Animations in Physics Learning

Patric Dahlqvist
Department of Computer and Systems Sciences
Stockholm University and Royal Institute of Technology, KTH. Sweden
patricd@dsv.su.se

Abstract: The study reported on in this paper investigates the effects of different presentation formats on learning an important principle in classical mechanics (the principle of equivalence). The presentation formats were abstract (classical vector representation), analogue (a more experience based illustration) and animated analogue. The study was conducted (N = 55) at the department of physics, Stockholm University.

Analyses indicate that animations do not facilitate learning in this case. An interesting observation is that the analogue and animated groups performed better than the abstract group on the analogue problems. But the abstract group did not outperform the other groups on the abstract problems. A tentative interpretation is that it may be the case that the students in the concrete conditions expended more effort into applying an abstract thinking on their concrete memory image.

Introduction

When arguing for the use of multimedia in educational settings the usual argumentation follows the “more is more” path (Scaife & Rogers, 1996), that is: a picture is better than (a thousand) words, an animation is better than a still, sound is better than silence, etc. However there is not much empirically founded work to support that line of arguing. In this study we try to address some of the questions regarding the effectiveness, in regard to learning outcome, of different multimedia presentational formats in the domain of Physics.

Theories of cognition and learning

The cognitive theories that are of interest in this study are of two different categories; theories about learning in general and theories about the interplay of different presentational formats.

There is an ongoing debate within cognitive science between what could be called the situated camp (e.g. (Lave & Wenger, 1991)) and the traditionalist camp (e.g. (Andersson, 1995)). The issues discussed are very interesting and have direct impact on the design of learning material. However important and interesting this debate is, we believe that the results of this study could be applicable in both camps (Wærn, Dahlqvist, & Ramberg, 2000).

When creating instructional material you have to be aware of what your goal is. Understanding, remembering, or applying are three different outcomes. A strategy that facilitates learning in one of these outcome classes need not facilitate learning in the others (Levin, 1989). Ohlsson (1996) makes a distinction between skill acquisition and higher-order learning. In skill acquisition the outcome is competence. The outcome of higher-order learning, on the other hand, is understanding. Skill acquisition has throughout the short history of cognitive science been quite successful. There are models like ACT-R and SOAR which are both theoretically powerful and empirically founded (Reimann & Spada, 1996). Research about higher-order learning, on the other hand, is still in its infancy (Ohlsson, 1996). What we aim at in this study is what Levin would call understanding and what Ohlsson might prefer to call higher-order learning.

It is fairly well established that visual instruction aids are very powerful means for enhancing learning (Wærn, 1995). However, since human attention and perception is limited, different presentational formats can interfere with each other (Andersson, 1995). Paivio has put forth a theory about the processing of information in the mind, the Dual-Coding theory. In this theory he claims that the human mind has two distinct (but inter-connected) systems, one to process language and another for the rest of the information (Paivio, 1986). These theoretical arguments
promote the use of multiple presentational formats in instructional material. This claim is also founded on some empirical findings. Mousavi, Low, and Sweller (1995) for instance, claim to have increased learning of geometry problems by mixing auditory and visual presentation modes.

**Presentational Formats**

When constructing instructional material, whether it concerns books, videocourses, or educational software, there are many different ways to present the learning material. The choice of media puts different restrictions on which presentational formats are possible. For example, it is not possible to use sound in an ordinary book. But there are still many choices to be made: text or picture, diagram or images, etc.

**Illustrations**

The use of pictures in prose has been thoroughly studied by many research programs (for a longer summary see (Willows & Houghton, 1987) or (Mandl & Levin, 1989)) and it is quite clear that, used with some common sense, pictures facilitate learning from text. Pictures in themselves can have different functions. Levin (1989) has classified pictures in prose learning according to five different functions: Decoration, Representation, Organization, Interpretation and Transformation. There is no uniform theory or even design principle that states how to use pictures in all learning situations. It is very much dependent on the task. The saying that "a picture is worth more than a thousand words" is not always true (Winn, 1987). Levin (1989) joins the cautious choir and states: "Two things that we have learned from research on pictures in text are that pictures are not uniformly effective in all prose-learning situations, and that not all types of pictures are equally effective." (p. 97)

**Animations**

In many computer-based instructional products animations have become popular. Unfortunately, the animations are often used to impress rather than to teach (Rieber, 1990a). There is a lack of theoretical foundation for the use of animations in computer-based instruction. Animated graphics represent a subset of instructional graphics but to which extent animations depart from and coincide with static visuals is questioned (Rieber, 1990a).

In contrast to static graphics, animated graphics can show information about two important visual attributes: motion and trajectory. Animations can provide information about an object’s motion, if it is moving, if the motion is changing, and how it is moving (path, patterns, etc.). They can also show information about which way the object is moving (Rieber, 1996).

There has not been very much research done on how, if at all, animations can facilitate learning. However there are some studies (ChanLin & Chan, 1996; Mayer & Anderson, 1992; Mayton, 1991; Poohkay & Szabo, 1995; Rieber, 1990b; Rieber, Boyce, & Assah, 1989). The problem is that the results are inconsistent. Rieber (Rieber, 1990b) shows that animations facilitate learning for children (under certain conditions) but not for adults (Rieber et al., 1989). On the other hand there is for example the study by Mayton (1991) which suggests that the use of animations in computer-based tutorials can be beneficial for adults.

Even though the results from the research on animations in instructional material are mixed to some degree, the use of animations in computer-based instruction still appears to have significant potential (Milheim, 1993). Palmiter and Elkerton (1993) found in a study that in a condition of text only, users spent less time learning a different, but similar, task than did the users furnished with animations. Milheim has put together a set of guidelines (Milheim, 1993) on how to design and use animations in instructional material. Some of these guidelines are:

- Develop simpler animations rather than complicated ones. In general, the animated graphic should be sufficiently complex to convey the important information within it, yet simple enough to be easily understood.
- Use animations when the instruction includes the use of motion or trajectory. In terms of motion animation can clearly show specific characteristics of an object while it is moving, e.g. its trajectory.
- Avoid overuse of animation since it can be distracting to learners.

The animations used in the instructional material in this study has been designed with these guidelines as a point of departure.
Method

A study was conducted at the department of physics at Stockholm University. It tested if there were differences in the learning outcome regarding the principle of equivalence when provided with different kinds of illustrations. This principle within Newtonian physics concerns acceleration and was regarded as suitable for animating according to Rieber's (1996) notion of what information animations can provide further than still illustrations. 55 first-year students counted as subjects. The study was conducted in two phases, with 35 subjects taking part in the first phase and the remaining 20 subject participating the next year (same course and same education). The principle of equivalence was part of the curriculum for the course they attended during the period of the study. The study was conducted before the principle of equivalence was treated in the course. All the subjects participated in the study voluntarily.

Design and Procedure

To perform the study a small CBI\(^1\)-program was constructed. This program tried to teach the students one important principle in classical mechanics: the principle of equivalence. A test was also administered in the program in order to test if the subjects had learned something from the initial instruction phase. The study was conducted in groups of 3 to 10 subjects at a time. On entering the room where the study took place the subjects randomly picked a computer with one version of the CBI-program already started. There were 10 computers in the room, and each session therefore consisted of a maximum of 10 participants. During the time the subjects ran the CBI-program the supervisor was always present in the room. The supervisor answered questions regarding the use of the program, when there were misconceptions due to language difficulties (some of the subjects did not have Swedish as their native language), or other non-physical science related questions. When seated, the subjects followed the on-screen instructions. After the subjects were finished they just left the room, and the supervisor collected the data that had been saved in a text file.

Material

Illustrations

The illustrations were of three different kinds: abstract, analogue and animated analogue. Abstract here means a classical illustration with arrows representing vectors which represent forces (gravitation and inertia) (see Figure 1). This illustration was constructed for another study (Ramberg, 1996) relating to the same area in physics.

![Figure 1: The abstract illustration](image1)

The analogue illustration is a more everyday experience-based type of illustration which the student can relate to, in this case a railroad cart seen from the inside, with a helium balloon attached to the floor and a steel ball hanging from the ceiling (see Figure 2).

![Figure 2: The analogue illustration](image2)

The animated analogue illustration consists of the same setting as the analogue with the exception that movement is added. In the animation, the sequence proceeds from: the railroad cart standing still, accelerating, travelling at constant speed, applying its breaks until it comes to a halt. The sequence is then repeated.

\(^1\) Computer Based Instruction.
The CBI-Program

The program consisted of four phases: an introduction, a learning phase, a test phase, and a debriefing phase. The introduction consisted of a text that explains some practical details about the program. The introduction also contained three background questions regarding the subjects' gender, age, and previous knowledge of the principle of equivalence.

The learning phase consisted of a text and one of the illustrations described above. The text was divided in four parts containing increasingly more detailed explanations of the principle of equivalence. When the subjects were finished (with the learning phase, before the test phase) they were asked to estimate (on a scale ranging from 1 - 10) how much they felt they had understood and how much they felt they had learned.

The test phase consisted of three different types of problems:

1. In one problem the subject’s task was to predict what would happen to grass growing on a record player (the old-fashioned kind with a turntable). This problem was varied so that in one problem the scenario consisted in a rotating turntable whereas in another, the turntable was not rotating. Hereafter referred to as question number 1 and 2, or the grass questions.

2. Another problem consisted in the subjects filling in the missing parameters in one abstract-type illustration given that a particle is accelerating to the left or to the right. Hereafter referred to as question number 3 and 4, or the abstract questions.

3. In the third problem the subjects were to predict what would happen to the balloon in the railroad cart given that the railroad cart is accelerating, keeping an even pace, or applying its breaks. Hereafter referred to as question number 5, 6 and 7, or the analogue questions.

All the questions were multiple choice questions. After having answered the questions the subjects were asked to motivate their choice, i.e. give an explanation in plain Swedish (or English). After each question the subjects were asked to estimate (on a scale from 1 - 10) how difficult they experienced the problem to be, and also, how confident they were that they had answered it correctly.

In the debriefing phase the subjects were asked how much they felt they had understood and learned. There were also some questions regarding the use of the program itself.

There were three different versions of the program corresponding to the three different types of illustration. Within the three different versions there were two different orderings of the test questions (called 1 & 2), summing up to six different versions. The variation in presentation order was performed to eliminate any effects of presentation order. In both versions the two questions about the grass on the record player (see above) came first. In the version called 1 the two questions about the missing parameters followed, and after that the three questions about the balloon in the railroad cart. In version 2 it was the other way around.

Results

The participants’ answers were grouped according to which kind of illustration they received during the learning phase. These groups are hereafter called: abstract, analogue, and animated. In all there were 55 participants resulting in 19 in the abstract group and 18 in both of the analogue and animated group.

Quantitative Results

The answers were counted as correct when totally correct. In questions 3 and 4 there had to be four correct statements to count as a correct answer (the correct picture and three correct parameters). On questions 1 and 2 there were almost identical results in all the groups. There was almost the same number of correct answers (Table 1) and the mean values of the estimations, on how certain they were of the answer and how hard the question was experienced to be, were very close to each other.

<table>
<thead>
<tr>
<th>Group</th>
<th>Question</th>
<th>Rotating turntable (#1)</th>
<th>Turntable not rotating (#2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract (19)</td>
<td>6</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Analogue (18)</td>
<td>8</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Animated (18)</td>
<td>6</td>
<td>17</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: The number of right answers on the grass questions (1 & 2) (The total number of subjects in each group within parenthesis.)
Concerning the abstract questions (number 3 & 4) there was a drop in performance in the animated group compared to the other two groups (see Table 2). On the other hand the abstract group were significantly (p<0.05) more certain about their answers being correct compared to the other two groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Accelerating right (#3)</th>
<th>Accelerating left (#4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract (19)</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Analogue (18)</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Animated (18)</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2: The number of right answers for the abstract questions (3 & 4) (The total number of subjects in each group within parenthesis.)

On questions 5 & 6, the analogue and animated groups were better than the abstract group. The ceiling effect on question 7 is obvious (see Table 3).

<table>
<thead>
<tr>
<th>Group</th>
<th>Accelerating (5)</th>
<th>Breaking (6)</th>
<th>Constant Speed (7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract (19)</td>
<td>7</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>Analogue (18)</td>
<td>14</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>Animated (18)</td>
<td>15</td>
<td>14</td>
<td>18</td>
</tr>
</tbody>
</table>

Table 3: The number of right answers for the balloon questions (5, 6 & 7). (The total number of subjects in each group within parenthesis.)

Qualitative Results

When comparing the answers and the motivations it seems that most of the subjects that answered correctly also understood the principle well. There were a few obvious "guessers" but they often made a wrong guess.

Besides the multiple-choice answers, the subjects were asked to motivate each answer in what we called "Plain Swedish". These motivations show some very interesting tendencies. There seems to be a connection between the kind of language used and the illustration provided. For a more thorough analysis see (Wærn et al., 2000).

Concluding remarks

The reason to have the grass questions (1 & 2) was that it would be an unknown presentation format for all the groups. If one of the groups would have had a better score on the first question this could be taken as an indication that the presentation format of this group made for a better and deeper understanding of the principle of equivalence. This did not happen, but this does not say that there are no differences between the presentation formats. More research is needed to sort these questions out.

It is reasonable to assume that the analogue and the animated groups should outperform the abstract group on the balloon questions. This because they are more familiar with the presentation of the problem. But following this line of reasoning the abstract group should outperform the analogue and animated groups on the abstract questions. This did not happen. This could be because the abstract question was too difficult (small amount of correct answers). A tentative interpretation is that it is easier to move from an analogue representation to an abstract than vice versa. It can be hypothesized that physics students are more used to abstract representations and descriptions and this in turn made it easier for the analogue and animated groups to perform well on abstract problems. Another interpretation is that it may be the case that the students in the analogue and animated conditions expended more effort into applying an abstract thinking on their concrete memory image, whereas the students in the abstract condition had difficulties in seeing the concrete application of the principle.

Subjects were asked to rate the difficulty of the problems and how confident they were in their answers being correct. The analogue and animated groups rated their confidence significantly lower on the abstract problems and slightly lower on the other problems. One hypotheses is that the analogue group has a deeper understanding of the principle but when presented with a presentation of the problem they had never seen before they felt uncertain. This
however does not account for the fact that the abstract group did have about the same confidence level on the analogue questions (5, 6 & 7).

A possible reason for the learning difficulties in the abstract groups lies in the fact that the behavior of the balloon is counterintuitive. In the explanations to their answers, many students based their reasoning on prior experience. Ramberg & Karlsgren (1999) found similar effects in another study.

Throughout the test the animated group did not differ significantly from the analogue group. This is in accordance with what Rieber and associates (Rieber et al., 1989) found in their study.

Based on these results, it seems that animations do not add anything to the learning outcome in physics teaching. However the use of illustrations based on everyday scenarios can be beneficial. Instructional designers should also work with contradicting the everyday experiences. Concrete examples and illustrations are better in this respect than abstract reasoning.

References