Roger Andersson

Teaching and learning geometrical optics with computer assisted instruction

- changing conceptions about vision, image and ray
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Roger Andersson. *Teaching and learning geometrical optics with computer assisted instruction - changing conceptions about vision, image and ray*

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Abstract

The information and communication technology, ICT, is opening new possibilities for the educational arena. Previous research shows that achieving positive educational outcomes requires more than simply providing access to computer hardware and software. How does this new technology affect the teaching and learning of physics? This thesis focuses on the field of geometrical optics. It reports two studies, both in Swedish upper secondary school. Important for the use of the ICT in physics education is the teaching strategy for using the new technology. The first study investigates with a questionnaire, how 37 teachers in a region of Sweden use computers in physics education and what intentions they follow while doing so. The results of this study show that teachers' intentions for using ICT in their physics teaching were to increase students' interest for physics, to increase their motivation, to achieve variation in teaching, and to improve visualization and explanation of the phenomena of physics. The second study investigates students’ conceptual change in geometrical optics during a teaching sequence with computer-assisted instruction. For this purpose we choose the computer software "Constructing Physics Understanding (CPU)"; which was developed with a base in research on students conceptions in optics. The thesis presents the teaching sequence developed together with the teacher. The study is based on a constructivist view of learning. The concepts analysed in this study were vision, image, ray and image formation. A first result of this study is a category system for conceptions around these concepts, found among the students. With these categories we found that students even at this level, of upper secondary school, have constructed well-known alternative conceptions before teaching, e.g. about a holistic conception of image. The results show also some learning progress: some alternative conceptions vanish, in some cases the physics conceptions are more often constructed after teaching. The students and the teacher also report that the CPU program gave new and useful opportunities to model multiple rays and to model vision.
List of papers

Paper I
The implementation of ICT in Physics education. Teachers’ reflections on their intentions and actual use. Andersson, R. & Magnusson, K. Submitted to NorDiNa, Nordic Studies in Science Education.
Introduction
Teaching and learning physics concerns the understanding of the concepts and methods of Physics. Physics is a natural science that explains observable phenomena with models. A model includes concepts and explanations which are based on theory. An important part of physics education research is to study the students learning of the concepts of Physics. The students construct their own cognitive stable element in the form of conceptions about the phenomena of Physics that the students experience during the Physics teaching (Niedderer 2001). Learning is seen as a process of cognitive development leading from certain already-existing conceptions along learning pathways towards the science conceptions to be learnt (Duit and Treagust 1998).

The field of optics is a complex area for the students and many studies have shown students’ difficulties in learning optics, see for example (Andersson and Kaerrqvist 1983; Guesne 1985; Galili, Bendall et al. 1993; Galili and Hazan 2000; Tao 2004) Some studies are focusing on research based on practical problems (Lijnse 1995; Méheut and Psillos 2004). In one study the focus is on the problems of teaching and learning optics in a practical context (Andersson and Bach 2005). Most studies focuses on the students’ learning in a teaching without computers. This study is focusing on teaching and learning at upper secondary school geometrical optics with computer assisted instruction. There are studies in other areas of science focusing on computer assisted instruction, see (Windschitl and Andre 1998) reports on the use of computer simulations to enhance conceptual change by a constructivist instruction in teaching human cardiovascular system.

ICT, information and communication technology opens new possibilities for teachers to present optics. It gives new possibilities to study models of geometrical optics with the help of different software. One should distinguish between “simulation” software and “modelling” software (Schecker 1998). In the simulation software the physics theory is built in, whereas in modelling software students have to formulate themselves the physics laws they want to use. Several simulation programs in geometrical optics are available, and the program chosen for this study was CPU. (Goldberg 2000)
The use of ICT in Physics education

Important questions in the start of this project were to what extent the teachers use ICT and what their intentions for using ICT were. To answer these questions a study to investigate the teachers use and intentions were carried out. A questionnaire was developed with open questions. 37 teachers in a large region of Sweden participated. The results of the study show that teachers’ intentions for using ICT in their Physics teaching were increasing the students interest for Physics, increasing their motivation, achieving variation in teaching, visualization and explanation of the phenomena of Physics. The results show also that most teachers do use ICT and computers in their Physics teaching and that for most teachers the implementation of ICT has had an effect on their teaching. This is an interesting result that the teachers report that the implementation of ICT has affected the teaching differently in different areas of Physics. A report of this study has been submitted for publication and is included in this licentiate thesis. (Andersson and Magnusson 2007). One of the aims of the present research is to design a teaching sequence in geometrical optics, an area where the computer plays a major role.

The setting for both studies is upper secondary school. Physics is a subject taken by students who major in Science and Technology. The subject of Physics is in Swedish upper secondary school divided into two courses. Geometrical optics is part of the first course.
Theoretical framework
This study’s theoretical framework is a constructivist perspective on students’ knowledge, where knowledge is not evaluated merely as correct or incorrect but analyzed in terms of ideas, views and cognitive constructs (Galili and Lavrik 1998). Cognitive constructs are stable constructions about a phenomenon in the student’s cognition.

Constructivism
The view that students construct their knowledge from individual and/or interpersonal experiences and from reasoning about these experiences is called constructivism (Windschitl and Andre 1998). The learner in the constructivist perspective is viewed as an active partner engaged in constructing meaning and bringing his or her prior knowledge to bear on new situations, and if the purposes are worthwhile, adapting those knowledge structures (Driver 1995). There are several forms of constructivism, for example cognitive constructivism and social constructivism. These two are distinct but complementary constructivist perspectives (Cobb 1994). The social constructivism focuses on the learners’ interaction with others while the cognitive focuses on the individual cognitive constructions. This study is focusing on the later.

Concept and conception
Physics consist of many concepts. Even a smaller field like optics are consisting of many concepts. When a student constructs a view of a Physics concept, we call it a conception. A conception is seen as a hypothetical set of statements, skills, procedures, that the researcher attributes to one or more students in order to account for students’ behaviour in a set of given situations (Tiberghien 1997). There is a large volume of research on students’ conceptions and difficulties in science (Pfundt and Duit 1994).

Conceptual change
Educational conditions that promote conceptual change have been described by (Posner, Strike et al. 1982). The authors were among the first to introduce the idea that students would abandon their pre teaching conceptions for a more scientific conception introduce through teaching. The teaching should be designed to consist of ideas that do not fit into the students’ existing ideas (Duit and Treagust 2003). Later research has been critical to the view that a student abandons the earlier conception totally. (Chinn and Brewer 1993) postulate that there are seven forms of students’ responses to a situation that confronts
with their earlier conceptions, where abandoning the earlier conception is only one form. (Mortimer 1995) proposes a model of a conceptual profile where a student holds multiple conceptions at the same time. (Taber 2000) presents in a study of a student’s conceptions of chemical bonding and founds evidence for that the student holds multiple frameworks. The student uses different explanations very used in a range of overlapping context.

**Students’ conceptions in optics**

An overview of previous research

**Nature of Light**

What is light? For many children light is associated with the light they meet everyday. Turning on the light bulbs at home, here the language indicates light. So in another word light equals electric light. What about the light outside, the sunlight? For some children the source of daylight is not easy to identify. How can there be daylight when there is no sun? Children make distinct differences of light coming from different light sources, like light bulb and sunlight (Guesne 1985)

**Light propagation**

Children rarely make explicit the idea of light moving in space. When they do it is almost always in the case of very great distances. For example if they consider the case of the sun stopping to shine, they are aware that it will take some time before we know it (Guesne 1985). In another study by (Langley, Ronen et al. 1997), students’ preconceptions were tested and they found that students didn’t indicate direction in their representation of light. This is also true for many students in the sight context. The sun is for the children associated with light and that light has to propagate before we see it. The children meet mostly light in the everyday life that comes from sources at small distances, for example when they turn on the light bulbs in their homes. This gives the children no opportunity to experience the lights propagation.
Vision, the role of light and eye

Vision is a concept that is common to everyone in everyday life. It’s a vital sense for us and we have a rich experience of optical phenomena. Mostly these experiences are not reflected upon, but children do construct explanations from an early age as they instinctively interpret the world around them (Guesne 1985; Feher and Rice 1988; Osborne, Black et al. 1990). For a study about older students and prospective elementary teachers’ prior constructions conceptions about various aspects of light, e.g. vision and shadow (Bendall, Goldberg et al. 1993). In the common use of language there are possibilities to observe a lot of the everyday thinking about seeing. Most of them attribute to the idea that the eye plays an active role, while the object ‘looked at’ has a passive role (Guesne 1985). One example of the impact of the language is: “To see right through someone.” The language shows that the common thought about seeing is that the eyes send out something making it possible for us to see. (Bach 2001)

![Figure 1. Guesne (1985) show a progression in conceptions of vision.](image)

The figure show a progression in conceptions of vision held among 13 to 14-years-olds students, from a light bath conception toward conceptions of a “physicist”. With the term “physicist” we mean the through the teaching intended conceptions, based on physics theory (Guesne 1985).
The progression is in four different models from

- First model: the bath of light when no mechanism is defined between the eye, the light and the object.
- Second model: light gets a role to light up the object
- Third model: there is a movement from the eye to the object included.
- Fourth model: the physicist’s model, which is very rare among children. The eye being the receptor of light is a conception of vision that only few children construct.

The lack of this correct model of vision is also giving problems for students to understand the notion of virtual images.

Young children may make no connection between the eye and the object being viewed, whereas older children may regard vision as light coming to the eye (Osborne 1990). There is also a difference between seeing luminous and non-luminous objects (Guesne 1985) have found that for the non-luminous objects the students might adopt an “active role” where the eye acts not as a receptor of light but as an active agent. This is also reinforced by everyday language (e.g. look this way), and is also found in children’s media e.g. (X-ray vision).

Where is the light? Children aged 10-11 and 13-14 where asked in a French study, ‘Where is the light in this room?’ The interview took place in daylight

Example of responses:
- In the bulbs. ‘It’s the bulb that light up. (Marie, 14 years)
  -Because the sun beats down and you can see that it’s lighter than in the shadow. (Lionel, 11 years)

In the children’s response the researchers found “two different concepts of light: light equated with its source, with its effect, or with a state; and light recognized as a distinct entity, located in space between its source and the effect it produces.”(Guesne 1985) The first concept is more common among the younger children, and the light as entity in space is more spoken among the older ones. This doesn’t mean they have abandon to equate light with its source and effect.
What is a shadow? How do children explain shadow? In the study above (Guesne 1985) 13-14 year old children where asked what a shadow is and how it is formed? The responses indicate an awareness of the similarity between the object and its shadow. Only in a minority of cases the children are capable of giving an explanation of the shadows formation. (Langley, Ronen and Eylon 1997) found that light was associated with shadow formation mainly in the sense that a light source was mentioned verbally and depicted pictorially. Rarely did the rays students used extend as far as the shadow. (Feher and Rice 1988) found evidence in a study that students give light multiple roles, different phenomena different explanations. Light is different when explaining image than explaining shadow. (Galili and Hazan 2000) suggest that children can perceive shadows in much the same way as optical images. Shadows can be manipulated in the same way as independent objects. There is a need to see light as an entity in space for being able to give an explanation of the formation of shadows. This is a concept which is constructed at a later age than equating light with its source and effect.

(Heywood 2005) presents three categories of representations in students’ reasoning how we can see an object. Visual representation where students’ focus is on looking and seeing, the eye looking at the direction of the object. Light representation, where students’ reasoning is concerned with where light is travelling. The third category is dual representation, students’ employing both visual representation and light representation.
The concept ray

Children can actually place light on linear rays without having any idea of the movement of light along these rays. But they can only locate light on the rays if they have the notion of ‘light-entity in space’. This means that the younger the children are the more meaningless the question of path of light is. The problem is connected to our senses which can not experience light propagate in space. (Galili and Lavrik 1998) concludes that student lack the understanding that this is a propagation of a physical entity. Student is unaware of the relationship of light and energy. The concept ray is complex. What is ray showing? Physicists define rays by assuming that light goes in straight lines from one point of the source to one point of the image. So, a ray is a model for one linear part of the light beam in geometrical optics. These diagrammatic representations are called light rays. Do students use the concept the same way? In the literature about students' conceptions, not much is found about students' ideas of rays. So these results are somewhat new. In the class room teacher use black board lasers to show nice rays, but do the students just see the representation of the way that light travels or do they see it as the light? The concept closely is related to the concepts of Image and how an image is formed.

Imagery

In everyday life, the processes of image formation, the spreading of illumination and many other observed optical phenomenon seem to be instant. Our experience confirms neither the wave nor the particle nature of light. Light appears as stationary and continuous. Two different schemes as framework for thinking about imagery are presented. In a holistic- image-scheme, the image is regarded as an image as a corporeal replication of an object, which moves, remains stationary, or turns as a whole (Galili and Hazan 2000). This conception is often constructed by students before instruction. The second conception is an image-projection- scheme: ‘Each point is related to the corresponding object point by a single light ray which transfers it’ In this scheme the
image undergoes a deconstruction to a collection of points, each being transmitted by means of single light ray. Image construction is complex and one difficulty for students are to use multiple rays and point to point mapping simultaneously (Galili, Bendall et al. 1993). The difficulties of light and students’ difficulties with light as an entity in space is pointed out as a problem in image construction by (Heywood 2005). Students need to understand the correlation between light and the information about the image it contains.

**Constructing Physics Understanding, CPU**

The program used in this study is CPU: Constructing Physics Understanding. The program is developed under coordination of the San Diego State University. (Goldberg 2000) The CPU pedagogy and materials are closely aligned with National Science Education Standards (NSES 1996) and the Benchmarks for Science Literacy (AAAS. 1993). “The pedagogy is based on cycles consisting of: Eliciting students' ideas; guided development, in which students modify or discard their old ideas and/or develop new ones in a movement toward target ideas; consensus building, where students share understanding developed in the activities, clarifying and solidifying target ideas and; application of target ideas to new situations.

The program consists of two parts: The Simulation Software and the Curriculum Units. The simulation software consists of simulations for all parts of the physics curriculum, for example mechanics, wave theory and optics. The curriculum unit provides classes and activities. In this study we only use the part of the program that consists of the optics simulations, Shadows & Pinholes, Reflection & Refraction, Mirror Images and Lens Images. All these simulations are found in the Simulation software. There is also a paper and pencil version available of the CPU, but for this study we have only used the computer version.
The CPU pedagogy presumes that students will take a greater responsibility for their own learning. They are supposed to make own prediction which are not confirmed by experiment. This is done during the elicitation phase. The idea is to make the students’ prior conception visible and that these prior conceptions can be challenged during the developmental phase. The hope is that the students’ conceptions will be developed and during the application phase the students’ can use their developed conceptions in a new situation. In the design of the teaching sequence we use some of these ideas. One example is making students earlier conceptions visible and this is done by asking students to make predictions. The teacher also used this in the teaching during class discussion, but this phase is more obvious during the students own work with the computer.
<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shadows &amp; Pinholes</td>
<td>Using point sources, line sources and complex sources of light, you could explore the properties of simple and complex shadows (using various blocking objects) and pinhole images. The element palette also includes a colour filter that you can place in front of a point source. There are six options for the colour of the filter (red, green, blue, yellow, cyan and magenta), so you can study colour shadows and you can also mix colours on a screen to produce almost any other colour.</td>
</tr>
<tr>
<td>Lens Images</td>
<td>You can explore image formation with converging and diverging lenses.</td>
</tr>
</tbody>
</table>

Table 1. Description of the two simulators from CPU used in this study.

In this study we have used the Light and Colour unit and the two simulators associated with the concepts of this pilot study, i.e. vision, ray, image and image formation. These two simulators are built up on a common idea. Students are not given anything from the start, but have to build up the situation through inserting objects on a working board. The simulation is not showing any rays without the students adding light rays and starting the simulation.
Research question
1. How do students' conceptions of vision, ray, image formation and image change during a computer assisted teaching sequence in geometrical optics?
Design of the study

![Diagram](image)

Figure 3. The figure shows the overall design of the study.
This study is a pilot study of a larger study, which was performed during 2005. The results will be used in an upcoming study. It includes two parts as the figure show above. The results are based on the pilot study. The results will be used in an upcoming study. The CPU program ("constructing physics understanding "; Goldberg et al., 2000; see http://cpuproject.sdsu.edu/) was chosen as a computer program for the study. The material consists both of simulation software and texts for teachers and students. The purpose was to test one teaching sequence with CPU, in one class, together with the core items of our pre- and post-test and the equipment for collecting the data, e.g. video and audio data. This thesis is based on the pilot study. One and the same teacher was involved through all parts of this study.
Pre-study
The cooperation with one teacher involved in the pilot study started with a short pre-study, preformed 5 months before the pilot study. One class, which was not part of the later pilot study, was involved. The CPU program was used and first tasks for pre- and post-test of the pilot study were developed and evaluated. The tasks developed for students' own work with the CPU program were also evaluated.

The tryout of the tests and tasks was conducted over a three lessons sequence. In the first lessons the students took a test version of the pre-test.

The second lesson was focusing on introducing the computer program CPU. First the teacher gave a short introduction and afterwards the students had the possibility to try the program on their own. No tasks were given. This gave us the opportunity to see how much and what sort of introduction the program would need in the later pilot study.

In the final lesson the time come for students to work with the computer program and assigned tasks. The students were working in pairs with the program. Each task was given out one by one. The students had to individually turn in a prediction before being allowed to work together with the classmate and the computer program. After working with the program to solve the task, the pair handed in an answer to the task. The students’ discussion while working with the computer program was recorded, some on both video and some groups only audio. After this lesson a few students were selected to be interviewed about the pre-study. Questions were asked about the tests, the tasks and the program.

After these three lesson tryout of tasks and tests we had data in the form of test results and students predictions and answers to the given tasks. We also had audio recording of the students’ discussions while working with the tasks. We also had some audio recorded interviews with the students after the tryout.
Results of the pre-study

The data from the pre-study was studied in cooperation with the teacher. That gave teacher the possibility to have his own thoughts and ideas about the results. It also gave the teacher a view of the students’ difficulties in learning the concepts of optics. The main problem found was in the central concept of geometrical optics, the image formation. The students are able to do one-to-one mapping of object and image point for the relevant rays. But they have a main problem in including the idea of this mapping occurring by divergent and converging fluxes of rays. In most of the students’ answers on tasks consisting of image formation, the students use only a few rays, relevant for constructing the image. This is a problem for them when solving problems that require the use of other rays. This problem has been pointed out by (Goldberg and Bendall 1995). This problem became the main concern for the teacher and the main intention for the teacher to focus on during the teaching sequence in the pilot study.

The experiences from the students’ use of the CPU in the pre-study were that the students found the concept of light spray new and did help them in solving problems requiring more than one ray from each point on the object. One student explained that the light sprayed helped realising that there are rays going upwards. In the CPU program there is a possibility to use a light spray, which is a light source sending out rays in all direction. This is an area where we found students did have problem with. Maybe the CPU program could contribute to students’ conceptual development to use multiple rays. Together with the teacher one learning outcome we agreed on was to affect students’ conceptions about rays to involve multiple rays. It’s also interesting to notice that the students in the interviews report that the use of the computer program helped them in understanding the propagation of light rays. This was the base to build the teaching strategy on.
Teaching strategy

The teacher in today’s school has many tasks to perform. The most obvious but not a trivial one is determining which learning tasks are the most appropriate for students to work on (Shuell 1987).

In all teaching, the intentions behind the choices the teacher makes are important. To use ICT in teaching without well-developed intentions is not a good teaching strategy to achieve the intended educational outcomes. In this study, the definition of teaching strategy used is taken from (Scott, Asoko et al. 1991). They suggest that pedagogical decisions for teachers are made at three levels. First, the teacher needs to foster a learning environment, which will be supportive for learning. A second level of decisions for the teachers involves the teaching strategies and the third is about specific learning tasks. They define teaching strategies in terms of overall plans, which guide the sequencing of teaching within a particular topic. They suggest four factors, which teachers must take into consideration when deciding about teaching strategies:

- Student’s prior conceptions and attitudes.
- The nature of the intended learning outcomes.
- An analysis of the intellectual demands involved for learners in developing or changing their conceptions.
- A consideration of the possible teaching strategies, which might be used in helping pupils from their existing viewpoints toward the science view.

An important part of the teaching strategy is the intentions the teachers have. The teaching strategy for the pilot study was intentionally and by the definition used developed in close cooperation with the teacher of the class. Focus where on a teaching strategy based on constructivist view on learning. The intended conceptions for the teaching are part of the categories in the result section, starting on page 28. The intentions were to focus on the propagation of light and not introduce rays from the beginning. The intention was to use students’ own prior conception because in the constructivist view learning is seen as a process of cognitive development leading from certain already-
existing conceptions along learning pathways towards the science conceptions to be learnt (Duit and Treagust 1998). The teacher would present situations and give the students possibilities to discuss and present their views. The teacher was not supposed to present the intended conception, but to challenge the students’ prior conceptions with new situations and questions.

Pilot study

Overview of the pilot study.

The pilot study was conducted at an upper secondary school in a class with students who major in science. The school is located in a smaller Swedish city. The students come from different social backgrounds. This is their tenth year in school. The students have had some formal teaching in physics during their years in compulsory school. The physics curriculum of the compulsory school includes some optics

- The number of students taking part in the pre-test was 14.
- The number of students taking part in the post-test was 16.
- All the students who took the pre-test did take the post-test.
- There were two students who took the post-test that did not take the pre-test.
- The number of lessons was 14 +2 for pre and post-test.
The total of 16 lessons was spread over a three month period. The students normally take this course about a semester later. An exchange was made with a mathematics course. In the overview of the lessons in table 2 we can see that most of the students were present during all lessons. The use of the CPU program is also presented in the overview to show for what how and how often it was used.

The teaching sequence was designed together with the teacher. The shorter pre-study was carried out with the same teacher.

The idea behind the teaching strategy for the teaching sequence was to focus on the concept of image and vision without introducing rays from the beginning. In the teaching the teacher did not introduce this concept until the other concepts of the teaching sequence had been introduced. This was presented on page 20.
<table>
<thead>
<tr>
<th>Lesson number</th>
<th>Lesson Content</th>
<th>CPU</th>
<th>Data collected</th>
<th>Number of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pre-test</td>
<td></td>
<td>Written tasks, Video</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>Introduction to physics, scientific method, light</td>
<td></td>
<td>Video</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>Light, reflection, shadow</td>
<td></td>
<td>Video</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Refraction, CPU</td>
<td>Introduction</td>
<td>Video</td>
<td>17</td>
</tr>
<tr>
<td>5</td>
<td>Student works on open written tasks</td>
<td></td>
<td>Video</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>Vision, light propagation</td>
<td></td>
<td>Video</td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td>Mirror</td>
<td>Teacher uses CPU for demonstration</td>
<td>Video</td>
<td>16</td>
</tr>
<tr>
<td>8</td>
<td>Mirror, pinhole</td>
<td></td>
<td>Video</td>
<td>16</td>
</tr>
<tr>
<td>9</td>
<td>Refraction</td>
<td>Students do laboratory work with CPU on the refraction law</td>
<td>Video</td>
<td>17</td>
</tr>
<tr>
<td>10</td>
<td>Diffraction, lenses</td>
<td></td>
<td>Video</td>
<td>16</td>
</tr>
<tr>
<td>11</td>
<td>Lenses and light's refraction through lenses</td>
<td>CPU and laboratory tools</td>
<td>Video</td>
<td>16</td>
</tr>
<tr>
<td>12</td>
<td>Students own work with developed tasks, see p.25</td>
<td>CPU as a tool for problem solving</td>
<td>Video</td>
<td>16</td>
</tr>
<tr>
<td>13</td>
<td>Students own work with developed tasks.</td>
<td>CPU as a tool for problem solving</td>
<td>Video</td>
<td>13</td>
</tr>
<tr>
<td>14</td>
<td>Students own work with developed tasks.</td>
<td>CPU as a tool for problem solving</td>
<td>Video/audio</td>
<td>12 (4 students were absent because they had finished all the tasks.)</td>
</tr>
<tr>
<td>15</td>
<td>Repetition</td>
<td></td>
<td>Video/audio</td>
<td>15</td>
</tr>
<tr>
<td>16</td>
<td>Post-test</td>
<td></td>
<td>Written tasks</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 2. The lessons of the teaching sequence and data around the lessons.
In the Table 2 on previous page, the content column is presenting which concepts the studies are being focused at during each lesson. This only presents those concepts that the teacher focuses on during the lesson; this does not exclude the use of other concepts during the specific lesson. The teacher used both experiments and computer simulations to introduce the new concepts. The table also presents the number of students attending the lessons. It shows that most students were present at all the lessons.

**Students own work with developed tasks**

Some special tasks were developed, based on similar tasks in the CPU material and earlier research on students’ conceptions, see p. 8. These special tasks were used to some extent in three situations.

- As part of the pre-test
- As part of students' group work during teaching, using the computer with CPU
- As part of the post-test

The group work with CPU was done during lesson 12 to 14. Each task was performed in two steps. In the first step the students were individually asked to write down a prediction on the task without using the CPU program. This correlates to the CPU pedagogy’s elicitation phase with the purpose of making the students conceptions visible for the students. Students were asked to explain some phenomena in the task as best as they could, based on their prior knowledge and experience. Before moving on to the next step the students had to hand in the prediction.

In the second step the students were working in pairs using the CPU program with the task and together solve it and hand in a solution. The idea of working in pair is that the students’ different conceptions should meet and the discussion between the students would develop the students’ conception’, maybe an alternation of the held conception or a start for developing a new conception.

This data have not been analysed but the students work are part of the teaching sequence and these are the lessons that focuses to a higher extend on students working with the computer program.
Questionnaire

The format of written questionnaire was chosen as most appropriate for investigating the students in the class of the pilot study. We utilised two types of questions:

- The first type of questions in the pre- and the post-test were used in earlier studies of the subject (Galili and Hazan 2000; Galili and Hazan 2001). The questions addressed the content knowledge and conceptions held by the students regarding light, vision and image (Appendix 1, tasks 1 and 6.).
- The second type of questions came from the CPU program and was also clearly related to alternative conceptions (Appendix 1, tasks 3 and 4.)

The questions were open format questions to increase the reliability of the collected data. We thus collected data of greater diversity than using a multiple choice test. To increase the validity of the questions they were tried out before the use in the pilot study. The try out was done in another group of students who had studied the content knowledge of optics. That gave us opportunity to rephrase some question and increased the validity of the questionnaire.

The questionnaire that was used in the pre and the post-test differed in some questions. The difference was that some questions were excluded in the post-test since they didn’t function in the pre-test. The pre-test was taken by the students under the condition there were no time limit. The time demanded by the students for taking the pre-test showed that the test was too long for the time given for the post-test. The questionnaire had to be shortened. The pre-test consisted of a 7 questions that were dived into sub questions, the pre-test totally consisting of 23 questions. The post-test consisted of 6 questions that were dived into sub questions, the post-test totally consisting of 18 questions.
The questionnaire was addressing conceptual understanding of:

- vision (the role of the eye and the light)
- light passing through a pinhole
- image formation and the location of the image and in relation to an observer and the screen
- imagery in mirrors
- the use of ray was not tested explicitly but the questions gave the students opportunity to use them

The questions are presented in the appendix.

The categories were developed after reviewing earlier research of students’ conceptions of optics. After a preliminary overview over the students answers the categories were slightly changed, some were excluded because there were no students found in these.

Geometrical optics deals with optical phenomena involving light propagation through an optical system and the creation of an illumination pattern, or an image. This process is the concept of image formation. For having the possibility to study these all the concepts in this process was included in the study: image, ray, vision and image formation.
Results and discussion

The results are presented in four different sections. Section 6.1 presents the categories developed for categorization of students’ conceptions in the pre- and post-test. For the concept Ray there is a presentation about the students’ conceptions in different tasks. Section 6.2 presents the results about conceptions around vision, image, ray and image formation. Section 6.3 presents the pilot study’s consequences for categories and tasks and section and 6.4 shows some special groups of students which show the same conceptual change. This section will also present differences in conceptual profile for some students.

Categories

The categories were developed after reviewing earlier research of students’ conceptions of optics. For an overview of this see p. 8. After a preliminary overview of the students’ answers the categories were slightly changed and some were excluded because there were no students found in these. Geometrical optics deals with optical phenomena involving light propagation through an optical system and the creation of an illumination pattern, or an image. “Sight plays an important role in learning geometrical optics. Sight enables us to detect and thus track light propagation paths; sight enables us to detect patterns of illumination, interpret them, and to identify related patterns(e.g., object and image).”(Langley, Ronen et al. 1997) Based on this the chosen concepts of this study are image, ray, vision and image formation. Below follows a description of the categories for each concept.
Vision

<table>
<thead>
<tr>
<th>Category name</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_1$ (Light bath)</td>
<td>Light bath as a condition for seeing, The eyes’ role is not mentioned.</td>
<td>“The person has eyes.”</td>
</tr>
<tr>
<td>$V_2$ (Looking with eye)</td>
<td>Eye look at the object, Vision is in focus.</td>
<td>“Through looking at it (the object) with the eyes.”</td>
</tr>
<tr>
<td>$V_3$ (Source to object)</td>
<td>Light from light source to object</td>
<td><img src="image.png" alt="Diagram" /></td>
</tr>
<tr>
<td>$V_4$ (Object to eye)</td>
<td>Light from object to eye.</td>
<td>“Light reflects on the object and goes back to the eye.”</td>
</tr>
<tr>
<td>$V_5 = V_3 + V_4$ (Intended)</td>
<td>Light from light source reflects on the object and gets into the eye</td>
<td>“Light goes from the some light source and the objects reflects the light and some rays reach the eye.”</td>
</tr>
</tbody>
</table>

Table 3. The categories of vision.

The students’, who hold concepts which are categorised into category $V_1$, do not talk about the role of the eye for seeing something. Students’ explains vision with the fact that humans have eyes. This is also found in earlier research (Guesne 1985).

In $V_2$, the eye has an active part by looking at the object. However, there is nothing in the students talk about why the eye has to be active. No talk about how the light travels. (Heywood 2005) have also found this category and describes it that students’ talk about
visual representation, the concern in the students’ answers are on looking and seeing the object.

The category V\textsubscript{3} is a category where students’ responses are focusing on light coming from a light source and reaching the object. The connection between light source and the object to been seen is indicated in the students answers. But the connection between the object and the eye is not expressed in the students’ answers.

In category V\textsubscript{4} the students’ is focusing on in their answers on the light coming from the object to the eyes. The link between the light source and the object is missing.

The more scientific answers to the question are categorized in V\textsubscript{5}. This category is a combination of the two categories, V\textsubscript{3} and V\textsubscript{4}. Light comes from the light source and is reflected in the object and some of the light needs to reach our eyes for us to be able to see the object.
### Table 4. The categories of Image.

<table>
<thead>
<tr>
<th>Category name</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_1$ (Holistic)</td>
<td>Holistic view, the picture is something that cannot be dissolved into points. Speaking of one part.</td>
<td>From pre-test task 3: “There is a shadow in the enlightened area.” (On the image)</td>
</tr>
<tr>
<td>$I_2$ (Biology)</td>
<td>The image is developed in the brain. The student uses an explanation from biology.</td>
<td>“One gets an image in the eye that is received by the brain.”</td>
</tr>
<tr>
<td>$I_3$ (Intended)</td>
<td>Point to point correlation between object and image. The image can be dissolved into an infinite number of points</td>
<td></td>
</tr>
</tbody>
</table>

Image as a concept is how the students’ talk about the image, describing what an image is. We make a distinction to how the image is formed, even though this is closely related. The main difference is that image formation is connected to light propagation. The conception lying behind category $I_1$ is a well-known result of previous research (Galili and Hazan 2000). The students who hold conceptions that are categorised in $I_1$ are never talking about the object or the image being dissolvable into points. They might talk about parts of the image, but then it is a rather large part of the image. Students who use terms from biology and talk about the image being formed in the brain are categorised in $I_2$. The conception of physicists is found in the category $I_3$. They show in their answers that the light from the object might be dissolved into infinite number of points which then are correlated to points in the image.
Ray
In this study the concept ray is separated from other concepts like image and vision. One aim is to test how this works. The categories intend to show what students’ understanding looks like when using "rays", especially in their drawings. How they use the rays is included in the categories of image formation.

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>R₁</td>
<td>Ray indicating direction of light</td>
</tr>
<tr>
<td>R₂</td>
<td>Visual rays, going from eye to object.</td>
</tr>
<tr>
<td>R₃</td>
<td>The ray is indicating direction and the starting point on the object or the end point on the image is shown.</td>
</tr>
<tr>
<td>R₄</td>
<td>The ray represented by a straight line, indicating direction and both starting point on object and end point on image.</td>
</tr>
</tbody>
</table>

Table 5. The categories of ray.

Category R₁: Ray as indication of the direction of light
Description of category:
The students, who hold conceptions, which are categorised in category R₁, use rays in their answers only to indicate a general direction of light. The rays must be included in a figure that the students add to answer the tasks. The only purpose for using the rays in this kind of answer is to show in which direction the light propagates.
Examples of students' statements, which fit into this category:

(Original student answer in Swedish)

These rays show the direction of the light. The student answer also includes eye rays that are the next category, so this answer is categorised in both categories.

**Category R₂: Rays as visual rays**

Description of category:
In the category R₂ the student uses rays to explain vision. The ray is going from the eye to the object that the person is looking at. This category is therefore only usable for analysing tasks involving vision. The use of visual rays appears only in students’ answer when explaining vision. Earlier research has found this conception and the name visual rays is taken from (Andersson and Kaerrqvist 1983).

For example of student answer in this category se the example above in category R₁ on previous page.

This category includes all students’ answer where student uses in text or figures rays that goes from the eye.
Example of a problematic case is:

<table>
<thead>
<tr>
<th>(Original student answer in Swedish)</th>
<th>(Translation into English)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personen ser föremålet genom att fixa det med ögonen.</td>
<td>The person sees the object by fixating it with the eyes.</td>
</tr>
</tbody>
</table>

Does this only mean that the eye must look in the direction of the light object, or does it mean the eye sending out rays?

**Category R₃: Rays going from one point or to one point**

**Description of category:**
The category $R₃$ is used for answers where a student focuses on light coming from a specific point on the object or light ending on a specific point on the image.

The problematic with this category is that it is hard to decide if a student with a figure has the intention to include both the start and the end point. The student in this category is drawing a line to illustrate a ray, and it has both a start and an end point. That student will be categorized in $R₄$. If the students do not include any start or end point, the students will be categorized in $R₁$. 

33
Category R₄: Rays going from one starting point to one end point

Description of category:
The students who link the start point on the object with the endpoint in the image are categorized in category R₄.

Examples of students' statements, which fit into this category:

The difficulty in this category is to tell if the students’ intention is to show that the start and the endpoint on the ray are in a point to point correlation. A ray has always two points but do the students in their figures and answers have an intention to show the correlation between the two points?
<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>(Students answers there possible)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I</strong>₁ (holistic)</td>
<td>Holistic view, the picture is something that cannot be dissolved into points. Speaking of one part. From pre-test task 3: “There is a shadow in the enlightened area.” (On the image)</td>
<td></td>
</tr>
<tr>
<td><strong>C</strong>₁ (one ray coming/goiing to the corresponding point)</td>
<td>One ray from one object point to corresponding point on image</td>
<td></td>
</tr>
<tr>
<td><strong>C</strong>₂ (two rays coming/goiing to the corresponding point)</td>
<td>Two (relevant) rays from one object point to corresponding point on image</td>
<td></td>
</tr>
<tr>
<td><strong>C</strong>₂ (two rays not coming/goiing to the corresponding point)</td>
<td>Two or more rays (relevant) from one object point going to different points on the image. Two or more rays going to one point of the image but coming from different points of the object. The student uses more than one ray but cannot correlate object and image points.</td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>---------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>C₃ (intended)</td>
<td>More than two rays going from one point on the object to the corresponding point of the image. The object can be dissolved into an infinite number of points.</td>
<td></td>
</tr>
</tbody>
</table>

Table 6. The categories of Image formation.

In this category there is a focus on how student construct an image in an optical system. This is a central question in geometrical optics. In the category I, the students considers about the whole image or part of it travelling through the optical system. This is the same category as found under Image.

Category C₁ is for students who in their answers use only one ray from each point on the object to the corresponding point on the image. The students are not using the fact that there are an infinite number of rays leaving each point of the object. If the students use 2 rays they are categorised in to C₂ if they are able to connect start and end point with both rays or category C₂' if they are using two rays but are not able to connect the start and end points with the 2 rays. If the students in their answers shows the scientific conception and in their answers indicate that an object can be dissolved into object points which can send out an infinite number of rays and there is a connection between object and image points, the category is C₃.
How are the pilot study conceptions related?

The concepts of this pilot study are closely related. Students hold at least one conception for each concept. Vision is the concept that stands out some, since the other three are related to image and image formation. Ray is a concept that we only use together with some other concept. Vision is the concept that we use mostly alone.

But if a student holds the physicist’s view for one concept, does that mean the same student must hold the physicist’s conception for another of the concepts? We concentrate here only on the three concepts image, ray and image formation. If a student holds the conception I$_3$ (intended conception of the teaching) then it’s not necessary that the student holds the conception R$_4$ (intended conception), since the R$_4$ demands both an object and an image and the conception includes nothing about the object. The same is also true for a student holding the conception R$_4$ then a student doesn’t have to hold the conception I$_1$. Since R$_4$ does only not include that the image can be dissolved into infinite number of points.

If we look at the relation between I$_3$ and C$_3$ (intended conception), a student that holds the conception I$_p$ must hold the conception C$_3$, since the conception I$_3$ demands dissolving the image into infinite number of points which is also part of C$_3$. The same is also true for at student holding the conception C$_3$, and then this student has to hold the conception I$_3$. Since C$_3$ includes a dissolving of the object into infinite number of points that correspond to a corresponding point on the image.

Finally if we have the conceptions C$_3$ and R$_4$, a student holding the conception C$_3$ must hold the conception R$_4$, since C$_3$ demands a correlation between a point on the object and corresponding point on the image. But a student holding the conception R$_4$ doesn’t have to hold the conception, because for R$_4$ doesn’t mention anything about the number of rays from each point on the object to each point on the image.
Results about conceptions around vision, image, ray and image formation

The Tables in the coming sections show the total results of selected tasks from the pre- and post-test. Each concept is categorised and presented separately. The number N is the total number of received answers that have been categorised for each concept. The tasks were all open tasks and therefore the students had a choice of how to solve tasks, for example they could choose to use or not to use rays in their answers about how an image is formed. The pre and post-test are presented together to give a possibility to study the differences. From the pre-test (see appendix xxx), only tasks number 1, 3, 6 and 7 were selected and categorised and for the post-test (see appendix xxx), only tasks number 1, 2 and 6 were categorised.

For each concept the number of tasks used for categorisation is presented. The total maximum number of answers is also presented whenever that is possible. There were 14 students taking the pre-test and 16 students taking the post-test. The increasing number of the index is showing a more complex and closer to the scientific answer to the task, the exception is index for the categories of the concept image, there category I2, this is a category for students using explanations from biology. The category in each concept with the highest index number is the category for answers that were intended with the teaching sequence. The numbers presented in the text refers to the actual number of student answers and in brackets the percentage of the total received answers.

The pre- and post-test are found in appendix 1 and 2.
Vision

In this part of the results we present students’ conceptions about the concept of vision. There was one task in both the pre- and post-test which was related to the concept of vision. The possible maximum number of student answers in the pre-test were 14 and in the post-test 16. The numbers of received answers were in the pre-test 13 and in the post-test 15. The results are based on following task:

A person is observing an object. Explain how the person can see the object.

The pre- and post-test results according to the defined categories are shown in table 7.

<table>
<thead>
<tr>
<th>Category</th>
<th>Pre-test (N=13)</th>
<th>Post-test (N=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_1$ (light bath)</td>
<td>1 (8 %)</td>
<td>1 (7 %)</td>
</tr>
<tr>
<td>$V_2$ (looking with eye)</td>
<td>6 (46 %)</td>
<td>0</td>
</tr>
<tr>
<td>$V_3$ (source to object)</td>
<td>1 (8 %)</td>
<td>1 (7 %)</td>
</tr>
<tr>
<td>$V_4$ (object to eye)</td>
<td>0</td>
<td>1 (7 %)</td>
</tr>
<tr>
<td>$V_5$ (physics)</td>
<td>5 (38 %)</td>
<td>12 (79 %)</td>
</tr>
</tbody>
</table>

Table 7. Pre- and post-test results about vision (N=13 or N=15 are results from 1 task)

In category $V_2$, we have student who in their answers focus on the eye looking at the object. This conception was found in 6 (46 %) answers in the pre-test. This results shows that most of the students before teaching use this well known everyday life conception (Guesne 1985) in spite they had some earlier instruction in lower grade physics in this
content area. For this age group the role of eye in vision is rather important. We expected this number to be smaller before teaching. An explanation to this might be that students parallel to their learning in school still hold everyday life conceptions.

In the post-test, we find no answers in this category, so some learning can be seen in this direction: students do not use this everyday conception about vision anymore.

Some typical answers from students in the V2 (looking with the eye) category is:

<table>
<thead>
<tr>
<th>Original student answers in Swedish</th>
<th>Translation into English</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1: Genom att titta på föremålet. Man får en bild i ögat som sen tas upp av hjärnan.</td>
<td>By looking at the object. One gets an image in the eye that the brain then can receive.</td>
</tr>
<tr>
<td>S2: Personen ser föremålet genom att fixa det med ögonen.</td>
<td>The person sees the object by fixating it with the eyes.</td>
</tr>
</tbody>
</table>

The focus in this student’s answer is on fixating the object with the eye.

Other well-known prior conceptions like the light bath condition (Guesne 1985) were only observed with one student, category V1, both in pre- and post-test; so they play a minor role in teaching optics in this age group.
Already 5 students (38 %) before teaching answered in category V₅, which means that they see light coming from the light source to the object which reflects it and then light goes into the eye.

Some typical answers from students in the category V₅ (intended answers) of this type are:

(Original student answers in Swedish)                                  (Translation into English)
Ljuset som faller på föremålet reflekteras till personens ögon          The light which falls on the object reflected it to the person’s eyes.
Ljuset lyser på föremålet och från föremålet kommer bilden i hennes ögon. The light shines on the object and from the objects comes the image to her eyes.

This answer shows a physics explanation for vision but remains in preliminary holistic conception for image.

This category of intended physics explanation increased to 12 (79 %) students in the post-test, which again indicates some learning. This was expected, since a focus in the teaching strategy was on vision.
In this part the results about the students’ conception about the concept of image is presented. The numbers of tasks relevant to the concept of image were four in the pre-test and two in the post-test. The maximum possible student answers in the pre-test were 56 and in the post-test 32. The numbers of received answers were in the pre-test 36 and in the post-test 13. The results are based on the following task from pre-test and task 1, 4 and 6 from the pre-test and task 1 and 2 from the post-test.

**Task 3**

A light source is placed in front of a convex lens and the image of the light source is reproduced on a screen. The image on the screen is sharp.

a) How does the image look like on the screen?

b) What happens with the image if the place an obstacle in front of the lens that covers part of the lens (see illustration above) Explain with text and figure.

c) In the figure an eye is placed out. What can we see through the eye?

d) Where in the figure can we place the eye to see through the eye an image of the light source? Answer with A, B, C, D, E, and/or F.

e) What do we see if we take away the screen and the eye is placed in E or F?

The pre- and post-test results according to the defined categories are shown in table 8.
### Table 8: Pre- and post-test results related to the concept of “image” (N=36 and N=13 are results from 4 tasks in the pre-test and 2 tasks in the post-test)

<table>
<thead>
<tr>
<th>Category</th>
<th>Pre-test (N=36)</th>
<th>Post-test (N=13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I₁ (holistic)</td>
<td>31 (86 %)</td>
<td>4 (31 %)</td>
</tr>
<tr>
<td>I₂ (Biology)</td>
<td>5 (14 %)</td>
<td>2 (15 %)</td>
</tr>
<tr>
<td>I₃ (Intended)</td>
<td>0 %</td>
<td>7 (54 %)</td>
</tr>
</tbody>
</table>

31 (86 %) of the students’ answers before teaching are found in category I₁, which means that most of the students’ answers indicate a holistic conception of image in the pre-test. This is a well known prior conception (Galili and Hazan 2000), in spite they had some earlier instruction in lower grade physics in this content area. This is a strongly held conception among the students in the pre-test. In the post-test there are only 4 (31 %). This indicates some learning. Some typical answers from students in this category I₁ (intended answers) are:

**Original student answer in Swedish**

![Student Answer Diagram]

The obstacle blocks part of the image.

S2: Det blir en liten ”ljusbild” på skärmens. S2: It becomes a small “light image” on the screen.

The student focuses in the answer on the image as a part of the screen.
The category I₃ with the intended answer was not found in the pre-test. Maybe this is a result of the category definition, which is rather narrow, in the way that it requires the students to show that the image can be dissolved. The students have to include in the answers to be categorised into this category. This category increased in the post-test to 7 (54%) answers, which indicates some learning. It was expected that this number would be higher in the post-test. Some typical answers from students in this category I₃ (intended answers) are:

- (Original student answer in Swedish) S1: Det kommer ljusstrålar från hela ljuskällan, även om vissa ljusstrålar förhindras av hindret kan man fortfarande se en bild.
- (Translation into English) S1: There comes light rays from the entire light source, even if some light rays are blocked by the obstacle, you can still see an image.

The student’ shows an awareness that light ray comes from the whole light source. The light source can be dissolved into an infinite number of light points.

The category I₂, students uses explanations from biology, a special category found in the students answers. Before the teaching this category had 5 answers (14%). The students remain strongly with conceptions from biology instruction. The students maybe have adopted this more strongly from their earlier instruction than the physics conceptions relevant for this content. In the post-test the number has decreased to 2 answers (15%). The teaching has influenced the students to answers the task from a Physics perspective.
Some typical answers from students in this category I_2 (biology) are:

<table>
<thead>
<tr>
<th>Original student answers in Swedish</th>
<th>Translation into English</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1: Man får in en bild i ögat som sedan tas upp av hjärnan.</td>
<td>S1: One gets an image in the eye that in received by the brain.</td>
</tr>
<tr>
<td>S2: Personen har ögon! I ögonen finns linser som reflekterar ljuset. Ljuset går med nervsystemet upp till hjärnan där en bild framträder.</td>
<td>S2: The person has eyes! In the eyes there are lenses that reflect light. The light moves through the nervous system up to the brain where an image appears.</td>
</tr>
</tbody>
</table>

The students in their answers focus on explaining vision from a biologist perspective.

Interesting is to notice the overall use of the concept image is decreasing from the pre-test to the post-test. In the post-test the number is noticeable low even if the number of task that was in the post-test were fewer than in the pre-test.
Rays

In this part the results about the students’ conceptions about the concept of Ray are presented. The number of tasks relevant to the concept of Ray was 4 in the pre-test and 3 in the post-test. The maximum possible student answers in the pre-test were 56 and in the post-test 32. The number of received answers, related to the concept ray, was in the pre-test N=31 and in the post-test N=42. The results are based on the following task 3 and in addition task 1, 4 and 6 from the pre-test and task 1, 2 and 4 from the post-test.

Task 3

A light source is placed in front of a convex lens and the image of the light source is reproduced on a screen. The image on the screen is sharp.

a) How does the image look like on the screen?
b) What happens with the image if we place an obstacle in front of the lens that covers part of the lens (see illustration above) Explain with text and figure.

c) In the figure an eye is placed out. What can we see through the eye?
d) Where in the figure can we place the eye to see through the eye an image of the light source? Answer with A, B, C, D, E, and/or F.
e) What do we see if we take away the screen and the eye is placed in E or F?
The pre- and post-test results according to the defined categories are shown in table 9.

<table>
<thead>
<tr>
<th>Category</th>
<th>Pre-test (N=31)</th>
<th>Post-test (N=42)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R₁ (direction)</td>
<td>26 (84 %)</td>
<td>24 (57 %)</td>
</tr>
<tr>
<td>R₂ (visual rays)</td>
<td>4 (13 %)</td>
<td>3 (7 %)</td>
</tr>
<tr>
<td>R₃ (one point and direction)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>R₄ (two points and direction)</td>
<td>1 (3 %)</td>
<td>15 (36 %)</td>
</tr>
</tbody>
</table>

Table 9. Pre- and post-test results related to the concept of “ray” (N=31 or N=42 are results from 4 tasks in pre-test and 3 in post-test.)

26 (84 %) of students' answers in the pre-test are using Rays only for showing the direction of the light, with no special point to start and no special point to end, category R₁. In the post-test the number has decreased to 24 (57 %) of the students’ answers. It was expected that the number should be high in the pre-test but it was expected to decrease more in the post-test. The high number of students answers using rays for showing only the direction was expected since the use of Rays are a strong conception for students in explaining how an image is formed. It often goes together with a holistic understanding of image.
Some typical answers from students in this category R₁ (direction) are:

(Original student answer in Swedish)

S₁:

The rays indicate only the direction of the light.

The category R₄ had 1 (3 %) student answer in the pre-test and 15 (36 %) in the post-test. This indicates some learning. It was expected that this number should be even higher in the post-test. Some typical answers from students in this category R₄ (intended) are:

(Original student answer in Swedish)

S₁:

The category R₂ (visual rays) includes 4 (13 %) of the students and R₃ no students in the pre-test. In the post-test the number of students in category R₂ has decreased to 3 (7 %). The category R₃ remains without any students in the post-test. The difference between the categories is rather small and unclear. The category R₃ is included since it was expected
that some students would hold this conception. The difference between category R₃ and R₄ is not clear, since there is consensus how a scientific category about rays would be defined.

The drawings of the students show a more aware use of the Ray in the post-test.

Pre-test

Post-test

The figure shows the same student’s answer in the pre and the post-test. But the result show also an increasing use of Rays overall in the students answers in the post-test. The categorisation this might be correlated to the decreasing use of the concept of Image. The students are in the post-test more focused on how the Image is formatted than discussing the Image itself. In the pre-test the students lack of knowledge how an Image is formed puts their focus on the Image.
Image formation/ construction

In this part the results about the students’ conceptions about the concept of Image formation/construction is presented. The numbers of tasks relevant to the concept of Image formation were 4 in the pre-test and 2 in the post-test. In this concept of image formation the students have shown that they hold parallel conceptions, therefore it is hard to calculate the maximum possible student answers in the pre-test and in the post-test. The number of received answers related to the concept Image formation was in the pre-test 35 and in the post-test 35. The results are based on the following task 2 and in addition task 4 from post-test and task 1, 3, 4 and 6 from the pre-test.

Task 2

A light source is placed in front of a convex lens and the image of the light source is reproduced on a screen. The image on the screen is sharp.

a) How does the image look like on the screen?

b) What happens with the image if the place an obstacle in front of the lens that covers part of the lens (see illustration above) Explain with text and figure.

c) In the figure an eye is placed out. What can we see through the eye?

d) Where in the figure can we place the eye to see through the eye an image of the light source? Answer with A, B, C, D, E, and/or F.

e) What do we see if we take away the screen and the eye is placed in E or F?
<table>
<thead>
<tr>
<th>Category</th>
<th>Pre-test (N=35)</th>
<th>Post-test (N=35)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_1$ (holistic)</td>
<td>31 (89 %)</td>
<td>4 (11 %)</td>
</tr>
<tr>
<td>$C_1$ (one ray coming/going to the corresponding point)</td>
<td>4 (11 %)</td>
<td>17 (49 %)</td>
</tr>
<tr>
<td>$C_2$ (two rays coming/going to the corresponding point)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$C_2'$ (two rays not coming/going to the corresponding point)</td>
<td>0</td>
<td>10 (29 %)</td>
</tr>
<tr>
<td>$C_3$ (intended)</td>
<td>0</td>
<td>4 (11 %)</td>
</tr>
</tbody>
</table>

Table 10. Pre- and post-test results related to the concept of “image formation”
(N=35 are results from 4 tasks in pre-test and 2 in post-test)

The pre- and post-test results according to the defined categories are shown in table 10. 31 (89 %) of the students’ answers in the pre-test show a holistic conception $I_1$ in their answers. In the post-test the number has decreased to 4 (11 %). This indicates learning. The teaching has had an effect on the students’ conception. This was expected because of the teaching strategy. For example of student answers in the category of holistic conception see p 43.
In the pre-test 4 (11 %) of the students’ answers are categorised in $C_1$, the student uses one Ray from each point on the object to a corresponding point on the Image. In the post-test this category has increased to almost half of all students’ answers, 17 (49 %). This indicates that students have learned that an image can be dissolved into object points that send out rays.

Some typical answers from students in this category $C_1$ (one ray coming/go to the corresponding point) are:

(Original student answer in Swedish)

S1:

The rays connect one point on the light source with one point on the image and show direction.

The category $C_2$, two rays coming/go to the corresponding point, was an expected conception to be found in both pre-test and post-test. But the results show that students who use two rays in their answers are not able to do the point to point mapping and are categorised in category $C_2$. The category $C_2'$ has no students’ answers in the pre-test, but 10 (29 %) in the post-test. This indicates that the student have learnt to use more than one ray from each point, but are not able to connect them in a point to point mapping.
Some typical answers from students in this category C$_2$ (two rays not coming/goiing to the corresponding point) are:

(Original student answers in Swedish)

S1:

![Diagram S1](image)

S2:

![Diagram S2](image)

The students use more than one ray from each light point on the light source, but they do not end at the same point on the image.
The increase in the category C₃, the intended conception from 0 in the pre-test to 4 (11 %) in the post-test was expected to be higher because it indicates some intended learning.

Some typical answers from students in this category C₃ (intended) are:

(Original student answers in Swedish)

S1:

S2:

Both students clearly show they have understood the use of multiple rays. Student S1, shows the direction of the light only in front of the lens, might be a little hard following the light after the lens. Student 2 has this figure in addition to the task to illustrate clearly that the student understands the use of multiple rays.
Experiences from the use of the computer program in the teaching sequence

How are the results of the conceptual change among the students’ conceptions for the concepts of this study related to the use of the computer program CPU?

What impact had CPU on the students’ learning? The results of the students learning presented above are the result of many factors. One is the teaching sequence with the use of CPU, but it’s impossible to say to what extend it had an impact. The teacher was asked about the teacher’s experience of teaching with CPU and the teacher’s thoughts about the program’s impact on the students. One advantage the teacher saw was the possibility to illustrate multiple rays in a new way compared to black board teaching. The students were able to solve questions with less teacher involvement. The program gave the students possibilities to understand the nature of physics, as a natural science that explains observable phenomena with models. The program was a way to introduce models. The program gave us new opportunities to teach students construct an image in an optical system without using only a few “construction rays”.

In the students own reflections during the interviews, in the pre and pilot study we found that they found the use of light spray in the CPU useful for understanding multiple rays. The program gives opportunity to model the use of multiple rays that are not easily possible otherwise.
Another reflection from the use of CPU was that the programs possibilities to model vision were found positive for the students learning. The program gave teacher possibilities to show situation and present situation there vision is included in a situation of image formation. Figure 5, which is from CPU gives the teacher possibility to show what an eye in that position would see on the screen.
Discussion of the results

One group of students found in the data are the group using visual rays. The students who use the concept of visual rays for explaining how we can see something are not fully affected by the teaching. The results show the number of student answers in category R_2 is decreasing but not completely disappearing, see p. 47. This conception seems to be strongly held by the students.

One common group found in the data from the pre-test is students with a holistic view. In the pre-test there were 31 answers in the holistic category I_1, but only 4 remained in that category in the post-test. Out of the four who remained three have now been affected by the teaching and have started to construct with point to point correlation. But they are mixing this construction with a holistic view. One example is found in the answers to task 2 in the post-test, where a student is combining a holistic view explaining in the answer that only the lower part of the object is magnified, but the drawing shows that the student is trying to use point to point correlation for two Rays. Due to this the student is categorised in both I_1 and C_2'. The group who abandons the holistic view starts using Rays for a point to point correlation. They manage well in using the point to point correlation for one Ray between the points, but do not succeed for multiple Rays.

An interesting group of students is the category C_2' (two rays not coming/going to the corresponding point). The students are holding a conception in between the C_1 and C_2, they are able to use more than one ray but not able to do a point to point correlation. They are holding an intermediate conception, (Petri and Niedderer 1998) This category is interesting because they have to some extend understood multiple rays, but not point to point mapping. Students’ difficulties of constructing a conception after teaching that includes both multiple rays and point to point mapping where also found in a study by (Galili, Bendall et al. 1993).
Consequences of the pilot study for the categories and tasks

The study reported here is part of a pilot study. This section is a summary of the experience from the study. The focus is on the consequences for the tasks in the forthcoming main study. In this study all the tasks were open questions giving the students the possibility to extend their answers. The Category I found in this study and which is most dominant in the pre-test is probably context dependent. An earlier study (Andersson and Kaerrqvist 1983) did avoid this answers that the vision is explained by terms from biology, by in the questions asking explicit for what happens between the object and the eyes. In their study they do focus on vision and the category of visual rays is part of the vision categories. This studies dividing of the concepts into vision and image and with different categories in image and vision is something not to common in earlier research.

R₃ is a complex category, because every ray has a start and an end point. It’s rather hard in the categorisation work to see if the students have indicated an explicit end or start point.

The vision categories, V₃ and V₄

Is it possible that the students that have been categorised in one of the categories V₃ or V₄ takes the other category as obvious? In the category V₃, the student reasons that light goes from the light source to the object. Maybe the same student in see it as obvious that light goes from the object to the eye. Because the scientific answers is a combination of both the categories.

The tasks about vision are troublesome because student might take some factors for obvious. There might be problems for the students interpreting how to extend their answers, what parts should be included. How do students interpret the question: How do we see an object? The picture that complements the task illustrates an object and a person with her eyes in focus. Maybe the student finds it hard to understand the task what parts should be included. The person on the picture needs to focus by turning the eyes toward the object, so the eyes can receive light. Maybe when a student answers we need to look
at the object this is what they think about. They might take it for obvious that we at the same time need to get the light into the eyes.

The category $C_2$ had no students in this study, but was a category that was expected to be found. It’s also logical to from one ray move on to two rays and finally more multiple rays in students’ conceptions about image construction. Maybe have only a category for students who use one ray and point to point mapping, in this study category $C_1$, and one for students who use more than one ray and point to point mapping. In other words to combine category $C_2$ and category $C_3$.

**Future work**

The idea for the future study is to apply both a quantitative control group design with pre- and post-test as well as a qualitative design to follow the learning process of some students in more detail with data from all along the instruction (Niedderer 2001; Niedderer et al. 2005). These students are observed closer by video, and artefacts of their work will be taken as additional data. The control group design with comparison between four classes is planned according the following table:

<table>
<thead>
<tr>
<th></th>
<th>Without computer</th>
<th>With CPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>With a teaching strategy (TS)</td>
<td>4 classes</td>
<td>4 classes</td>
</tr>
</tbody>
</table>

Table 11. Design of the main study.

This study has helped identify some of the students’ difficulties with image formation, but also the possibilities to use the computer to help the students in their studies.
Conclusions

Teaching sequence.

When designing the teaching sequence one problematic area we found was the introduction of the concepts of rays. In the teaching sequence of this study one object was to teach the other concepts of optics without using the concept of rays. Students hold strongly to their earlier conceptions. We found in our study students that still hold on to eye rays.

This study has shown how important the concept of image formation is for geometrical optics. Because the other concepts are dependant on student’s having a useful conception in image formation. The core of geometrical optics is to be able to understand that in the model light from a light source can be dissolved into an infinite number of points, all sending out an infinite number of rays. To construct an image students have to be aware of this and then understand that light propagates in space. This light propagation is problematic. If a student understands image formation then the student have and most hold a good conception in the concept of image and ray. It’s not enough for students to have in terms of our study a high index in the conceptions of vision.

The CPU gave new possibilities to show geometrical optics that were found useful for the students and the teacher. The program gave possibilities to give new problems to the student; the possibility to model opens this.
Acknowledgement

First I like to thank my supervisors Kjell Magnusson and Hans Niedderer who both have played a major role in the creation of this thesis. Without your support this would never have been written. Your energy and time as well as respect for my ideas have been truly stimulating.

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I am also grateful to those at Karlstad University that have supported my work. Another important person in the accomplishment of this work is the teachers of all the schools who took part in both my studies that are part of this thesis. Without them this would not be possible. Also important in my life is all my family and friends, especially my Maria. She has been supportive during all the hard time finishing this thesis. Finally I like to send a thought to both my parents that I would have liked to have been present with me now.
References


http://cpuproject.sdsu.edu/.


Appendix 1
Pre-test

Here are the tasks given to the students in the pre-test for analysing the students’ conceptions of vision, ray, image and image formation.

Task 1

A person is observing an object. Explain how the person can see the object.

Task 3
A light source is placed in front of a convex lens and the image of the light source is reproduced on a screen. The image on the screen is sharp.

a) How does the image look like on the screen?

b) What happens with the image if we place an obstacle in front of the lens that covers part of the lens (see illustration above)? Explain with text and figure.

c) In the figure an eye is put in. What can we see through the eye?

d) Where in the figure can we place the eye to through the eye see an image of the light source? Answer with A, B, C, D, E, and/or F.

e) What do we see if we take away the screen and the eye is placed in E or F?
Task 4

a) What do we see on the screen if we place a “pinhole” (a small opening in an obstacle) between the light source and the screen? Sketch and explain the screen’s appearance.
b) What will happen if we change the size of the pinhole? Explain?
c) How does the screen’s appearance change if the pinhole is moved from A to B? Explain.
**Task 6**

A lamp is on and attached to a small aperture on a card.

a) What can be observed on a screen placed opposite the card see (figure below)? Explain your answer with a figure.

![Diagram of lamp, card, and screen](image)

b) If we move the lit lamp some distance away from the card, how will it affect the appearance on the screen (see picture below)? Explain with a figure.

![Diagram showing lamp, card, and screen](image)
Appendix 2

Here are the tasks given to the students in the post-test for analysing the students’ conceptions of vision, ray, image and image formation.

Post-test

Task 1

A person is observing an object. Explain how the person can see the object.

Task 2

---

Light source | Lens | Screen
A light source is placed in front of a convex lens and the image of the light source is reproduced on a screen. The image on the screen is sharp.

a) How does the image look like on the screen?
b) What happens with the image if we place an obstacle in front of the lens that covers part of the lens (see illustration above) Explain with text and figure.

c) In the figure an eye is put in. What can we see through the eye?
d) Where in the figure can we place the eye to through the eye see an image of the light source? Answer with A, B, C, D, E, and/or F.
e) What do we see if we take away the screen and the eye is placed in E or F?
Task 4

A lamp is on and attached to a small aperture on a card.

a) What can be observed on a screen placed opposite the card see (figure below)? Explain your answer with a figure.

b) If we move the lit lamp some distance away from the card, how will it affect the appearance on the screen (see picture below)? Explain with a figure.
Paper I
The implementation of ICT in Physics education.

Teachers’ reflections on their intentions and actual use.

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Roger Andersson is a PhD student in Physics education at Karlstad University and since 2003 associated with the national graduate school in science and technology (FontD) at Linköping University. His main focus of research is on teaching strategies and learning processes in Physics education with support of ICT.

Kjell Magnusson is Professor of Physics at Karlstad University. He has a considerable experience from undergraduate and graduate education at universities, including science teacher education. His science education research interest is mainly within the field of empirical studies of teaching and learning processes.
The implementation of ICT in Physics education.

Teachers’ reflections on their intentions and actual use.

Abstract
This article explores experienced primary teachers views on the implementation of ICT, information and communication technology, in their Physics teaching. The teachers are reflecting on their intentions and the actual use of ICT, which is opening new possibilities for the educational arena. A questionnaire was developed for collecting the teachers’ reflection and the questionnaire was based on open questions. The results show that teachers use ICT with a variety of intentions and that the implementation of ICT has in general had an impact on their teaching.

Background
Research shows that achieving positive educational outcomes requires more than simply providing access to computer hardware and software (Cuban, 2001). In 2003 an international comparative study on the use of ICT, information and communication technology, in the school was presented, (Hylen, 2003). It showed that Sweden had lost its position in the top when comparing different countries statistics over the use of ICT. There are numerous investigations, see e.g. (Hylen, 2003), but few of them investigate what ICT is actually used for and the intentions behind the use. (Sakellariou, 2002) In Sweden, much has been invested in hardware and software during the last decade. There is a foundation supporting and investigating the use of ICT in education, the Knowledge-Foundation (www.kks.se) but there is not enough focus on the actual use of the technology. The Knowledge Foundation presents reports every year over the use of ICT in Swedish schools, but the focus is on the knowledge and use of ICT, but not how it supports the pupils learning. (Sutherland et al., 2004) points out that importance of not seeing ICT as tool that could exchange all other tools. More research is needed on the questions of what ICT can be used for and why. (Smeets, 2005) has investigated the use of ICT in primary school, and concludes that teacher use ICT mostly as a complement and have not changed existing pedagogical practices. In this paper, a group of teachers were asked about their use of ICT in Physics.
The information and communication technology is opening new possibilities for the educational arena (Wheeler, 2001). Rather a complex myriad of variables is involved in enhancing teaching and learning with ICT raising difficult questions for evaluation of the implementation (Venezky, 2001). There is a scarcity of research about science teachers’ beliefs, attitudes, and intentions concerning the use of ICT, in the form of ICBSs (interactive computer based simulations) and LIBEs (laboratory inquiry-based experiments) (Zacharia 2003). The earlier mentioned international studies (Hylen 2003) are not focusing on a specific subject in school, and not on the purposes and intentions behind the use of ICT. The present study is focusing on Physics education in Sweden and upper secondary school. What are teachers considering when choosing to use ICT in the Physics classroom? What are the intentions for using ICT and what are they using ICT for?

Upper secondary school Physics in Sweden is divided into two successive Physics courses. The two courses extend over different periods at different schools. The schools also have the freedom to include the Physics courses in the school year they prefer. In Swedish Primary School, Physics is a compulsory subject.

In all teaching, the intentions behind the choices the teacher makes when planning the education are important. To use ICT in teaching without well-developed intentions is not a good teaching strategy to achieve the intended educational outcomes. In this paper, we see teaching strategy as all the choices a teacher makes that affect the actual learning for the students. An important part of the teaching strategy is the intentions the teachers have.

The object of this study is to find and investigate these intentions among teachers. The potential of ICT has been on discussion on the educational arena for a couple of decades now. Many in this arena focus on the possibilities of using ICT in the classroom. Closely related to the question of the intention behind the use, is the question of the role ICT has in the classroom. We define role here as the function the computer has in the classroom, is it used for assisting the teacher with demonstrating the phenomena of physics, is it used for the students to measure the Physical quantities in the Physics lab or is it used for assisting students in their studies giving them access to information through the Internet. Has the evolving possibilities of using ICT changed the teaching methods teachers use? How do the teachers reflect upon their use of this new medium?
**Research questions**

The main research questions addressed for this study were:

To what extent do Physics teachers use ICT in Physics education?

What intentions do upper secondary Physics teachers’ have for using ICT in their Physics teaching?

Have the Physics teachers changed their teaching strategy when introducing ICT in their Physics teaching?
Methodology

The Context.
This investigation was focusing on the views of some Physics teachers in upper secondary school and was intended to give the teachers possibilities to express their own thoughts and reflections. The teachers’ schools were visited and the research was done using a questionnaire. One reason for using a questionnaire was to be able to let the all the teachers at the school giving their own personal view and that at the same time. The reason to do it at the same time was so that the teacher would not discuss their view with the other teachers of the school. The questionnaire gives us possibility to do this.

The schools are all public upper secondary school in the area of Värmland and north Västra Götaland. The pupils in the schools are in the ages of 16-19. The schools are located in both urban and more rural areas

Data collection- the questionnaire.
The questionnaire comprised 15 open-ended questions about the use of ICT and 4 yes/no questions on the teachers use of different forms of ICT. The first two questions were on the teacher’s experience and the sex of the teacher. The questionnaire was divided into six parts:

General questions about the teachers’ use of ICT including frequency of use.

What computer programs the teachers used?

How were decisions made about the implementation of ICT?

If the teacher use Internet and questions about the use.

If the teacher use CBL (calculator based laboratory) and questions about the use.

The teachers own thoughts about using ICT in their teaching.

The focus of the questionnaire is on the part of the intentions and the purpose the teacher sees in the use. Direct questions about teachers’ intentions and purposes were asked during all parts of the questionnaire. All questions are set in the Physics context.
To find proper questions for the questionnaire, a group interview has taken place, involving teachers from another selected school. These teachers were only part in the development of the questionnaire and not in the main study. The discussion lead to some minor changes, but also that the abbreviation MBL, microcomputer based laboratory, was changed to CBL. The later being more commonly known among these teachers.

The selection of schools was done by inviting fourteen schools in the area to participate. A letter was sent to the head teacher of the Physics department at the schools. Nine schools chose to participate, they were all visited, and through the questionnaires, 37 teachers were asked about their use of ICT. The teachers answered the questionnaire privately and without time pressure. Only teachers actively teaching Physics were asked to take part in this study. The teachers also had the opportunity to demonstrate how they use computers, what programs they use and how they work with ICT in the classroom.

The research method in this study is quantitative, but the questions are open and there are opportunities for the teachers to expand their answers. This gives possibilities for a qualitative analysis including partly also the teachers’ reasoning. The categories were developed through iterative study of the data. Two category systems were developed for the analysis. One for categorizing the frequencies of teachers’ use of ICT in the teaching and one for the intention of the use.
Analysis

Categories for the extent of using ICT.
The extent of using ICT was categorized after looking at the teachers’ answer to an open question about it. This resulted in five categories:

Uses ICT every week or lesson
Uses ICT at least once a month
Uses ICT during students’ laboratory work.
A couple of times each Physics course or semester.
Seldom

Categories for the Intentions of using ICT.
The main questions relate to the teachers intentions for using ICT in their Physics teaching. To identify their intentions three questions in the questionnaire was used for categorization.

What is your purpose when using ICT?
If you use Internet, what is the purpose?
What advantages do you see with the use of ICT in your Physics teaching?

The answers on these questions were analysed together and lead to five categories. The teachers answered some questions about their intentions and might give answers that could fit into more than one category. The categories found are Variation, Visualization, Explanation, Measurement and Interest.
The characteristics of these categories are briefly described below.

**Variation**: to use ICT as a way to renew teaching and to thus create a variation in the teaching. The teachers focus in their reasoning on the aspect of variation as a mean to increase motivation.

**Visualization**: to more clearly show the student the phenomena of Physics.

**Explanation**: the focus is on explaining Physics and use ICT as a tool to explain the phenomena of Physics.

**Measurement**: ICT as a modern way of measuring physical quantities. This is mainly done in the laboratory but to some extent also during demonstrations.

**Interest**: The idea is that students’ interest for Physics may increase if they use modern tools. The teacher sees ICT as a tool that the students are familiar with from private and other activities and enjoys using.

**The participating group of teachers.**

The number of teachers in this study is 37, consisting of 30 men and 7 women. To identify their teaching experience, one question was on how many years of teaching experience they had. The years of teaching experience is referring to their total years of teaching, not depending on the age of the students nor the subjects taught.

The group of teachers show a wide range of teaching experience from newly graduated teachers to having over 40 years of experience. 20 teachers had been teaching in schools for more than 29 years, 10 had between 10 and 20 years of teaching experience and seven teachers had less than 10 years.
**Results**

**The extent of using ICT in the Physics teaching.**

The answers reported here are based on an open question. The teachers were introduced in the questionnaire’s introducing text into the term ICT, which was to be seen as more extensive than only computers. It includes the use of MBL for example.

Most of the teacher, 30 out of 37 teachers, state that they do use ICT in their Physics teaching. The 7 who state that they do not use ICT will not be part of the rest of the results. 6 of the teachers use it as often as every week or lesson, while 3 teachers report to use it at least once a month and 9 teachers claim to use ICT a couple of times per semester or course. 6 teacher state using ICT only in combination with laboratory work. Note that the teachers have not stated how often they use ICT for laboratory work. Finally, 6 of the teachers answer that they use ICT only rarely.

**In which parts of the Physics course do the teachers use ICT?**

The most common part of the Physics course where ICT is reported to be used is in Mechanics, where 18 of the teachers claim to use it. 5 teachers report using ICT during the Electronics part, 2 of these however not so often. Optics is a part of Physics where 4 teachers state that they use ICT. 3 of the teachers answered that they use it in all parts of Physics. 8 teachers use it with laboratory work without specification. 2 teachers did not answer the question.

The reported results are based on an open question, and teachers may, depending on their answer, be found in more than one of the above groups.
The intention of the teachers when using ICT in their Physics teaching.
The result is based on three questions in the questionnaire. A teacher’s answer could be categorized into more than one category. 15 of the teachers answer that they use ICT with the intention to visualize the concepts of Physics. 9 teachers say they want to renew their teaching and add ICT to give their teaching a variation. 4 teacher uses ICT with the intention to explain Physics. A tool for measurement is a reported intention for 11 of the teachers. 5 of the teachers use it for increasing the student’s interest in Physics. The results are summarised in Figure 1.

![Intentions](image)

Figure 1. The diagram shows the frequencies of the different categories for teachers’ intentions using ICT in their Physics teaching.
How often do teachers in the different intention categories use ICT?

The data gives a possibility to study how frequently the teachers in the different categories use ICT in their Physics teaching. The data shows that there is a difference between the categories.

*The teachers with the intention to use ICT for visualization.*

Here the most dominant category is the 6 teacher who use ICT for visualization a couple times during each Physics course or semester. 3 teachers use it at laboratory work, 3 teachers at least once a month and 2 uses ICT every week or lesson. 1 teacher seldom uses it.

*The teachers with the intention to use ICT for measurement.*

There are 11 teachers in this category and 3 of them use ICT every week or lesson, 3 at laboratory work, 2 teachers use ICT for a couple of times per Physics course or semester while 3 teachers use it more seldom.

*The teachers with the intention to use ICT for variation.*

In this category there are 9 teachers and 4 of them use ICT to increase variation in their teaching a couple of times per course or semester, 2 each week or lesson, 1 teacher use ICT for variation at least once a month while 2 only seldom.

*The teachers with the intention to use ICT for interest.*

3 teachers in this category use ICT to increase interest during laboratory work, 1 teacher uses it every week or lesson while 1 teacher use ICT for interest a couple of times per course or semester.

*The teachers with the intention to use ICT for explanation.*

This is a small category of only 4 teachers, there half of them uses ICT for explanation of Physics each week or lesson and the other 2 at least once a month.
<table>
<thead>
<tr>
<th></th>
<th>Variation</th>
<th>Visualization</th>
<th>Explanation</th>
<th>Measurement</th>
<th>Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Every week</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Once a month</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>During labwork</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>A couple of times per course semester</td>
<td>4</td>
<td>6</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Seldom</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1: The frequencies of the use of ICT for the different intentions categories.

**Have the use of ICT in the Physics classroom changed the teaching compared to before?**

For 16 of the teachers, the use of ICT has, in their own opinion, changed their teaching of Physics compared to before. 9 say that they teach the same way as always while one answers both yes and no to the question, 4 of the teachers have not answered the question.
Has the use of ICT changed the teachers’ teaching in the different intention categories?

To further look at the question, whether ICT has changed the teaching of Physics one can relate it to the different categories of intentions. This is presented in Table 2. We see that in the category of Variation 53% see ICT as a mediator for changing the teaching and almost the same number, 50%, in the category Measurement. For the other three categories, the number is 78% for Explanation and 75% for both Interest and Visualization.

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variation</td>
<td>50 %</td>
<td>50 %</td>
<td>8</td>
</tr>
<tr>
<td>Visualisation</td>
<td>75 %</td>
<td>25 %</td>
<td>15</td>
</tr>
<tr>
<td>Explanation</td>
<td>75 %</td>
<td>25 %</td>
<td>4</td>
</tr>
<tr>
<td>Measurement</td>
<td>64 %</td>
<td>18 %</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>(Partly 18%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interest</td>
<td>75 %</td>
<td>25 %</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 2. Has ICT changed the teachers’ teaching in the different intention categories?

N=Number of teachers answers.
Discussion

The majority of the teachers in this study report that the use of ICT has made a change in their teaching of Physics. They have changed their teaching and to involve ICT means change the strategy of how they teach Physics. Teaching strategy is an important part of this study, and the result is clear for the intention categories of explanation, interest and visualization. Maybe the new technology that now is available gives them possibilities. We have to be aware that our results are based on the teachers’ perspective.

(Scott, Asoko, & Driver, 1991) define teaching strategies in terms of overall plans, which guide the sequencing of teaching within a particular topic. They suggest four factors that teachers must take into consideration when deciding about teaching strategies:

- Students’ prior conceptions and attitudes.
- The nature of the intended learning outcomes.
- An analysis of the intellectual demands involved for learners in developing or changing their conceptions.
- A consideration of the possible teaching strategies, which might be used in helping pupils from their existing viewpoints toward the science view.

The most obvious traditional focus of teachers planning has been on the second factor, the learning outcomes. For the teachers of the intention categories explanation and visualization, the third factor is what they in their answers tend to focus on.

Visualization, the intention that most teachers in this study report, can be used as a term for many forms of objects in the physical world as well as in the VR (virtual reality)-world to represent aspects of the Physics phenomena. The concept has been actualized through the development of the new technology and the new opportunities for the educational arena that have opened. Teachers who have been interested in visualization have also changed their teaching strategy to make ICT part of the teaching. The results also show that this category of teachers is using ICT to a larger extent outside the schools laboratory. Maybe teachers do not find use for visualization in the Physics laboratory.
These teachers in the intention category of Explanation are in a similar way interested in how to use the new possibilities for explaining Physics. These teachers have probably been reflecting over the question of how to use ICT in the teaching and what to change for making the best use of it.

The intention category of Interest for increasing the students’ motivation with ICT is probably where teachers see the computer as a modern tool that the students are familiar with. One-teacher reports that for the girls in his Physics classes the computer in Physics teaching is a tool that they feel well acquainted with, compared to the other tools. The teacher describes an increasing motivation for the girls when using the computer; while the other tools of Physics they feel are more for boys. Once again, the intention of stimulating interest is a key to change the teaching and ICT is identified as a means of achieving this.

The intention of creating variation in the teaching is stated by teachers who are less frequent user of ICT in the teaching. They may perhaps have exchanged some other tool used in the teaching with computers, but without changing the teaching.

To use ICT to measure is the intentions of teachers who use a modern tool in exchange with the older one. The effect on the teaching is not so strong. There is however a greater number of teacher who say they have the intention to use ICT for measurement, compared with the number of teachers reporting that they use ICT for laboratory work.

One limitation of the data is that it does not give us the possibility to find in more detail what a teacher means with an answer of using ICT a couple of time per course. The length of a Physics course, and also the hours of laboratory work, differs between the schools.

One major question in the field of ICT and education is how to use the computer to improve learning. The computer is one element of ICT and there has been an enormous increase of the number of computer programs for the educational arena. To teach Physics the teachers can have access to programs with different functions: simulation, multimedia, modelling, and computer-based laboratory. The different programs have different purposes. This report has studied the teachers’ intentions.

Important is not only to choose the right kind of ICT, but rather to find which teaching strategy will improve the students’ learning. A future study will focus on the effect of a
teaching strategy and the use of a computer program for students’ learning in optics. This study has found that optics is an area where teachers are using ICT.

Conclusions.

Physics teachers use ICT in different fields of Physics with a variety of intensity: variation, visualization, explanation, measurement and interest. The teachers use ICT with a rather high frequency and some teachers in all the intention categories use it every week. A high number of teachers report that the use of ICT has changed their teaching of Physics.

References


Teaching and learning geometrical optics with computer assisted instruction

The information and communication technology, ICT, is opening new possibilities for the educational arena. Previous research shows that achieving positive educational outcomes requires more than simply providing access to computer hardware and software. How does this new technology affect the teaching and learning of physics? This thesis focuses on the field of geometrical optics. It reports two studies, both in Swedish upper secondary school. Important for the use of the ICT in physics education is the teaching strategy for using the new technology. The first study investigates with a questionnaire, how 37 teachers in a region of Sweden use computers in physics education and what intentions they follow while doing so. The results of this study show that teachers’ intentions for using ICT in their physics teaching were to increase students’ interest for physics, to increase their motivation, to achieve variation in teaching, and to improve visualization and explanation of the phenomena of physics. The second study investigates students’ conceptual change in geometrical optics during a teaching sequence with computer-assisted instruction. For this purpose we choose the computer software "Constructing Physics Understanding (CPU)”, which was developed with a base in research on students conceptions in optics. The thesis presents the teaching sequence developed together with the teacher. The study is based on a constructivist view of learning. The concepts analysed in this study were vision, image, ray and image formation. A first result of this study is a category system for conceptions around these concepts, found among the students. With these categories we found that students even at this level, of upper secondary school, have constructed well-known alternative conceptions before teaching, e.g. about a holistic conception of image. The results show also some learning progress: some alternative conceptions vanish, in some cases the physics conceptions are more often constructed after teaching. The students and the teacher also report that the CPU program gave new and useful opportunities to model multiple rays and to model vision.