THE INFLUENCE OF PROBLEM SOLVING ON STUDYING EFFECTIVENESS IN PHYSICS

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ABSTRACT

This study reports the outcomes of a research, the purpose of which was to establish how solving dispersed data problems can affect studying effectiveness in physics. Data were collected through pre-tests and post-tests for students and questionnaires for teachers. The authors of this article created a new type of problem with superfluous or nonsufficient data that has been offered for solving: so-called dispersed data problems.

The results showed that solving dispersed data problems increases studying effectiveness in physics.

Key words: Solving Physics Problems, Real-life problem solving, Dispersed Data Problems Empirical study.

INTRODUCTION

The popularity of exact science has declined both in Estonia and abroad. How is it possible to motivate students and increase their studying effectiveness? There are several possibilities for this. One of the most widely used is solving problems.

Solving problems plays a major role in studying physics. E.g. Rolf Plotzner (1994) argues that the most efficient way of studying physics is independent solving of less complicated problems. Many researchers (Styer, 1998; Bolton, 1997) complain that students solve problems mostly mechanically, not giving a thought to the contents. In this case, the objective is to reach the right number called the answer by using provided numbers. The classical problem solving methods (Reif, 1995; Heller, Keith & Anderson, 1992) prescribe repetition of physical quantities, units of measurements; learns and practices converting of units; repeats laws and remembers respective mathematical models or formulae; learns to analyze physical problems and solve them.

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Problem solving also plays an important role in developing regulative and transformative skills. The transformative skills are: observing the problem; questioning; hypothesizing; planning investigations; investigating; analyzing and interpreting data; communicating results. The regulative skills are: planning; monitoring; evaluating one's studying (De Jong & Njoo, 1992; De Corte & Linn, 2003).

Problem solving requires application of a previously learned theory by the solver (Heller, Keith & Anderson, 1992; Heller & Hollabaugh, 1992; Fuller, 1982). This requires analytical capacity and a capacity to analyze a problem and to solve it.

Although scientists and teachers are convinced that solving problems is very beneficial for learning, students, nevertheless, are not. The objective for them is not studying physics but finding the right answer. In real life, unfortunately, the text of the problem prompts the quantities, then respective "letters" are remembered or looked up, and then the formulae where these "letters" occur are used. Often students consider the case of a "letter" to be irrelevant. They express the necessary letter of the quantity to be found, and then insert the numbers into the formula, and – problem solved! (Ganina & Voolaid, 2005).

Solving problems this way does not fulfil any of the aforesaid objectives. This kind of solving is facilitated by a circumstance that amount of data provided for traditional physics problem is limited to actual solving needs. But it is not the case in real life.

In order to facilitate deep learning, so-called dispersed data problems (hereinafter DDP) can be used.

The research target of this paper was to establish how solving dispersed data problems can affect studying effectiveness in physics. New types of physics problems have been elaborated for the purposes of this paper.

The goal of research is to experimentally monitor the impact of dispersed data problems on Physics studying effectiveness

Research hypothesis. Dispersed data problems increase studying effectiveness because these are closely related to real life, make students analyze the situation and find a suitable strategy for solving. All this increases studying effectiveness.

METHODOLOGY OF RESEARCH

Theoretical basis

Problem solving is an integral part of most physics courses. Many teachers would like their students to learn to use physics principles and concepts to solve problems. However, experienced teachers know that this is a difficult task.

Various researchers offer their strategies for solving problems, and there are different theories how to make solving problems more effective. There are some examples hereinafter.

Dan Styer (2002) argues that solving a physics problem usually breaks down into three stages, and offers a following method of solving: 1) Strategy design (Classify the problem by its method of solution; Summarize the situation with a diagram; Keep the goal in sight (perhaps by writing it down). 2) Execution tactics (Work with symbols; Keep packets of related variables together; Be neat and organized; Keep it simple. 3) Answer checking (Dimensionally consistent? Numerically reasonable (including sign)? Algebraically possible? (Example: no imaginary or infinite answers.) Functionally reasonable? (Example: greater range with greater initial speed.) Check special cases and symmetry. Report numbers with units specified and with reasonable significant figures.)

Hollabaugh (1993) finds that two factors can help make student a better physics problem solver. First of all, student must know and understand the principles of physics. Secondly, student must have a strategy for applying these principles to new situations in which physics can be helpful. He calls these situations problems. Hollabaugh mentions that many students say, "*I understand the material, I just can't do the problems*." He thinks that in this case maybe student needs to develop here problem-solving skills, but to that must have necessary strategies. Heller & Hollabaugh (1992) state that as with so many other studying activities, it is useful to break a problem solving strategy into major and minor steps. They outline five major steps of they strategy: Focus the Problem, Physics Description, Plan a Solution, Execute the Plan, and Evaluate the Solution.

Harvey Mudd (1997) recommends the following steps when solving problems:

1. Draw as many diagrams of the situation described in the problem statement as are necessary to make the situation and your analysis clear.
2. Read the entire question or problem as many times as necessary to be confident that you know precisely what is being asked in each section. Make a mental note whether the same intermediate quantity will figure in several calculations.
3. In force problems, isolate the appropriate components of the system and sketch a force diagram for them. Put a coordinate system on each diagram. Deduce the appropriate equations of motion. In other problems, cite the appropriate laws and relations, and justify the equations you deduce where necessary. Be certain that all symbols you use have been defined, either by context or explicitly.

4. Complete the algebra using symbols; outline your formula. If no values have been provided, check your formula using dimensional analysis. If values have been provided, substitute them into the formula, being sure to respect their precision and units. Compute the requested value. Round your answer to the precision of the least precise given value upon which your result depends.
5. Look at your answers and ask if they make physical sense. If they don't, go back over the calculation. Check the formula to be sure that it displays the appropriate dependencies on the givens.

Five-step algorithmic structure developed by USA Physics educators from Minnesota University (USA) work extensively on studying different problem solving strategies and skills. One of these researchers, Patricia Heller (1992) offers the five step strategy of problem solving: (1) Visualize the problem: In this step learner develops a qualitative description of the problem; visualizes the events described in the problem using a sketch; writes down a simple statement of what to be found out; writes down the physics ideas which might be useful in the problem and describes the approach to be used. (2) Describe a problem in physics terms (physics descriptions); (3) Plan a solution; (4) Execute the plan and (5) Check and evaluate the answer.

If we look carefully at all problem-solving strategies presented above, it becomes clear that the previously mentioned algorithmic structures have similar steps of problem solving.

Some researchers argue that today classic methods are not effective any longer. Results from Physics Education Research (PER), however, demonstrate that traditional ways of teaching with problem solving are inefficient and ineffective for promoting true physics expertise Gerace and Beatty (2005). PER findings give rise to a perspective on physics expertise, studying, and problem solving that can illuminate the reasons why problem solving in traditional instruction fares poorly and suggest remedies. At the heart of the remedies lies a rethinking of the instructional model in which teachers focus less on presenting subject material and more on engineering studying experiences and guiding students' studying efforts, while students strive to become active, selfmonitoring constructors of knowledge.

Jill H. Larkin; F. Reif (1979) says that these studies show that an inexperienced student tends to solve a problem by assembling individual equations. By contrast, an expert solves a problem by a process of successive refinements, first describing the main problem features by seemingly vague words or pictures, and only later considering the problem in greater detail in more mathematical language.

David P. Maloney (1994) finds that traditional textbook problems helped us learn physics not because solving such problems is the best way to learn physics, but because we were motivated to use them to help us learn. Recent work in physics education research has led to several ideas for alternative problem structures, or alternative ways to approach traditional problems; these have been shown to be more productive for focusing students' attention on the conceptual basis of problem solving.

While agreeing with the aforesaid, we hereby still outline our own approach. Solving a problem in physics consists of two parts: physical and mathematical. In the physical part, it is necessary to gain an overview of the situation first: what exactly takes place, and how. Then the problem solver makes simplifications, selects between models, applies appropriate formulae, and prepares necessary calculations. After solving, the student must assess the accuracy and feasibility of the result. This is when the problem is essentially being solved.

In the mathematical part, the problem-solver converts formulae, calculates equations, converts units of measurement, and calculates the necessary value. This is the formal solution of the problem.

Often enough the physical part is limited only to finding suitable formulae and preparing equations. The mathematical part is considered to be more relevant as it is easier to check out. But in studying physics, it is just the physical part that is relevant (Ganina & Voolaid, 2007).

In fact, the starting point should be an overview of the situation, accompanied by an illustrating sketch if necessary. Then, suitable models for depicting the situation should be chosen: e.g. uniform or non-uniform motion, background body, whether or not air impedance should be taken into account or not, etc. Then there should be a discussion on if it is necessary to draw up an equation or not, can any of the values be considered as equal for preparing the equation, etc (Aleven & Koedinger, 2002; Ganina & Voolaid, 2005).

How could we achieve the position that physics problem solving would help students to actually learn physics not just skills of manipulating formulae? We argue that the easiest and cheapest way to increase the efficiency and popularity of studying physics is to solve a new type of problem. The novelty of our problems lies in separating the data from the text of the problem, and presenting more or less data than necessary for the solution. We call these problems Dispersed Data Problems (DDP).

Some other researchers also noticed that solving the problem depends largely on the form of the question and interpretation of basic data (Neuman & Leibowitz, 2000, Palincsar & Brown, 1984).

Below we present the study, in which we have tried to find out the impact of DDP on studying effectiveness.

Methods of Research
Research involved assessment of scientific literature, empirical study, tests for students and questionnaires for teachers, observation, statistical examination of data.

Sample and Respondents of Research
620 pupils from Estonian secondary schools participated in the empirical study.

Design of Research
During the 2007/2008 academic years, we conducted research in order to establish whether dispersed data problems increases studying effectiveness or not. The research is still under way, with 620 students (upper secondary grades from 10^{th} to 12^{th}) participating from 14 schools all over Estonia: 10^{th} grade: 286 students; 11^{th} grade – 236 students, and 12^{th} grade – 98 students. 14 teachers participated in the research, and they were introduced to new type of problems and possible ways of solving before the empirical study started. The teachers also gave information on the methods that they had used with their group or class before the post-test.

When piloting, we used a so-called comfort sample**,** that is, schools and teachers who had a record of good collaboration with us, who had always carried out experiments and submitted results. To randomise the results, the authors of this thesis were not involved in carrying out experiments and/or supervising them at schools. We proposed that the teachers use frontal solving (the teacher himself/herself playing the active role), use pair work and group work (where the students play an active and decisive role, and the teacher is a mere advisor). It was possible to use formulae, workbooks, course books, handbooks, and online resources while solving the problems. These options were used by teachers according to their needs.

Prior to introducing a new topic, a multiple answer pre-test on this topic was taken by the students. The students were divided into a control group and an experimental group. The difference in the teaching was that the control group solved classic problems, and the experimental group solved the DDP. The number of problems solved in both groups was the same. After studying the topic there was a post-test. During solving DDP problems or after that the students had an opportunity to express their opinion on the problems either in writing or orally. The teachers collected these opinions, noting also the date of the submission.

Tests were prepared by topics and the questions varied in composition: one portion of these tests checked the knowledge and understanding of physical quantities, units of measurements and concepts, so-called knowledge portion; the rest checked problem-solving and drawing conclusions –

so-called skills portion. The questions in the test are based on the Estonian National Curriculum in Physics and National Examination in Physics (National Examinations and Qualifications Centre of Estonia, 2008). For every questions of the test, we asked students to substantiate why they had chosen this specific answer. Correct substantiation involved the right solving path, right pattern, right conversion, or inference. The tests consisted of 10 multiple choice questions with 4 to 6 possible answers. The time limit for the test was 30 minutes, use of additional materials and the calculator was not allowed. The experiment involved the topics of mechanics, thermodynamics and electromagnetism as it is easy to practice problems that are related to everyday life with these topics.

DDP consists of a description of a situation and a question. Basic data are dispersed, and there is either more or less data than required. Our concept was that there is never just-the-right-amount of data in real-life situations. As a rule, there is a need to look or ask for more. It is also necessary to decide whether or not use all data or leave unnecessary facts aside. It is only natural that solving this kind of problems takes more time but we consider every moment of it be worthwhile for the students: they learn to analyze, to find correlations and interdependency, and thus memorize more.

Theoretical basis for preparing problems is the same as preparing the classical physics problems: subject-based, didactical, practical, etc (Reif, 1995; Heller, Keith & Anderson, 1992). Our addition is the superfluous or nonsufficient data that enables students to analyze the situation and pick the relevant data. These give necessary experiences for everyday life as the new type of problems are related to real life situations.

Characteristics of DDP:

- Students find the situation familiar or easily projected.
- All bodies occurring in the problems are real, that is – all have a name, specific shape and form, mass, volume, color, etc.
- All parameters for equipment occurring in the problems are taken from their user manuals (specifications).
- There are superfluous data present in the problems, but there can also be something missing. This will be announced before solving. Students must find the missing data from a reference book, Internet or ask their teacher.
- Description of the situation is given without numeric data. Numbers are presented separately at the end of the problem.

While analyzing the problem, students have to use abstract thinking, idealize objects and phenomena, find relevant processes, search for additional data (from memory, textbook, handbook, the Internet, etc), cast aside superfluous data and conditions which do not significantly affect the result, etc. It is important to notice that the simplified model would not lose the relevant characteristics of the bodies and phenomena that could lead to wrong, unrealistic results.

When solving the problem the student has to analyze the data and the problem; prepare/draw up a model/layout; code the data and convert the units; idealize features and phenomena; search for addition data; reject superfluous data; reject additional conditions; select the model of solving and ways of solving; select formulae; prepare equations; solve the problems; interpret and present the results.

We arranged the new problems into three sections:

1) Ordinary question in an unusual circumstance
2) Unusual question in an ordinary circumstance
3) Ordinary question in an ordinary circumstance

An example of a problem in the first section:

I received a letter from a friend in the US where he mentions that mowing the lawn is time-consuming but is fortunately inexpensive. The power consumed by the lawn mower costs only 80 cents per one mowing session.

How big a lawn can be mowed for this money in Estonia? (Can you mow your summer cottage lawn for this amount?)

Data: From the user manual of the mower: engine capacity 1,6 kW, mowing range 48 cm, rotation speed 2880 rotations/per minute, mass 16 kg, noise 96 dB, the price 1550 EEK.

Average speed of the mower 3.6 km/h, average force to move the mower 80N.

The student's possible line of thought.

We know only how much it costs. It is the sum for power consumption. **The problem:** do we pay for the time of consuming electricity, for work done, or used power? If this is clear, another **problem** arises: how do we find the amount of work? This is dependent on the price of electricity. Let us simplify by assuming that the price for electricity in Estonia and the US is the same. **The problem:** how much is 0.8 USD in EEK? I learned how much is to be paid for work done. **A problem:** How much work can be done for this money? Etc, etc.

After solving it, the truthfulness of the result should be checked. An expert advice from the father, friend or teacher is welcomed.

After solving the problem it appears that the frequency, mass, noise level, price and force are unnecessary data.

The students muster considerably more knowledge and skills solving these problems in comparison to solving the traditional problems.

Our problems had a varied content and level of difficulty, and the teacher had a sufficient choice of material. Thus we aimed at avoiding the probable influence of specific problems on the post-test results.

At the same time, we asked the teachers and students to express their opinion about the method. It appeared that most of the students (about 80%) were apprehensive about the dispersed data problems – they could not and would not solve this type of problems. Teachers also experienced difficulties as they had no prior practice of studying new type of problems.

It is appropriate to mention here, beforehand, that the method gave best results when students worked in groups. We proposed that teachers use frontal solving (the teacher himself/herself playing an active role), use pair work and group work (where the students play an active and decisive role, and the teacher is a mere advisor). It was possible to use formulas, workbooks, course books, reference books and online resources while solving the problems.

We argue that solving DDP increases studying efficiency as superfluous or nonsufficient data forces the student to analyze the situation, that is – to use the physical component when solving. Solving takes up more time but we think that the process facilitates retention in long-term memory (as shown by our initial, unprocessed research results).

RESULTS OF RESEARCH

In the table below, we have recorded the pre-test and post-test results.

Table 1. Means (M) and standard deviation (SD) by treatment and gender on the 100-point scale.

Groups	gender	n	Pre-test		Post-test		Gain
			M	SD	M	SD	
Experimental	Male	156	38.4	2.7	81.2	4.3	+42.8
	Female	144	42.3	3.3	71.4	3.8	+29.2
	total	**300**	**40.4**	3.7	**76.3**	4.4	+**36.0**
Control	Male	158	40.1	3.0	60.1	3.5	+20,0
	Female	162	38.5	3.1	58.6	3.7	+20.2
	total	**320**	**39.3**	3.3	**59.4**	3.2	+**20.1**

As you can see from the table, solving the DDP enables an increase in teaching efficiency by 36% on the average.

The results of our questionnaire indicated that after the experiment ended, 78% of the students evaluated the new type of problems highly despite the fact that 80% of them did not like the unconventional problems at the beginning (as mentioned hereinbefore).

In order to establish which factor – whether the presentation of the data separately from the text of the problem, or insufficient/superfluous data – is dominant in changing studying effectiveness, additional experiments were carried out. We presented one and the same problem in two different ways. In once case, the data had been embedded in the text, in the other case, the data was separately at the end of the text. The results proved that the separate data presentation increased effectiveness ca 5–6%. Most probably the students envision the situation more vividly if there are no distracting numbers in the text.

Correlation coefficients were calculated to find possible correlations between students' gender and pre-test and post-test results in experimental and control group.

Our data very clearly demonstrate a strong correlation ($r=0.84$, $p<0.05$) between two factors: type of the problem, and results of the post-test. Thus, solving DDP has a deep effect on studying efficiency in physics.

Correlations and their significance are presented in Table 2.

Table 2. Correlation coefficients between students' satisfaction with the problem type, and their gender, results of the pre-test and post-test. Correlations with a medium and string effect have grey background ($p<0.5$).

	suitability of the problem	pre-test result	post-test result
Gender	0.72	–0.08	0.22
Type of the problem	0.20	0.07	0.84
Grade	0.54	–0.19	0.03

Table 2 indicates that DDP was better suited for older grades ($r=0.54$). At this stage of the research we cannot specify the reason which may be that the older students have better analysis skills and are able to make use of their experience in learning.

Male students were more in favour of dispersed data problems than female students ($r=0.72$, $p<0.01$).

Our results indicate the higher effectiveness of new type problems compared to the classical problems. The results are trustworthy as the deviation is considerably higher than standard deviation**.** But these results need to be tested with a larger sample and also in other fields of physics. Also at different school levels – this method may not be suitable for all age groups.

DISCUSSION

The results of the research proved that solving DDP increases studying effectiveness in physics. As said before, this pedagogical experiment used a new type of problems where – differently from classic problems – there were more or less initial data than necessary for solving. The data had been presented separately from the problem text. The new type problems were divided into three sections: ordinary question in an unusual circumstance; unusual question in an ordinary circumstance, and ordinary question in an ordinary circumstance.

Students had very different opinions on dispersed data problems: there were those who did not like the problems at all; there were those who said that such problems made them think, analyze and will be more useful in their future lives than traditional problems where all the required data have been given. The results of our questionnaire indicated that 78% of the respondents evaluated the new type of problems highly.

Teachers had also difficulties with the new problems at the beginning: they did not have prior experience and were apprehensive of the problems, fearing that these take up too much time during the lesson, and that they lack focus. At the end of our pedagogical experiment, the teachers had changed their opinion:

Many of them argued that solving DDP takes up more time than classic calculation problems, but students had more serious attitude towards DDP and thus were engaged in deeper learning.

CONCLUSION

The research target of this paper was to establish how solving dispersed data problems can affect studying effectiveness in physics. For this purpose, a new type of problem, so-called dispersed data problems were prepared – with considerably more or less initial data than required. This creates an affinity between problems and real life. The results showed that solving dispersed data problems increases studying effectiveness in physics by 36% on the average. Teachers may be recommended to use problems like DDP while almost all traditional problems can be used for this purpose, with additional data from everyday life.

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