Motivational Effectiveness of Experiments in Physics Education

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Abstract:
Physics school experiments play a crucial role in motivation of students. That is why innovation in physics education leads to the accent on physics school experiments. This study verifies the motivational significance of experiments in physics and in science education. The importance of experiments in physics education is investigated, with a focus on the different educational roles of the experiments. Our research findings illustrate the fact that experiments used by physics teachers are not always appropriate and sufficient for development of students' physics knowledge and skills. We used the method of video-study, which is based on the analysis of video records of physics lessons. Different kinds of physics motivational teaching techniques can be based on observation and experimentation. From the pedagogical constructivist point of view it is important to select appropriate physics school experiments. Combinations of motivational teaching techniques result in an upgrading of students' motivation for physics education. Concrete examples of these cognitive motivational teaching techniques such as simple experiments, application of experiments in everyday life, entertainment-edutainment experiments, family physics experiments, experiments supported by ICT, action research based on experiments etc. are presented. All physics motivational teaching techniques presented here are based on experiments and are verified by our empirical research and practical school experiences. Results of our research should be inserted into physics teacher training. Validation and dissemination of our findings are supported by international projects as EUSTD-web and MOSEM.

1 Introduction
An experiment is the most important educational and motivational tool in physics education. Every educational activity based on physics experiments can be a strong motivational stimulus. Physics teachers are often interested in creation of school experiments. But they usually do not think about the concrete implementation of the experiments in teaching and learning physics. A use of the wrong teaching method with an experiment results in a loss of educational objectives including motivation. We try to solve whether this statement is true or false:

Physics school experiments play a crucial role in motivation of students in physics education. This study tries to verify the motivational significance of experiments in physics education.

2 Cognitive motivational teaching techniques in physics education
We discovered two sets of cognitive motivational teaching techniques in physics education by the use of a factor analysis (Trna & Trnová, 2006):
Physics cognitive motivational teaching techniques:
- Stimulation through unconscious perception and experimentation
- Use of models of natural objects and phenomena
- Solving problem tasks and projects
- Demonstrating simple experiments and toys
- Seeing paradoxes and tricks
- Watching films, video programs and using computers (ICT)
- Experiencing humour in physics
Interdisciplinary cognitive motivational teaching techniques:
- Use “Physics for life” (energy, environment etc.)
- Application of physics knowledge in technology
- Exploitation of history related to physics discoveries and physicists' lives
- Reading sci-fi literature and watching sci-fi films
- Application of physics and art

Most cognitive motivational teaching techniques are based on experiments. That is why we try to verify the hypothesis:
*The physics experiment forms a crucial element in effective cognitive motivational teaching techniques.*

For testing this hypothesis we used the empirical educational method of a students’ questionnaire. The students’ ages were between 14 to 15 years. The questionnaire was applied in 2009 within 50 ungifted students (according their teachers identification) of lower secondary schools in Czech Republic. Gifted students were 20 participants of “Physics Olympiad 2009”, the same age as ungifted group. We supposed that our sample of gifted students for physics were a sufficiently representative sample of physics gifted students. We verified a research question “Which cognitive motivational techniques do ungifted and gifted students prefer?” The following questionnaire item for testing the above mentioned hypothesis was used as a suitable formulation:

*What attracts and interests you most about physics (underline as many activities as you like)?*

- Application of physics and art
- Application of physics knowledge in technology
- Solving problem exercises and projects
- Use “Physics for life”
- Demonstrating simple experiments and toys
- Exploitation history related to physics discoveries and physicists’ lives
- Seeing paradoxes and tricks
- Reading sci-fi literature and watching sci-fi films.
- Watching films, video programs and using computers (ICT)
- Experiencing humour in physics

<table>
<thead>
<tr>
<th>Cognitive motivational teaching technique</th>
<th>Gifted students N=22</th>
<th>Ungifted students N=50</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>frequency</td>
<td>%</td>
</tr>
<tr>
<td>1 Application of physics and art</td>
<td>7</td>
<td>31,8</td>
</tr>
<tr>
<td>2 Application of physics knowledge in technology</td>
<td>10</td>
<td>45,5</td>
</tr>
<tr>
<td>3 Solving problem exercises and projects</td>
<td>8</td>
<td>36,4</td>
</tr>
<tr>
<td>4 Use “Physics for life”</td>
<td>11</td>
<td>50,0</td>
</tr>
<tr>
<td>5 Demonstrating simple experiments and toys</td>
<td>17</td>
<td>72,3</td>
</tr>
<tr>
<td>6 Exploitation history related to physics discoveries and physicists’ lives</td>
<td>9</td>
<td>40,9</td>
</tr>
<tr>
<td>7 Seeing paradoxes and tricks</td>
<td>17</td>
<td>72,3</td>
</tr>
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</table>
Motivational techniques “demonstrating simple experiments and toys” and “seeing paradoxes and tricks” have highest level of the frequency of students’ answers. The cognitive motivational teaching techniques based on physics experiments strongly affect both the gifted and the ungifted students. We thus verified the hypothesis about high motivational effectiveness of school physics experiments, especially simple experiments (Trna & Trnová, 2008).

3 Implementation of physics experiments

Physics experiments can be used in all teaching/learning phases. Our research findings illustrate the fact that experiments used by physics teachers are not always appropriate and sufficient for development of students’ physics knowledge and skills (Trna, Trnová & Novák, 2010). We used the method of video-study (Tesch, 2005), which is based on the analysis of 62 video-recordings of physics lessons (Janík & Míková, 2006). All of physics lessons were filmed in 2004-05; the topics were “Composition of forces” (27 lessons; 8 teachers) and “Electric circuit” (35 lessons; 11 teachers).

Table 2. Implementation of experiments

The category “experiment is not in progress” is the most frequent one (77%) in the analysed lessons. If we compare the results of all phases, there are unsatisfactory results: the total time spent on experimentation is insufficient and the proportion of the phases is unreasonable. Research findings based on video-study describe phases of the use of experiments and show
that experiments used by teachers are not always appropriate for improvement of students’ knowledge and skills.

4 Experiments in physics learning tasks
Our research findings (Vaculová, Trna & Janík, 2008) also based on video-study describe implementation of experiments in learning tasks. We realised this research in physics lessons of 13-14 years old students with the use of the video study. All 62 video-recordings of physics lessons were filmed in 2004-05; the topics were „Composition of forces“(27 lessons; 8 teachers) and „Electric circuit“(35 lessons; 11 teachers).

<table>
<thead>
<tr>
<th>Experimental solution</th>
<th>Oral solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>(14%)</td>
<td>(34%)</td>
</tr>
<tr>
<td>(27%)</td>
<td>(25%)</td>
</tr>
</tbody>
</table>

Table 3. Experiments in learning tasks

The learning tasks containing results in the form of an experiment are rarely (only 14 %) used in physics education. This is alarming research outcome.

5 Simple experiments
It is possible to expect that every physics experiment has a motivational impact on students. The fact that simple experiments give the strongest motivational effect is verified by several studies (Trna, 2005). Pedagogical research based-on teaching methods are necessary for the use of simple physics experiments in every day school practice with a high level of motivational effectiveness.

The simple experiment is a special type of school experiment (Haury & Rillero, 1994). We define the simple experiment by description of its aspects which are (Trna, 2005):

- Transparency
- Activity of students
- Easy realisation
- Creativity of students and teachers
- Low costs
- Prevention of misconceptions
- Motivational effects

Simple experiments are the source of strong motivation because they can activate cognitive needs such as problem solving, but can also satisfy the needs of our senses and kinaesthetic activity. Simultaneous activation of two or more cognitive needs can result in a strong
motivational impact. Simple experiments are profitable in education, because they do not require complex and expensive equipment and students can perform them in class and at home.

From the pedagogical constructivist point of view it is important to select appropriate physics school experiments. We developed a typology of simple experiments conducive to the implementation in cognitive motivational teaching techniques.

6 Special motivational kinds of simple physics experiments
Concrete examples of these physics motivational kinds of simple physics experiments are (Trná, 2008):

- Impressive simple physics experiments and observation
- Problem and paradox simple physics experiments
- Simple physics experiments in everyday and safe living
- Entertainment-edutainment simple physics experiments
- Family physics simple experiments
- Simple physics experiments supported by ICT
- Simple physics experiments for skills and creativity development

All the simple physics experiments were created from empirical research and were verified and validated using action research within a school setting.

6.1 Impressive simple physics experiments and observation
This type of motivational simple experiments is connected with the emotive experience of surprise and beauty. We can include many demonstrations of optical and astronomical phenomena: a rainbow, celestial observation, discharges in gas etc.

![Figure 1. Butterfly Emerges from Stellar Demise in Planetary Nebula NGC 6302](http://hubblesite.org/gallery/).

6.2 Problem and paradox simple physics experiments
The problem and paradox simple experiment have a very strong motivational impact. We present an example of such kind of simple experiments:
We cover a full glass of water with card (or hard paper) and we carefully press this on the surface of the water. We support the paper by hand and turn the glass upside down. Then we remove the support hand. Water won’t pour out. The pressure force of the surrounding air holds the water in the glass.

Figure 2. Air pressure effect

6.3 Simple physics experiments in everyday and safe living

Everyday and safe living are two groups of very interesting educational contents used in physics education. We receive a powerful source for students’ motivation by the implementation of simple experiments in everyday and safe living:

The hydrostatic pressure in water has an effect on human organism during swimming and diving. We put the test tube with a membrane into a plastic bottle and close the bottle with a cap with valve and overpressurize it with a small tyre pump. The rubber membrane buckles. This experiment simulates painful squeezing of eardrum during diving. If we fix a thin hermetic plastic wrap onto the test tube tightly, the overpressure causes the rupture of the membrane. Similarly to the membrane, the eardrum in overpressure caused by water during diving can end up perforated. The water gets to the balanced organ through the ruptured eardrum. The result should be sickness, loss of orientation and even drowning.

Figure 3. Model of the eardrum
6.4 Entertainment-edutainment simple physics experiments
The toy in the role of a simple experiment includes the need to use senses, kinaesthetic activities and relaxation function. There is successful evidence of the motivational efficiency of toys. Bubble makers, yo-yos, click-clacks, and kaleidoscopes are good examples.

![Image](image-url)

Figure 4. Wooden toys

6.5 Family physics simple physics experiments
Physics experimentation can be passed into families. “Family physics education” can bring families (parents and grandparents) important information about new technical equipment at home (microwave, mobile phone etc.) and also about risks in everyday living (transport, fire, poisonous materials etc.).

We paint the sole of the foot with oil (water, paint, etc.) and we step on absorbing paper (blotter). Use a ruler to measure the widest (w₁) and narrowest part (w₂) of the footprint. We can calculate $I = \frac{w₂}{w₁}$. Results we evaluate by using the table.

<table>
<thead>
<tr>
<th>Type of foot</th>
<th>Value of I</th>
</tr>
</thead>
<tbody>
<tr>
<td>normal foot</td>
<td>less 0.45</td>
</tr>
<tr>
<td>start to be flat</td>
<td>0.45</td>
</tr>
<tr>
<td>flat foot</td>
<td>more 0.45</td>
</tr>
</tbody>
</table>

![Image](image-url)

Figure 5. Flat foot

6.6 Simple physics experiments supported by ICT
ICT (information and communication technologies) can be use effectively for implementation of simple experiments for teaching physics. Applications of experiments by use of ICT are:
- Video recordings of experiments
- Database of video recordings and photos with descriptions on the Web
- Video handbook with instructions for teachers how to demonstrate experiments
- Video recordings of students’ experimentation
- Web presentations of school experimentation
- The motivational effect of experiments is based on students’ interest to use ICT

6.7 Simple physics experiments for skills and creativity development
Use of simple experiments in education therefore supports development of students’ skills of experimentation and develops their creativity. This approach is especially profitable for physics education of gifted students. As an example, we present a simple experiment demonstrated by a teacher during a lesson and alternative simple experiment made by students:

*A glass tube with water is closed at both ends. There is an air bubble in the water. If the tube is inclined appropriately, the bubble begins to move upwards by uniform motion (constant velocity).*

![Figure 6. Uniform motion – teacher’s experiment](image)

*A glass test tube with water is closed. There is a glass ball in the water. If the tube is inclined appropriately, the ball begins to move down by uniform motion (constant velocity).*

![Figure 7. Uniform motion – student’s alternative simple experiment](image)

7 Conclusions and recommendations
School physics experiment is significant instrument for effective and motivational physics education. Simple physics experiments have strong motivational effectiveness and can be used in several cognitive motivational teaching techniques. There are several applications: impressive simple physics experiments, problem and paradox simple physics experiments, simple physics experiments in everyday a safe live, entertainment-edutainment simple physics experiments, family physics simple experiments, simple physics experiments supported by ICT, and simple physics experiments for skills and creativity development.
Not only physics teachers’ knowledge but particularly acquiring skills to experiment simply is very important (Royer, Cisero & Carlo, 1993). Physics teachers’ professional skills development of experimenting has three stages:

1. Physics experimentation skill (complex competency to carry out physics experiments).
2. School experimentation skill (complex competency to carry out school experiments).
3. Skill to teach students by experiments (competency to teach students by school experiments).

These professional skills are acquired through experiences of the teacher and that is why acquiring these skills is not possible during pre-service teacher training and especially into-service training.

Our findings were supported also by international projects as SYSTEM, EUSTD-web and MOSEM.

Our future research and development problems are:

- To discover new motivational teaching techniques
- To study cognitive structure of motivation of students
- To state rules for measuring motivational effectiveness of experiments
- To produce motivational tools, especially simple experiments

8 References