the content for the lesson. In the future, the student teachers with no background in educational sciences will be given more guidance in acquiring and using learning research in their task.

References


