

DOI: 10.15804/tner.2024.75.1.11

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Physics as a Subject Matter in Primary Education Teacher Students' Training: Possibilities for Elimination of Misconceptions

Abstract

The research focused on the issue of physics subject matter in higher education of primary education teachers. It explained students' misconceptions on an example of the subject matter about a pulley. The research aimed to study on a sample of 79 students the effectiveness of the designed IBI in eliminating misconceptions in favour of scientifically acceptable concepts. The main research methods were the pedagogical experiment and content analysis of students' answers. Results showed that students' misconceptions changed statistically significantly in the post-test against the pre-test in favour of scientifically acceptable concepts. Thus, the research results may incentivise branch didactics of science subjects.

Introduction

The issue of developing science literacy has become a subject of scientific interest for many scientists – (e.g., Mateos-Nunez et al., 2018; Estapa & Tank, 2017; Hockicko & Tarjanyiová, 2020). The European Union has supported projects to develop science education for several decades. International projects include, e.g., S-TEAM, ESTABLISH, Fibonacci, PRIMAS, Pollen, La main à la pâte, the portal Scientix, etc. Part of the science literacy development is also the issue of natural science education out of school (Skoršepa et al., 2022). Europe and the world have also taken steps to improve education policies (Rochard et al., 2007) due to the results of PISA and TIMSS international studies. There are more reasons, from the declining popularity of science subjects falling interest in the study of sciences to the problem in the level of didactics and the search for new paradigms of science education (Papáček, 2010; Bellová et al., 2018).

Specific problems include students' misconceptions (Akkaya & Koksall, 2014), in particular of the physics subject matter (Albacete & VanLehn, 2000; Stepanović et al., 2019); Myneni et al. (2013) mention students' misconceptions of energy and force, simple machines.

Studies trying to solve the above problems see the solution in inquiry-based science education (Minner et al., 2010; Harlen, 2013; Dostál & Kožuchová, 2016; Kožuchová et al., 2022). As referred to by Papáček (2010), the instruction called “inquiry-based education (IBE)” and “inquiry-based science education (IBSE)” in natural science came to Europe from the US, where National Science Education Standards were even drawn up in 1996.

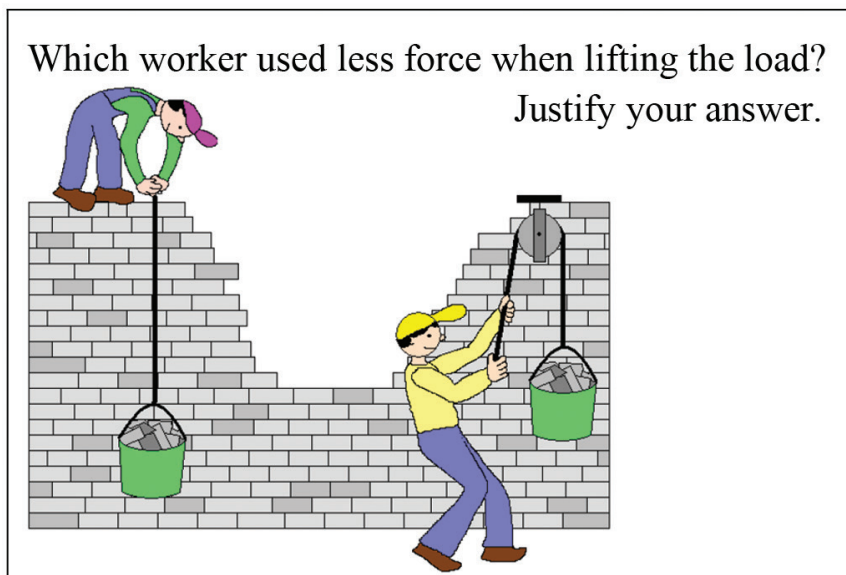
The presented research wants to address the given issue at the primary education teacher students' training level. It presents possible applications of IBE and its impact on achieving students' better educational outcomes.

Research Problem

In 2007, 386 primary school fourth graders underwent a pedagogical experiment to compare the effectiveness of inquiry-based and traditional instructions in science. One item in the didactic test compared forces required to lift the same load without a pulley and with a fixed pulley (Picture 1). The task was solved with zero success in the pre-test and the post-test in the control and the experimental group of pupils. The research concluded by reassessing teachers' teaching methods and pupils' activities. Despite the opportunity to experimentally find out that a fixed pulley does not change the force of lifting

the load, no pupil could use that knowledge when solving the task in the post-test (Rochovská, 2011).

Picture 1. Test item 2 (Rochovská, 2011; 2012)



Thus, Rochovská (2012) focused on IBE in primary education teacher students' training in her next research. In 2011, a sample of 122 primary education teacher students studying part-time was carried out in a pedagogical experiment to verify the effectiveness of IBI (IBI). One test item was the same as in the test for primary education pupils (Pic. 1). In the pre-test, no student in the control and the experimental group could solve the task correctly. In the post-test, 12.93% of the control group students solved the task successfully. Experimental group students were successful in 27.78%, which was also very little success. The results may have been influenced by the fact that they were external students, and part of the inquiry-based tasks was carried out within a distant study. Errors in inquiry may have caused students' misconceptions about the work of a fixed pulley (Rochovská, 2012).

For these reasons, the research was carried out in 2023. The research problem was the following question: What are primary education teacher students' misconceptions about a pulley, and how do they change under the influence of IBI carried out directly during the lesson?

Research Aim

The research aimed to determine primary education teacher students' pre-conceptions about a pulley, determine misconceptions and describe how they change under the influence of IBI. The aim and experience from the field were formulated in the research questions and hypotheses:

RQ: What are primary education teacher students' misconceptions about a pulley?

RQ: How do they change under the influence of IBI?

H₁: Primary education teacher students will achieve better results in the post-test than in the pre-test.

Methods

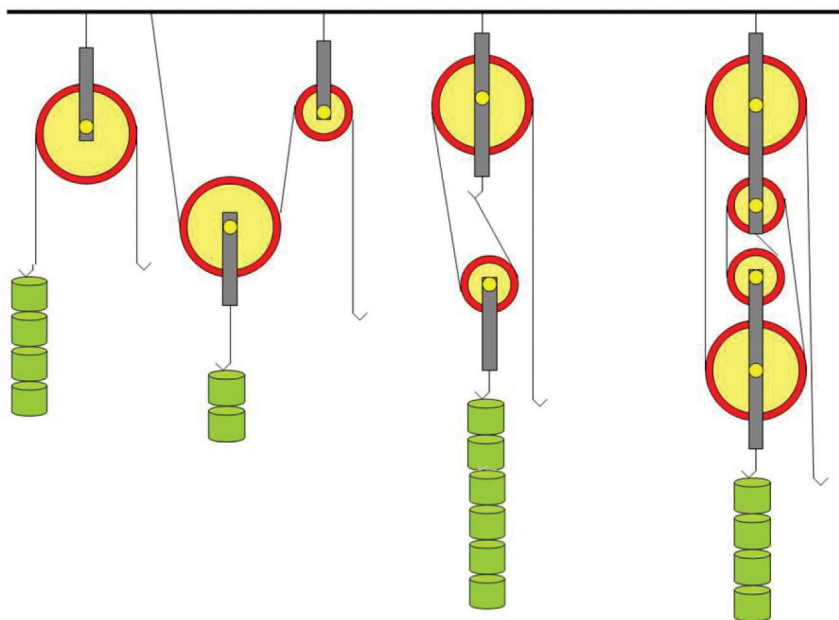
Research sample

The research sample consisted of 79 students with master's degrees in primary education who were in full-time and part-time study at Comenius University Faculty of Education in Bratislava; 97.5% were women, and 2.5% were men.

Research Tools and Procedures

A combined research strategy was used. Answers to the research questions were processed using a qualitative approach (open coding, subsequent thematic coding, description of created categories). Hypothesis H₁ was tested using a qualitative approach, with a pedagogical experiment – quasi-experiment as the main research method. There was no control group. Before and after the experimental intervention, students solved a didactic test of five items. They could obtain a maximum of 14 scores for their entirely correct solutions. The first item was to explain the concept of a pulley, and the second was to draw the mechanism working on the principle of a pulley. Based on the picture (Pic. 1), the third is to write which worker used less force when lifting the load and justify the answer. The fourth item was the question: *How many equal weights must be placed on the empty hook for the pulleys to be balanced in each case?* (Pic. 2).

Picture 2. Test item 4



The fifth item was: *Draw a hoist using force equal to half the weight of the load when lifting.* The strategy for checking students' answers was established when evaluating their results.

The experimental intervention consisted of applying IBI using methods designed by the authors of the research. Students were put into a stimulating situation leading to the formulation of the research problem: How do the devices operating on the principle of a pulley save our effort? Why is it suitable to use such devices? Students in groups designed the inquiry and aids. They recorded the course and results in protocols.

Data Analysis

Students' test results were analysed using a qualitative approach. Open coding was used to create codes for students' answers – text sequences. Researchers were returning to the codes, reassessing and modifying them. Next, the codes were grouped into categories, forming the skeleton of an analytical story about misconceptions and their change under the influence of IBI. Each task was calculated with descriptive characteristics. The hypothesis was tested by a paired t-test.

Research Results

Students' Misconceptions about a Pulley

Students described a pulley mainly as a device, machine or mechanism for lifting a load. They focused rather on the outer description of a pulley than on the essence of its concept, e.g., "Consisting of a wheel with a groove through which a rope is pulled". Based on drawings, the perception of a pulley was narrowed to a fixed pulley. In connection with that, misconceptions could be identified that a (fixed) pulley saves force when lifting objects. Students' answers allow for stating that they did not conceive force as a physical quantity but as a synonym for effort. Another concept from physics students misunderstood was work (they claimed a pulley makes work easier). Another misconception was, e.g., a "pulley reduces the body's weight".

Students' drawings depicted a pulley as a fixed pulley. In some cases, there was no sketch of the fixing of a pulley. Drawings of specific cases (e.g., a lift, well, crane) had no sketches of a pulley, and it was unclear which part of the device it was in. Drawings contained misconceptions, such as no indication of a load or illustration of the action of force.

Answers (Pic. 1) showed that students did not understand how a fixed pulley works. They answered, e.g., "When using a pulley, less force is required", "Because he used a pulley that helped him not use his full force". In addition, students did not perceive force as a scientific concept but as a human characteristic (he has strength). They did not distinguish between force and effort, work and energy.

Answers suggested that students understood, in a certain sense, the issue of easing the effort when lifting loads, e.g., "Because 'the rope' is fixed, he can lift the load more easily than the one who lifts the load from above without any other help". However, the assignment was to specify which worker used less force when lifting the load, not which exerted less effort.

Students' definitions and drawings contained attempts to describe balance on a pulley, e.g., "If it is balanced at both ends with the same weight, then both sides are at the same height level from the ground". Misconceptions were obvious in Task 4 solutions; students only guessed answers. Similarly, misconceptions were identified in answers in Task 5, where students drew a fixed pulley.

Change of Students' Misconceptions about a Pulley

When designing the inquiry procedure, the misconceptions were related to students not realising that it is necessary first to measure the force to lift the load

without using a pulley and only then use the pulley and compare the measured forces. Other misconceptions resulted in misunderstanding the inquiry strategy (e.g., only the procedure for constructing a pulley was described). Some students assumed they would measure the force with different numbers of weights.

Several misconceptions were identified in the variables determined in the protocols. Students incorrectly took, e.g., the weight, number of weights, their mass, the direction of force, its intensity or the position of the pulley for the independent variable. With the constant variable, students incorrectly assumed that the force or use of a free pulley would still be the same.

When formulating assumptions about the outcomes of the inquiry, students thought that they would save work (considering it a synonym for effort). The identified misconception was the assumption that the weight would be lighter and that when using a fixed pulley, they would need less force to lift the same load than without using a pulley.

In some cases, students incorrectly read measured values. Even if they understood that a fixed pulley does not change the lifting force, there was no mention that the lifting direction changed. The fact that they did not generalise the results can also be considered a misconception. However, they knew that with the help of a free pulley, the force when lifting a load is saved, specifically by half. With a hoist, they found four times less force.

The analysis of answers in the post-test directly following the experimental intervention made it clear that the understanding of the concept of pulley changed against the answers in the pre-test, and fewer misconceptions were identified (Tab. 1). In their more complex definitions of a pulley, students used mostly concepts like a (simple) machine, mechanism, tool or device. Definitions included a pulley description, e.g., “A freely rotating wheel on a shaft, there is a groove around it, where a rope is guided”. Many definitions were only descriptions. They also stated incorrectly that a pulley “makes work easier”.

Students’ drawings showed that they associated the concept of a pulley mainly with a fixed pulley. However, there were already more drawings with a free pulley or hoist in the post-test. Drawings of devices (e.g., a crane, well, lift) clearly showed in which part of the device the pulley was and how it worked. Some drawings depict the action of force, illustrated with arrows, hand, person, and load. In some drawings, the fixing of the pulley was missing.

After the IBI, almost a third of the students understood that a fixed pulley does not change the lifting force, only the force direction. More than two-thirds of the students still claimed that less force was used by the worker lifting the load with the help of a pulley (Tab. 1). Those misconceptions arose based on students’ reasoning – explanations that “it is easier for him with a pulley”, “he

made his work easier with a pulley”, “he needs less energy”. The misconceptions arose due to a misunderstanding that, in the assignment, the concept of force was a physical quantity. Conversely, students thinking the same way but understanding what the concept of force in mechanics means, stated that the force did not change but added, e.g., “exerted the same force, the direction changed”, “the same force, but less effort in B”, “the same, only one is destroying his lower back”.

In the post-test Task 4, students answered without mistakes or made mistakes only with one hoist. It also influenced Task 5 solutions. Some students drew a hoist incorrectly. They also drew a free pulley, which showed a misunderstanding of the assignment (the assignment was the concept of a hoist). The misconceptions consisted of, e.g., misunderstanding balance on a pulley, no drawing of the fixing of a pulley, or drawings of constructions that would not “hold” in reality.

Table 1. Descriptive characteristics – pre-test and post-test task solutions

| | | Task 1 | Task 2 | Task 3 | Task 4 | Task 5 | Total |
|--|-----------|--------|--------|--------|--------|--------|-------|
| Maximum number of scores possible | | 3 | 2 | 3 | 4 | 2 | 14 |
| <i>M</i> | Pre-test | 1.48 | 1.75 | 0.03 | 1.87 | 0.54 | 5.67 |
| | Post-test | 1.85 | 1.84 | 0.89 | 3.18 | 1.42 | 9.16 |
| <i>Mdn</i> | Pre-test | 1 | 2 | 0 | 2 | 0 | 5 |
| | Post-test | 2 | 2 | 1 | 4 | 2 | 9 |
| <i>Mo</i> | Pre-test | 1 | 2 | 0 | 1 | 0 | 4 |
| | Post-test | 1 | 2 | 1 | 4 | 2 | 9 |
| <i>SD</i> | Pre-test | 0.677 | 0.650 | 0.158 | 0.925 | 0.889 | 2.04 |
| | Post-test | 0.818 | 0.436 | 0.784 | 1.095 | 0.871 | 2.27 |
| min | Pre-test | 0 | 0 | 0 | 0 | 0 | 0 |
| | Post-test | 1 | 0 | 0 | 2 | 0 | 4 |
| max | Pre-test | 3 | 2 | 1 | 4 | 2 | 11 |
| | Post-test | 3 | 2 | 2 | 4 | 2 | 13 |

Using the paired t-test, a difference was found between the pre-test and the post-test ($t(78) = -13$, $p < .001$, Cohen $d = 1.46$). The score was higher in the post-test ($M = 9.16$; $SD = 2.237$) than in the pre-test ($M = 5.67$; $SD = 2.04$).

Discussion

Before the IBI, students' conceptions about a pulley were associated with a fixed pulley (which may have been inspired by the Task 3 picture). For them, it was just a load-lifting device. When describing the concept, they focused on a pulley's outer description rather than on its work's essence. The most frequent misconception was that a (fixed) pulley saves force when lifting loads. After the IBI, having tried out how a pulley and hoist work, their understanding of the concept changed and fewer misconceptions were identified. The perception of the concept was extended to a free pulley, hoist, and their work. Students understood to a greater extent that a fixed pulley changes only the force direction. They also comprehended balance on a pulley. The effectiveness of IBI was higher in the face-to-face form of study when compared with the effectiveness of IBI in the same topic in the distance form of study at another faculty of education in 2011 (Rochovská, 2012).

The subject matter of a pulley is usually presented to students, as well as the application of virtual manipulations. Research (Rouinfar et al., 2012) showed that students learned the concept of force on a pulley equally well using physical and virtual tools. One question in the research tested students' knowledge, asking how a pulley works and helps. After the first week of (physical or virtual) manipulation with a pulley, students could state correctly that the weight of the load would be distributed. In some cases, they simply stated that with the help of a pulley, the lifting was easier, or less force was used, giving no explanations. Another misconception was that with the help of a pulley, one needs to use less work or energy (similar to our research). Students who manipulated with a pulley physically could also feel the force exerted. Therefore, they reported more observations about the exerted force (Rouinfar et al., 2012). Similarly, Myneni et al. (2013) found that the number of misconceptions was reduced after virtual manipulations with a pulley (5 were identified in the pre-test, 2 in the post-test).

To make procedures in the IBI on the topic of a pulley more effective and to eliminate misconceptions, it would be useful during test solving to allow students again to manipulate a pulley, whether physically or using virtual tools, similarly as in the research by Rouinfar et al. (2013).

Limitations of our research consist in its (convenience) sampling and sample size. A qualitative approach was applied. Therefore, the sample was not as large as in purely quantitative research. Another limitation is the absence of a control group and missing data about respondents' secondary schools (thus their previous education in physics). The implication for further research is

the application of specific instruction procedures in pedagogical practice and the investigation of their effectiveness. Also, it should be found out what procedures the students from our research sample will use in their lessons about a pulley in their own pedagogical practice and what their effectiveness will be.

Conclusions

The IBI effectively changes students' misconceptions about natural phenomena in favour of scientifically acceptable concepts. The research confirmed that after the IBI, students achieved higher scores in the post-test than in the pre-test. Qualitative evaluation of misconceptions before and after the experimental intervention describes how they changed. Identified misconceptions in post-tests may be useful in designing further inquiry activities on a given topic, with the teacher as a facilitator directing students' inquiry activities in the desired direction.

The research results offer challenges for the didactics of science subjects in teacher students' higher education. It is necessary to change their attitudes towards the IBI to experience first-hand the effects it brings and see the meaning of its use in education.

Acknowledgement

The article is published as the outcome of the project VEGA No. 1/0033/22 Inquiry-based instruction in mathematics, science and technical education.

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