The Impact of Experimental Problem-Solving in Technical Education on Students' Knowledge Acquisition

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Abstract

Science and technical subjects are often considered to be difficult and not interesting for students. Teachers try to make the content of education more appealing by incorporating methods that engage students in independent work and problem-solving. One of the effective methods is experimentation. Currently, in addition to activating students during lessons, there is also an emphasis on their ability to evaluate the level of knowledge and skills they have acquired. In our research, experiments in the subject of technology were realised with a sample of 6th-grade primary school students. The goal of the research was to determine how students themselves evaluate the level of knowledge acquisition. The tool for formative assessment was a self-assessment record sheet that we designed. The article presents the research results that were obtained through statistical evaluation of students' responses.

Keywords: Experiment, Education, Formative Assessment

1 Introduction

Students' interest in science subjects at the primary school level in Slovakia has been declining (Fančovičová & Kubiatko, 2015). One contributing factor to this decline is the shift in educational priorities after 1989, when increased emphasis was placed on language studies, resulting in the marginalisation of science education. Consequently, the number of hours allocated to science subjects was reduced, leading to stagnation in practical and experimental instruction (Held et al., 2011, p. 10).

Specialised classrooms for practical subjects, such as technology classes in primary schools, were also eliminated. Research has shown that students' interest in the subject of technology is influenced by its practical focus, work with tools and equipment, and the workshop

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environment (Lukáčová, Bánesz & Štetková, 2024, p. 14). In studies conducted to uncover possible reasons for disinterest, students most frequently cited the difficulty of science subjects as a reason (Fančovičová & Kubiatko, 2015). Turning student disinterest into interest is possible by making science education more appealing and incorporating new teaching methods and approaches. Traditional lecture-based teaching does not motivate students, as it teaches 'how it works' without engaging them in 'why it works.'

Another factor affecting students' interest in science subjects is grading. Currently, students in science subjects are graded on a scale from 1 to 5. Summative grading is inadequate and insufficient, as it does not evaluate the students' actual knowledge or allow for assessment of their capabilities, acquired skills, opinions, or personal development. Summative grading with traditional scales once served as a decision-making mechanism reflecting student performance solely for parents (Szarka, 2017).

According to Kivunja (2015, p. 2119), the purpose of summative assessment is to provide "the primary means of communicating the nature and level of student achievements at different stages of education and at the end of study." Teachers often use tests for summative assessment to verify student knowledge, which encourages memorization and superficial learning (Black & Wiliam, 2010). In summative grading, students passively receive their grades, and there is no evidence that grades influence improvement in learning outcomes.

A different situation arises with formative assessment, where the student becomes an active evaluator of their own performance. Based on research results, Black & Wiliam (2010, p. 81) assert that "formative assessment can improve student outcomes." They view the classroom as a black box, into which students, teachers, rules, management demands, parents, tests, etc., enter from the outside. The output from this black box should be more aware and competent students, better test results, and satisfied teachers and parents. They identify the issue that if better output from the black box is expected, the onus for improvement is placed on the teacher, who must change the inner workings of the box. This insight led Black and Wiliam (2010, p. 82) to investigate a single aspect of teaching—formative assessment (FA). They argue that FA lies at the heart of effective teaching.

In FA, students are not to compare themselves to each other, so that the primary purpose of assessment is not competition but personal improvement. "Feedback for each student should focus on the specific quality of their work with guidance on what they can do to improve and avoid comparison with other students. This means students should be trained in self-assessment so they can understand the main goals of their learning and what they must do to achieve them" (Black & Wiliam, 2010, pp. 84, 85).

Formative assessment can also be used as a tool to evaluate the impact of incorporating students' ideas into the teaching of science subjects to improve student learning outcomes (Gerard, Spitulnik & Linn, 2010).

2 Experimenting in Science Education

In science education, teachers often use demonstrations and experiments. The choice depends on the educational intent. "A demonstration is used to show a phenomenon, law, etc. The purpose of a demonstration is to convey factual knowledge that prevents superficial understanding in students. Experiments, on the other hand, are specially designed situations for testing hypotheses. An essential part of an experiment is identifying variables—factors that can generally influence the experiment's results. Hypothesis formulation is the most significant factor distinguishing an experiment from other scientific methods" (Held et al., 2011, p. 53).

Experiments enable science teachers in subjects such as mathematics, physics, chemistry, biology, geography, and technology to make complex phenomena more accessible to students, particularly those that are difficult to grasp through theory alone. For instance, Beňuška (2024) effectively uses experiments in teaching high school physics to explain the causes of tornado formation. "Every experiment must have a clear purpose and objective. For meaningful experimentation, preconceptions (students' intuition based on personal experience) should be used as an appropriate starting point. Knowledge and its application must be implemented together" (Held et al., 2011, p. 10).

An essential condition for effective teaching through experiments is students' willingness and interest in solving problems. Experimentation in teaching contributes to integrating students' knowledge, which they gain through formulating ideas, observing, and reasoning (Gerard, Spitulnik & Linn, 2010). This means that students must possess scientific skills associated with scientific thinking. "These skills are essential for meaningful learning, which requires connecting new experiences with previous ones and integrating new concepts into a broader framework of related phenomena" (Held et al., 2011, p. 24).

For beginning teachers, incorporating experiments into education can be challenging. However, Duberman (1968) regarded the integration of experiments into education as a significant achievement, despite obstacles and a lack of experience. In current school practice, real experiments—classroom demonstrations—are often replaced by e-experiments.

In Slovakia, experiments were used as an educational approach in primary science education within the project "Let's Roll Up Our Sleeves" (Held et al., 2011, p. 78). This project was implemented as part of Slovak and French collaboration across multiple Slovak primary schools (NIVAM, 2024). The importance of experiments in developing students' thinking and reasoning is also evident from their inclusion in tasks in the European Physics Olympiad (EuPhO). In 2024, participants tackled three theoretical and one experimental problem, where solving the experimental task could earn them double the points of a correctly solved theoretical task (Mucha, 2024).

2.1 Worksheets as a component of experiments

In educational experiments, observed phenomena and collected data are recorded in writing. Throughout primary education, students should be guided in systematically and purposefully organising information obtained through empirical observation. Based on these observational records, students construct tables and graphs, describe relationships between variables, and draw conclusions and generalisations. According to the type of research-oriented concept, three types of written records can be used in education: worksheets, research journals, and research protocols (Held et al., 2011, p. 121).

Worksheets provide students with a systematic framework for documenting collected data, observations, and analytical processes (Syamsidar et al., 2021). They enable students to structure their thoughts and serve as an effective tool for enhancing learning (Toh et al., 2012). A key advantage of worksheets is that they facilitate understanding in experimental contexts (Amin et al., 2019).

A new trend in education is the development of interactive worksheets for experiments that can be adapted to current societal needs (Kotsis, 2024). ChatGPT is used in their creation. However, a barrier to their effective use in education is the insufficient preparedness of teachers in this area. Teachers require training to effectively use modern technologies (such as ChatGPT) to enhance students' knowledge (Kotsis, 2024).

The benefits that worksheets provide to students in learning motivated us to create experimental worksheets for primary school. As part of a study focused on the formative assessment of 6th-grade students in the subject of technology, we developed a workbook with example tasks for exploring the properties of technical materials. In this workbook, we designed 17 experiments focused on understanding the physical, mechanical, chemical, and technological properties of wood, metals, and plastics. Each experiment includes a worksheet for recording observed phenomena and findings. The worksheets are structured to guide students in gradually recording information from each step of the investigation.

Each worksheet includes a self-assessment record sheet, which serves as a valuable tool for formative assessment. In this self-assessment sheet, students were asked to express their satisfaction with their performance by choosing from three options: ‘I am very satisfied,’ ‘I am satisfied,’ and ‘I need to improve.’ They marked their choice with a cross on the self-assessment sheet. The content of the text in the record sheet varied according to the type of experiment.

3 Research Methodology

In our research, we examined the impact of experiments on students' self-assessment. The main goal of the study was to determine the level of knowledge and understanding in the cognitive domain through the implementation of experiments in the subject of technology within lower secondary education.

The primary tool for formative assessment in our study was self-assessment record sheets, which were included in the worksheets. The research subjects were 6th-grade students from fully organised primary schools. A prerequisite for a school’s inclusion in the study was the

professional qualification of the teacher instructing the subject. Eighteen schools from various regions of Slovakia participated, with the research conducted from February to June 2024.
The target population of our research comprised all 6th-grade primary school students. We implemented a purposive representative sampling method, selecting students based on specific criteria, such as fully organised schools and the qualification of technology teachers. In total, 573 students of 6^{th}-grade participated in our study. Since we opted for a quantitatively oriented research approach, it was essential to define the research variables. In our case, the independent variable was the experiment, and the dependent variable was the level of knowledge acquisition by the students.
The research objective guided the formation of the primary hypothesis for our pedagogical study, which we tested throughout the research process. We formulated our main hypothesis as follows:
H: Conducting the proposed experiments will statistically significantly affect students' level of knowledge acquisition.
To evaluate the research results, we applied methods of mathematical statistics. For the statistical verification of the main hypothesis H, we used the χ^2 - goodness-of-fit test. This test is appropriate for statistically determining the significance of differences and testing the hypothesis regarding the dispersion of a normal distribution (Markechová, Tirpáková & Stehlíková, 2011).
In a χ^2- goodness-of-fit test, it is necessary to formulate both null and alternative hypotheses. The null hypothesis assumes that there is no relationship (association, difference, etc.) between the observed variables. In contrast, the alternative hypothesis posits that there is a relationship between the observed variables.

In our research, we established a working hypothesis, H1:
H1: Conducting the proposed experiments will statistically significantly affect the extent of students' knowledge acquisition.

We assessed the extent of knowledge acquisition based on students' formative self-assessment. The working hypothesis was tested using the χ^2 goodness-of-fit test at a significance level of $\alpha = 0.05$ with degrees of freedom $k = 2$. Our aim was to determine whether the observed frequencies (empirical) statistically differed from the expected frequencies (theoretical) that correspond to hypothesis H1. We evaluated knowledge acquisition based on students' responses about their ability to explain the observed phenomena.

To verify hypothesis H1, we formulated the following statistical hypotheses:
Null Hypothesis (H10): The frequencies of formative assessment scores regarding students' ability to explain observed phenomena are equal.
Alternative Hypothesis (H1A): The frequencies of formative assessment scores regarding students' ability to explain observed phenomena are different.

4 Evaluation of Self-Assessment Sheets and Interpretation of Results

To process the research results, we used the online statistical software VassarStats. By entering the values obtained from the evaluation of the self-assessment sheets into the statistical software, we obtained the values shown in Table 1. In the table, the students' responses are organized in the Category section as follows:

A – I am very satisfied,

B – I am satisfied,

C – I need to improve.

Cate-gory	Observed Frequency	Expected Frequency	Expected Proportion	Percentage Deviation	Standardized Residuals
A	330	191	0.33333333	+72.77%	+10.06
B	216	191	0.33333333	+13.09%	+1.81
C	27	191	0.33333333	-85.86%	-11.87
D				----	----
E				----	----
F				----	----
G				----	----
H				----	----
	Reset	Calculate			

[Note that for df=1, the calculated value of chi-square is corrected for continuity.]		[For df=1, this is the uncorrected value of chi-square.]
chi-square =	245.25	
df =	2	[P is non-directional]
P =	<.0001	

Table 1: Calculation of the χ^2 test criterion for the ability to justify observed phenomena.

As shown in Table 1, the critical value of the χ^2 test criterion $\chi^2_{0,05}(2)$= 245.25. Since the calculated value, 245.25, is greater than 5.991, we reject the null hypothesis H0. The table also presents the p-value (P = < .0001), which is commonly used in hypothesis testing. This p-value is less than the established significance level of $\alpha = 0.05$, meaning we reject the null hypothesis and conclude that the frequency distribution of formative assessment in terms of students' ability to justify observed phenomena is significantly different.

Based on these findings, we assert that hypothesis H1 is valid, meaning that conducting the proposed experiments statistically significantly influenced the level of knowledge acquisition by students, as confirmed by their responses in the self-assessment record sheets.

For clarity, we evaluated the students' responses in the self-assessment sheets using descriptive statistics, as shown in Table 2.

	level of self-assessment	Absolute frequency	Relative frequency (%)
I know the reason why	very good	330	58
	good	216	37
	I need to improve	27	5
	TOTAL	573	100

Table 2: Evaluation of Self-Assessment Records in the Area of Students' Knowledge Acquisition.

The percentage analysis of student responses in the self-assessment records revealed that 58% rated their knowledge as 'very good.' The 'good' option was selected by 37%. It is encouraging that only 7% believe their knowledge is insufficient and feel they need to improve.

5 Conclusion

Formative assessment is not commonly practiced in Slovakia. In science subjects, including technology, summative assessment remains the preferred approach. Our research aimed to explore how students assess the level of knowledge they have acquired through conducting experiments and completing worksheets used to document observed phenomena. Based on the results from analysing the studied areas, we found that engaging in the designed experiments significantly impacts students' knowledge acquisition. Over half of the students rated their knowledge as very good, while 37% rated it as good. To generalise these findings, future research could compare data from self-assessment sheets with the results from a knowledge test focused on material properties.

Our study showed that students had no difficulty self-assessing their knowledge. They approached the assessment responsibly and aimed for an objective evaluation of what they learned through experiments. Some students who felt they needed improvement added comments to their self-assessment sheets, explaining why they believed their knowledge was insufficient. Examples include: "I can't explain it, but I really enjoyed the experiment," "I copied the answers from a friend," "It was great, but I don't understand why it happened," "I couldn't explain it without help from a friend," and "The teacher had to help me."

These student comments reflect a positive perception of the experiments, which we consider a significant factor in building a connection to science subjects.

References

Amin, B. D., Haris, A., & Swandi, A. (2019). Implementation of physics learning based on hypermedia to enhance student's problem-solving skill. *International Journal of Teaching and Education, 7*(2), pp. 1–11. http://eprints.unm.ac.id/id/eprint/18742

Beňuška, J. (2024). Od tornáda k firenádu. *Obzory matematiky, fyziky a informatiky*, 1/2024 (53), pp. 23–43. https://www.omfi.ukf.sk/documents/OMFI_2024_02.pdf

Black, P., & Wiliam, D. (2010). Inside the Black Box: Raising Standards through Classroom Assessment. *Phi Delta Kappan*, *92*(1), pp. 81–90. doi:10.1177/003172171009200119

Duberman, M. (1968). An Experiment in Education. *Daedalus*, *97*(1), pp. 318–341. http://www.jstor.org/stable/20023811

Fančovičová, J., & Kubiatko, M. (2015). *Záujem žiakov nižšieho sekundárneho vzdelávania o biologické vedy*. https://ojs.cuni.cz/scied/article/view/151/144

Gerard, L. F., Spitulnik, M., & Linn, M. C. (2010). Teacher use of evidence to customize inquiry science instruction. *J. Res. Sci. Teach.*, *47*, pp. 1037–1063. https://doi.org/10.1002/tea.20367

Held, Ľ. et al., (2011). *Výskumne ladená koncepcia prírodovedného vzdelávania (IBSE v slovenskom kontexte).*

Kotsis, K. (2024). ChatGPT develops physics experiment worksheets for primary education teachers. *European Journal of Education Studies*, *11*(5). doi: http://dx.doi.org/10.46827/ejes.v11i5.5274

Kivunja, C. (2015). Why Students Don´t Like Assessment and How to Change Their Perceptions in 21st Century Padagogies . *Creative Education*, *6*(20), pp. 2117–2126. doi: 10.4236/ce.2015.620215

Lukáčová, D., Bánesz, G., & Štetková, A. (2024). Pupils' attitudes towards the subject of technology as a factor influencing the choice of secondary school. *Journal of Technology and Information Education*, *16*(1), pp. 1–16. doi: 10.5507/jtie.2024.006

Markechová, D., Tirpáková, A. & Stehlíková, B. (2011). *Základy štatistiky pre pedagógov*. UKF v Nitre.

Mucha, Ľ. (2024). Európska fyzikálna olympiáda (EuPhO). *Obzory matematiky, fyziky a informatiky*, 1/2024 (53), pp. 53–58. https://www.omfi.ukf.sk/documents/OMFI_2024_02.pdf

NIVAM. (2024). *Inovatívne prístupy vo vzdelávaní.* https://www.statpedu.sk/sk/vzdelavanie/vzdelavacie-aktivity/inovativne-pristupy-vo-vzdelavani-prirodovednych-predmetov/

Syamsidar, R., Khaeruddin, K., & Helmi, H. (2021). The Effectiveness of using Student Worksheets to Practice Science Process Skills on Hooke's Law Material. *Jurnal Penelitian dan Pengembangan Pendidikan Fisika*, 7(1), pp. 83–90. https://doi.org/10.61969/jai.1337500

Szarka, K. (2017). *Súčasné trendy školského hodnotenia. Koncepcia rozvíjajúceho hodnotenia.* KOMPRESS Nyomdaipari Kft. Komárom.

Toh, P. C., Toh, T. L., Ho, F. H., & Quek, K. S. (2012). Use of Practical Worksheet in Teacher Education at the Undergraduate and Postgraduate Levels. Mathematics Education Research Group of Australasia. https://files.eric.ed.gov/fulltext/ED573382.pdf