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Dominika Koperová & Martin Rusek

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Editorial: Emerging Innovations and Persistent Challenges in STE(A)M Education

Martin Rusek

Abstract

The 22nd year of the PBE conference captured a noticeable shift in the community's focus, reflecting how digital tools and emerging technologies reshape approaches to STE(A)M education. The proceedings illustrate how traditional student-activating strategies such as project- and inquiry-based learning are being enriched by research on demonstrations, visualization, and outdoor or environmental learning. The authors explored the pedagogical impact of real versus video demonstrations, the use of augmented and virtual reality tools, and the integration of AI in teacher preparation. Several studies expanded beyond cognitive outcomes to include affective and motivational dimensions. Across the studies, promising practices included thoughtful blending of real and virtual representations, careful pedagogical use of AI, and sustained support for teacher capacity. The volume underscores that active, technology-enhanced learning is central to contemporary STE(A)M education and calls for systematic research, collaboration, and scaling of successful innovations.

INTRODUCTION

The 22nd year of the PBE conference demonstrated a gradual shift in focus within the community. Although many rationales remain anchored in traditional frameworks, the rapid expansion of new technologies is clearly transforming approaches to STE(A)M education. Compared to previous trends (Rusek & Vojíř, 2018), educational landscapes in STE(A)M are evolving rapidly which is reflected in work of the researchers participating in the conference. The main theme: students benefit more from student-activating strategies: project-based or inquiry-based learning, is being expanded by a look on the role of chemistry demonstrations, the use of interactive digital tools, and environmental or outdoor learning. This year's proceedings then took a step forward showing more directions for further research in the field.

THEMATIC CLUSTERS OF RESEARCH

Demonstration and Perceptual Engagement

The proceedings paper by Tesárková and Rusek (2025) showed results of a pilot investigation that revisited the traditional consensus on the use of real versus video demonstrations in chemistry. Despite new technologies bring possibilities unthinkable several years ago, the paper takes a cautious step back by evaluating how much are students able to learn from either type of chemistry demonstrations. The results suggested video demonstrations tend to be perceived as more accessible and engaging, while real-life demonstrations are valued particularly when sensory effects are crucial. This specifies previous publications on this issue (Škoda & Doulík, 2009) and aligns with Velázquez-Marcano et al. (2004), who found that combining video and animations helps students correlate the macroscopic, sub-microscopic, and symbolic levels of representation, improving conceptual understanding.

Visualisation and augmented reality

Several proceedings contributions indirectly brought supporting information. Digital task sequences, AR applications, interactive textbooks, and visualization tools were addressed. These are used to help students bridge between symbolic, sub-microscopic, and graphical representations — for instance, AR tools enabling 3D geometry drawing, or e-textbooks addressing energy flows and biomass. In their study, Kristanto et al. (2025) explored an AR application (*GeoTry*) for 3D geometry visualization. It challenges students to draw geometries themselves and compare their work with sample catalogues. The results, similarly, to other studies (Lee et al., 2023; Stanciulescu et al., 2024), showed this approach improves spatial visualization and engagement. Despite geometry brings different challenges, this approach may be utilised in visualising science structures too. An example how to bridge these findings and school practice was presented by Vácha and Ryplová (2025). Their study evaluated an interactive e-textbook on topics like biomass, photosynthesis, and ecological flows. It studied both cognitive and affective outcomes, demonstrating how such electronic curricula tools can support learning and motivation when well designed.

Teacher Preparation and AI Integration

Large Language Models and AI in general, have become an inseparable part of researchers' focus in the last couple of years (see e.g. Kasneci et al., 2023). PBE 2024 did not differ. Emerging research dealt with how student teachers engage with artificial intelligence tools (text generators, image tools, lesson design software) (Švandová et al., 2025) or school management's perspectives on the role of AI in education (Elmas & Adiguzel Ulutas, 2025). These studies reveal high interest and unease: enthusiasm for novel tools, yet concerns over pedagogical alignment, ethics, and clarity of learning outcomes.

Environment, Attitudes, and Motivation

Projects on "plant blindness" (Brčáková & Ryplová, 2025) or outdoor chemistry (Hrdlička et al., 2025) stressed the environmental aspects of science education. The results of such activities showed not only knowledge gains but also shifts in attitudes and increased student awareness of ecological roles—important for STE(A)M education in an age of climate crisis.

METHODOLOGICAL INSIGHTS

In terms of quality evidence-based instruction, methodological rigor plays a vital role. Study design and validation play an important role. Many studies in PBE 2024 employed quasi-experimental pre-/post-test designs, control groups, pilot testing, and expert validation of modules. Research spanned from preschool through university, though secondary level appears most common. Some studies with smaller sample sizes or limited geographic reach alert us to caution in generalizing, yet they form an important foundation more rigorous studies may build on in the future. As far as the focus of the studies is concerned, several studies (Hrdlička et al., 2025; Martinelli et al., 2025; Tesárková & Rusek, 2025; Vácha & Ryplová, 2025) moved from the more traditional focus on cognitive outcomes of the presented activities and focused on measures of attitude, motivation, or affect. These enrich the picture of what teaching innovations do but also raise measurement challenges (e.g. how to reliably measure "interest," "motivation," or "agency").

IMPLICATIONS FOR PRACTICE

As the conference has started as purely practical, evolving into a research-based event (Rusek & Vojíř, 2018), the following practices emerge as particularly promising, keeping the original direction of the conference focused on practice:

- Integrate both real-life and video demonstrations, chosen to match the learning goals and sensory affordances (Tesárková & Rusek, 2025).
- Focus on students' observation skills' development (Hašpl & Vojíř, 2025).
- Use AR and interactive visualization tools to support abstract content, ensuring that graphical representations are scientifically accurate and clearly labelled (Martinelli et al., 2025).
- Embed active, inquiry-based, project-based tasks within the curriculum, including outdoor and field-based investigations (Hrdlička et al., 2025; Šmídl & Maňásková, 2025).
- Incorporate AI with care: ensure pedagogical alignment, provide critical thinking around tool use, and monitor for equity and ethics in AI usage (Elmas & Adiguzel Ulutas, 2025; Švandová et al., 2025).

GAPS AND DIRECTIONS FOR FUTURE RESEARCH

While the proceedings provide a rich mosaic of research, several gaps and open questions remain. Longitudinal studies tracking retention of knowledge, attitude, or skills over time are rare. More work is needed in lower (elementary/preschool) levels to understand foundational STE(A)M attitudes and skills. Representational clarity: when students encounter misleading visuals or inconsistent symbolisms, their understanding may suffer, however, ways of visual literacy scaffolding remain underexplored. Scaling innovations: As typical for conferences, many studies are pilot or small scale. Research should examine implementation fidelity, cost, teacher capacity, and system-level adoption and authors supported into ongoing research instead of the conference presentation and publication being the final stage.

CONCLUSION

The articles in this proceedings collection underline that student-activating strategies are not optional extras but central to high-quality STE(A)M education today. They affirm that blending demonstration, project work, visualization, AI, AR, and environmental contexts can deepen understanding, motivate learners, and build scientific identity. However, to fully realize these potentials, we need sustained research of solid methodological design, abundant teacher support, attention to visual and conceptual fidelity, and intentional efforts toward equity. It is my hope that this volume will serve not only as a showcase of innovation, but as a call to educators, researchers, and policymakers to collaborate in refining, scaling, and embedding what works – for the benefit of all learners in STE(A)M fields.

LITERATURE

Brčáková, T., & Ryplová, R. (2025). Pilot Study on the Impact of Innovative Educational Approaches on Students' Knowledge and Attitudes Toward Plants: Insights into Addressing Plant Blindness. In Koperová, D., & Rusek, M. (Eds.), *Project-Based Education and Other Student-Activating Strategies and Issues in STE(A)M Education XXII.*, 33-41. Charles University.

Elmas, R., & Adiguzel Ulutas, M. (2025). School Principals' Perspectives on the Role of Artificial Intelligence in Education. In Koperová, D., & Rusek, M. (Eds.), *Project-Based Education and Other Student-Activating Strategies and Issues in STE(A)M Education XXII.*, 42-48. Charles University.

Hašpl, F., & Vojíř, K. (2025). Observational Skill Test: Construction and piloting of a scale aimed at the differentiation of organisms. In Koperová, D., & Rusek, M. (Eds.), *Project-Based Education and Other Student-Activating Strategies and Issues in STE(A)M Education XXII.*, 81-87. Charles University.

Hrdlička, J., Šrámová, A., & Sedláková, L. (2025). What does water hide? In Koperová, D., & Rusek, M. (Eds.), *Project-Based Education and Other Student-Activating Strategies and Issues in STE(A)M Education XXII.*, 98-105. Charles University.

Kasneci, E., Sessler, K., Küchemann, S., Bannert, M., Dementieva, D., Fischer, F., Gasser, U., Groh, G., Günnemann, S., Hüllermeier, E., Krusche, S., Kutyniok, G., Michaeli, T., Nerdel, C., Pfeffer, J., Poquet, O., Sailer, M., Schmidt, A., Seidel, T., . . . Kasneci, G. (2023). ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and Individual Differences, 103*, 102274. `https://doi.org/10.1016/j.lindif.2023.102274`

Kristanto, Y. D., Lavicza, Z., & Martinelli, A. (2025). It's time to build skyscrapers: A digital task sequence on graphs as representations of covarying quantities. In Koperová, D., & Rusek, M. (Eds.), *Project-Based Education and Other Student-Activating Strategies and Issues in STE(A)M Education XXII.*, 14-23. Charles University.

Lee, J.-K., Lee, S., Kim, Y.-c., Kim, S., & Hong, S.-W. (2023). Augmented virtual reality and 360 spatial visualization for supporting user-engaged design. *Journal of Computational Design and Engineering, 10*(3), 1047-1059.
`https://doi.org/10.1093/jcde/qwad035`

Martinelli, A., Kristanto, Y. D., Setiyawan, A., & Lavicza, Z. (2025). Drawing Surfaces: AR App for Learning Geometry. In Koperová, D., & Rusek, M. (Eds.), *Project-Based Education and Other Student-Activating Strategies and Issues in STE(A)M Education XXII.*, 56-63. Charles University.

Rusek, M., & Vojíř, K. (2018). Konference o projektovém vyučování: Ohlédnutí za 15 ročníky. [The conference about project-based education: A lookback into the last 15 years]. In Rusek, M., & Vojíř, K. (Eds.), *Project-Based Education in Science Education: Empirical texts XV.*, 35-43. Charles University.

Stanciulescu, A., Castronovo, F., & Oliver, J. (2024). Assessing the impact of visualization media on engagement in an active learning environment. *International Journal of Mathematical Education in Science and Technology, 55*(5), 1150-1170.
https://doi.org/10.1080/0020739X.2022.2044530

Škoda, J., & Doulík, P. (2009). Lesk a bída školního chemického experimentu. [The Glory and Misery of the School Chemistry Experiment]. *Výzkum, teorie a praxe v didaktice chemie XIX.*, 2(1), 238-254.

Šmídl, M., & Maňásková, Z. (2025). Formation of Metal Dendrites During Electrolysis: An Inquiry-Based Project for Secondary Schools. In Koperová, D., & Rusek, M. (Eds.), *Project-Based Education and Other Student-Activating Strategies and Issues in STE(A)M Education XXII.*, 88-97. Charles University.

Švandová, V., Sáblík, L., Klebanová, K., & Pospíšil, P. (2025). Artificial Intelligence in the Preparation of Chemistry Student Teachers. In Koperová, D., & Rusek, M. (Eds.), *Project-Based Education and Other Student-Activating Strategies and Issues in STE(A)M Education XXII.*, 24-32. Charles University.

Tesárková, T., & Rusek, M. (2025). Visual and Cognitive Aspects of Chemistry Experiments: Investigating the Benefits of Video and Real Demonstrations. In Koperová, D., & Rusek, M. (Eds.), *Project-Based Education and Other Student-Activating Strategies and Issues in STE(A)M Education XXII.*, 5-13. Charles University.

Vácha, Z., & Ryplová, R. (2025). The impact of using the interactive electronic textbook Biomass in Sustainable Landscapes on secondary school students. In Koperová, D., & Rusek, M. (Eds.), *Project-Based Education and Other Student-Activating Strategies and Issues in STE(A)M Education XXII.*, 49-55. Charles University.

Velázquez-Marcano, A., Williamson, V. M., Ashkenazi, G., Tasker, R., & Williamson, K. C. (2004). The Use of Video Demonstrations and Particulate Animation in General Chemistry. J*ournal of Science Education and Technology, 13*(3), 315-323.
https://doi.org/10.1023/B:JOST.0000045458.76285.fe

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Visual and Cognitive Aspects of Chemistry Experiments: Investigating the Benefits of Video and Real Demonstrations

Tereza Tesárková, Martin Rusek

Abstract

This pilot study investigated how pre-service chemistry teachers perceive and interpret selected chemical demonstrations when presented in video versus real-life formats. This study addressed the educational value of demonstrations—the most frequent experimental activity in Czechia—particularly their affective impact, perceived clarity, and cognitive contribution. Twenty-five undergraduate chemistry pre-service teachers observed three video and three real-life demonstrations, completing worksheets that assessed their responses and understanding. A worksheet and student discussion analysis were used to map their understanding and motivation The results indicate that while video demonstrations were rated as more engaging and accessible, real-life demonstrations were perceived as more illustrative and impactful when sensory effects were essential. Students emphasized the importance of theoretical scaffolding, including chemical equations and explanations, to support understanding. The study highlights the need for thoughtful integration of both video and real-life demonstrations in teacher training, along with future research into the explanatory elements that enhance learning outcomes.

Keywords

Experimental activities in chemistry; real-life demonstrations; video-demonstrations; chemistry education; pre-service teachers

INTRODUCTION

Over the past four decades, experimental activities have been a prominent topic in the discourse surrounding chemistry education. While traditional perspectives often equate the inclusion of experimental activities with high-quality teaching (Galloway & Bretz, 2015; Oliveira & Bonito, 2023), numerous studies suggest that the impact of current approaches to integrating experimental activities is either inconclusive (Hofstein & Lunetta, 2004) or minimal (Abrahams & Millar, 2008). Osborne (2015) further highlights that only a limited subset of chemistry education objectives necessitates practical activities. Nevertheless, experimental activities remain crucial in providing real-world context to chemistry instruction. They serve as a foundation for fostering scientific literacy by enabling students to evaluate and design scientific research (Janoušková et al., 2019). Without them, the educational experience risks losing its relevance and connection to authentic scientific practice (Hofstein & Mamlok-Naaman, 2011).

In the context of Czech schools, a tension exists between traditional curricula and modern educational practices. Chemistry teachers often adhere to legacy curricular frameworks, focusing on the structured delivery of content while neglecting the experimental component, which was originally integrated into specific topics (Vojíř & Rusek, 2020, 2021). This oversight translates to infrequent inclusion of experimental activities in classrooms, occurring approximately once a month in primary schools and, at best, once every six to eight lessons in secondary schools (Rusek et al., 2021). Consequently, students in primary schools encounter experimental activities in only about one in eight lessons, while secondary school students experience them slightly more frequently.

Teachers name several reasons for the limited presence of experimental activities, including the lack of specialised laboratories, insufficient storage for chemicals and equipment, safety concerns, and a lack of ideas for practical activities (Rusek et al., 2021). These challenges align with barriers observed internationally (Oliveira & Bonito, 2023). However, as Beneš et al. (2015) demonstrated, cost-effective solutions exist that enable the implementation of experimental activities in standard classrooms. Additionally, there is a wealth of methodological support available in Czech, including resources such as studiumchemie.cz and eBedox.cz, which offer extensive collections of experimental suggestions. The eBedox.cz database also provides safety guidelines for handling chemicals and their reaction products, addressing a critical area of concern.

To enhance the role of experimental activities in chemistry education, it is essential to increase teacher awareness of accessible material and methodological resources. Furthermore, in line with Osborne (2015) recommendations, emphasis should be placed on fostering science process skills that do not necessarily require the use of chemicals. This dual approach can enrich chemistry education, making it more engaging, relevant, and reflective of real-world scientific practice.

THEORETICAL BACKGROUND

The Necessity of Experimental Activities

While many goals of science education can be achieved through non-experimental (Osborne, 2015) methods (experimental activities in chemistry education, such as demonstrations of reactions, substance properties, and contextualisation of chemical calculations, predominantly focus on the macroscopic level—phenomena observable by human senses. However, these macroscopic observations are often explained to students at the symbolic level (e.g., chemical equations and formulas), which has been shown to be counterproductive (Gilbert & Treagust, 2009; Hamerská et al., 2024; Talanquer, 2011). Demonstrating substance properties and their reactions reduces theoretical abstraction but does not inherently lead to a deeper understanding of chemical principles. Integrating the submicroscopic level, which addresses particle and molecular behaviour, is essential for a comprehensive understanding of chemistry. This underscores the need to complement experimental activities with appropriate visualisations.

The abstract nature of chemistry, which relies on understanding processes at the molecular and atomic levels beyond direct human perception, contributes to its low popularity among students (Gilbert & Treagust, 2009; Talanquer, 2011). In this context, visualisation becomes crucial, enabling students to comprehend the structure of substances, particle interactions, and chemical processes (Cheng, 2018). Experiments play a vital role in bridging theoretical knowledge with practical observation, providing students with real-world insights into scientific principles and enhancing their motivation and engagement. Furthermore, practical demonstrations offer opportunities to contextualise scientific principles within everyday life, highlighting the relevance of chemistry to societal and personal experiences (Childs et al., 2015).

Conceptualisation of Experimental Activities

Student activities involving experimentation and hands-on engagement in science or chemistry education are referred to using a variety of terms which overlap. In the UK, the term practical science is widely referring to a broad set of experiences spanning from students observation to real hands-on experimentation (Holman, 2017). Practical work is another, frequent, term includes tasks beyond formal experiments (Abrahams & Millar, 2008), lastly, investigative projects emphasise students inquiry (Holman, 2017). Other authors also use terms such as experimental work, laboratory activities, fieldwork, or hands-on science. These are being used interchangeably depending on the context. Their implications of students conceptual learning, procedural skill-building, or engagement, however, differs.

In relation to project-based education, effectiveness of students' (inquiry) experiments has been evaluated (Kuncová & Rusek, 2020; Teplá et al., 2020; van Brederode et al., 2020; Vojíř et al., 2018). Recent endeavours to evaluate effectiveness of chemistry experimental activities have dominantly focused on laboratory work (Koperová et al., 2025). However, in the Czech educational system, teachers' demonstrations – activities based on s teacher's manipulation with objects and chemicals to demonstrate e.g. properties of compounds, represent the most-frequently employed experimental activities in Czech chemistry classrooms (Rusek et al., 2020b). For this reason, more attention towards effectiveness of demonstration is needed.

Both real and video demonstrations have unique strengths and limitations. Video demonstrations excel in providing safe, cost-effective, and repeatable learning experiences with enhanced visualisation capabilities (Velázquez-Marcano et al., 2004). However, they may fall short in offering the hands-on engagement and practical skill development afforded by real experiments (Baddock & Bucat, 2008; Thompson & Soyibo, 2002). Real demonstrations, on the other hand, foster active student involvement and create memorable learning experiences, effectively bridging theory and practice (Cheng, 2018; Oliveira & Bonito, 2023). However, they require significant resources, including chemicals, equipment, and safety measures, and carry risks of failure due to preparation errors or unfavourable conditions (Noetel et al., 2021). Addressing these challenges involves balancing the benefits of both approaches, integrating video demonstrations for safety and accessibility while maintaining real experiments to cultivate essential laboratory skills and deeper engagement.

GOALS

This study is a part of larger research aimed at supporting experimental activities in chemistry education. This pilot study to examine how pre-service chemistry teachers perceive and interpret selected chemical demonstrations when presented in video versus real-life formats. Student experiments or inquiry activities, represent a more complex set of tasks, therefore the first study was oriented on demonstrations only.

The study focused on identifying differences in students' affective responses, perceived clarity, and cognitive understanding of chemical processes, as well as on mapping the challenges that hinder deeper comprehension. The goal was to evaluate the usability of the developed research tool and inform the design of follow-up studies investigating the role of explanatory elements, such as chemical equations, in enhancing conceptual understanding.

The study was guided by the following research questions:

1. To what extent does the research instrument capture both cognitive and affective learning gains resulting from students' observation of a chemistry demonstration?

2. What difference, if any, is there between students' comprehension (conceptual understanding, affective engagement) of real and video demonstrations?

The answers to these research question have the potential to bring more clarity to evidence-based improvements to pre-service teacher training.

METHODS

Study design and methods

The students observed three pairs of chemistry demonstrations. First, they watched a selected video demonstration, upon which they independently completed the prepared worksheet. For the final item of the worksheet, they collaboratively interpreted the chemical nature of the observed process, recording their discussion as an audio file. This session was added to capture students' argumentation and their different conceptions of the observed demonstration (Erduran et al., 2004; Osborne et al., 2004).

Following this, a demonstration of similar nature was conducted in a real-life setting, allowing students to observe the process firsthand. After this demonstration, students once again completed the worksheet, including a group discussion. In the pilot study, the following demonstrations were presented:

Real demonstrations:

- Preparation and Testing of Hydrogen
- Reactions of Carbon and Sulphur with Oxygen
- Preparation and Properties of Acetylene

Video-demonstrations:

- Why a Candle Extinguishes
- Combustion of Gelatine
- Preparation and Properties of Chlorine

As obvious from the description, the first pair of demonstrations focused on gas properties. The second pair was represented by eye-catching exothermic reactions and the third, showed a more complex reaction demonstrating reaction of acetylene and chlorine with different compounds. This selection was made based on the palette of available demonstration at ebedox.cz with the intention to select pairs of comparable demonstrations. Since the same demonstrator conducted them on video and in reality, the duration of each pair of experiments was similar, 1-2 minutes each.

Description of the Research Tool

The worksheets comprised five items, with the first four designed to evaluate both cognitive and affective aspects of observing demonstrations. Items 1 and 3 included an additional prompt: "Explain why." The content of the worksheets was adapted from the study by Buntine et al. (2007). The research tool utilised a four-item scale where students responded to statements on a Likert scale ranging from 1 ("strongly agree") to 5 ("strongly disagree"):

1. I find this demonstration interesting.
2. This demonstration is related to what we learned in chemistry.
3. This demonstration was sufficiently illustrative for me.
4. Overall, I would rate this demonstration as useful.
5. Interpret and describe the essence of the observed chemical process.

The final item was responded by the students in groups of four. The discussion was recorded for further analysis.

Sample

The pilot study involved 25 third-year undergraduate students from the Faculty of Education at Charles University, enrolled in the teacher-training programme specialising in chemistry education at the Faculty of Education at Charles University. The They were chosen as participants of the "School Chemistry Experiments" – the first course focused on chemistry experiments from the point of view of chemistry teaching in the pre-service chemistry teacher curriculum. With exception of analytical chemistry laboratory, the students underwent laboratory courses in every other chemistry discipline. At the same time, this course is the first one where chemistry and practical education are merged.

For organisational purposes, the students were divided into two groups (Group 1: 12 students; Group 2: 13 students). This course represents the first explicitly focused on chemistry pedagogy, as the students' prior coursework primarily covered various chemical disciplines.

Data analysis

The data comprised three components: students' responses on Likert scales (items 1–4), their written justifications for selected responses (items 1 and 3), and group discussions on the essence of the observed chemical phenomena. The median was used to evaluate the Likert scale responses. Due to the small sample size, no advanced statistical methods were applied. The students' written responses were analysed using open coding facilitated by ChatGPT's *Qualitative Research Data Analysis* bot. It provided a preliminary set of codes, which were reviewed by the researchers and subsequently used to analyse the dataset. If a student's response could not be classified under any of the existing codes, a new code was created. The coding results were then manually verified by two of the authors to enhance reliability. Similarly, the transcribed group discussions were analysed using the same approach, ensuring consistency and accuracy in the qualitative analysis.

RESULTS AND DISCUSSION

To answer the research question, students' responses to the five items of the worksheet were analysed. Table 1 presents the medians of the values students reported on the Likert scale for each demonstration, reflecting their perceived interest, relevance to the chemistry curriculum, clarity, and overall usefulness. The results suggest that they found the video demonstrations more interesting overall (median = 1 for all three video demonstrations), whereas the real-life demonstrations were rated as "somewhat interesting" for two of the three cases.

Table 1: Students' responses to the worksheet items (1 = strongly agree, 5 = strongly disagree). Interest: 1. I find this demonstration interesting, Relation to chemistry curriculum: 2. This demonstration is related to what we learned in chemistry, Illustrativeness: 3. This demonstration was sufficiently illustrative for me, Usefulness: 4. Overall, I would rate this demonstration as useful. Experiments denoted in italic were shown on video, the rest as a live demonstration.

Experiment	**Interest**	**Relation to Chemistry Curriculum**	**Illustrativeness**	**Usefulness**
Gelatin combustion	1	3	2	3
Reaction of carbon and sulfur with oxygen	1	3	2	2
Preparation and properties of chlorine	1	2	2	2
Preparation and properties of acetylene	2	3	2	3
Candle combustion	1	1	1	1
Preparation and detection of hydrogen	2	1	1	2

The higher perceived interest in the real-life demonstration of gelatine combustion demonstration was supported by students' statements, such as, "In a video, it would just be a 'wow' effect; in reality, everything was visible (referring to the technical execution)." They also emphasised the role of the demonstrator in enhancing engagement. Conversely, the lower interest in the real-life demonstration of hydrogen properties was attributed to students' familiarity with the reaction, leading them to evaluate the interest from the perspective of its contribution to their own understanding. In the case of the demonstration of acetylene properties, the lower perceived interest was linked to what students described as reduced clarity, exemplified by the less vivid bubbling of gas in the video demonstration. These results indicate that students prefer real-life demonstrations when identifying gases. This preference is further supported by their written statements highlighting the importance of auditory effects in these experiments.

Students' evaluations of the relevance of demonstrations to their chemistry curriculum confirm earlier findings (Elmas et al., 2020). In this context, differentiating between video and real-life demonstrations did not clearly indicate substantial differences to better reflect the preliminary status of your findings. Students perceived a strong connection between the demonstrations on hydrogen production and candle combustion and their prior chemistry education. The properties of chlorine were rated as "somewhat related," while the remaining three demonstrations were assessed as neither related nor unrelated. This suggests a lower awareness of the educational content among the students, reflecting the traditional conception of experimental activities as tools to confirm previously explained phenomena rather than as a primary source of information (see Rusek et al., 2020).

The results revealed no significant differences in perceived clarity between video and real-life demonstrations. Students rated two video demonstrations (the reaction of carbon and sulphur with oxygen and the properties of acetylene) as "somewhat illustrative," while the preparation of hydrogen was rated as "illustrative." The ratings for the first two demonstrations likely reflect the effect of unfamiliar reactions. In their written responses, students expressed mixed opinions about the visibility of the ongoing reactions. They highlighted the need for additional explanations by the demonstrator or chemical equations to enhance clarity (see Talanquer, 2010).

For real-life demonstrations, students rated the candle combustion as illustrative due to its simplicity. The properties of chlorine were perceived as "somewhat illustrative," with students attributing this to the complexity of following multiple reactions occurring simultaneously in a series of wash bottles. They again emphasised the importance of including equations and explanations to aid comprehension, noting that they often struggled to independently deduce key concepts from videos without prior training in such analytical thinking (Kelly & Akaygun, 2019; Kelly, 2017). The combustion of gelatine was rated as neither illustrative nor non-illustrative, likely reflecting the limited exposure to organic chemistry demonstrations in their prior studies. Students noted difficulties in understanding the reaction mechanism, citing a lack of supporting knowledge and again underscoring the importance of explanatory equations.

The analysis of students' written descriptions of the observed reactions provided additional insights into the educational value of the demonstrations. Overall, the demonstrations were viewed as beneficial for supporting chemistry education, effectively linking theoretical knowledge with visual and practical illustrations of chemical processes (Galloway & Bretz, 2015).

As for the demonstrations' contribution to students' learning, students particularly appreciated the demonstrations' ability to visualise abstract concepts, such as the preparation and properties of hydrogen, the properties of chlorine, and the combustion of organic substances. Practical examples, including the characteristic sound effect during the hydrogen combustion test, experiments on carbon dioxide density, and visualisation of exothermic reactions, helped students better understand key chemical principles and enhanced their retention through illustrative presentations (Knox, 1990). However, some demonstrations required a stronger focus on theoretical explanations and a more structured approach. Students identified several challenges, including the absence of chemical equations, difficulties in understanding individual steps of the demonstrations, and insufficient connections to everyday applications. They also suggested improvements, such as dividing complex reactions into smaller steps and incorporating video materials to mitigate risks associated with less safe reactions (Seibert et al., 2019; Taber, 2018).

CONCLUSION

This pilot study aimed to evaluate the added value of real-life and video-demonstration in pre-service chemistry teacher training. It highlights the complementary roles of video and real-life demonstrations in chemistry education, as well as their respective strengths and limitations. The students included in this pilot study rated video demonstrations as slightly more engaging, providing a safe, cost-effective, and repeatable way to visualise complex reactions. However, real-life demonstrations were perceived as more illustrative and impactful for fostering deeper engagement, particularly when auditory and sensory elements were crucial. The findings underscore the importance of aligning demonstrations with educational objectives and providing students with adequate theoretical support, such as chemical equations and detailed explanations. Addressing challenges, such as limited clarity and insufficient connections to prior knowledge, is essential to maximise the educational value of both video and real-life demonstrations. Ultimately, due to the small sample, the study needs to be repeated to bring more conclusive results. The pilot study suggested that the demonstrations in the contemporary conception could benefit from some improvements. In the following research, the effect of chemical formulas and equations as well as the long-term effects of demonstrations on students‘ learning outcomes could be investigated.

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LITERATURE

Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. *International Journal of Science Education, 30*(14), 1945–1969. `https://doi.org/10.1080/09500690701749305`

Baddock, M., & Bucat, R. (2008). Effectiveness of a classroom chemistry demonstration using the cognitive conflict strategy. *International Journal of Science Education, 30*(8), 1115–1128.

https://doi.org/10.1080/09500690701528824

Beneš, P., Rusek, M., & Kudrna, T. (2015). Tradice a současný stav pomůckového zabezpečení edukačního chemického experimentu v České republice [The tradition and current state of auxiliary equipment for educational chemistry experiments in the Czech Republic]. *Chemické listy, 109*(2), 159–162. http://www.chemicke-listy.cz/ojs3/index.php/chemicke-listy/article/view/404/404

Buntine, M., Read, J., Barrie, S., Bucat, B., Crisp, G., George, A., Jamie, I., & Kable, S. (2007). Advancing chemistry by enhancing learning in the laboratory (ACELL): A model for providing professional and personal development and facilitating improved student laboratory learning outcomes. *Chemistry Education Research and Practice, 8*(2), 232–254. https://doi.org/10.1039/B6RP90033J

Elmas, R., Rusek, M., Lindell, A., Nieminen, P., Kasapoğlu, K., & Bílek, M. (2020). The intellectual demands of the intended chemistry curriculum in Czechia, Finland, and Turkey: A comparative analysis based on the revised Bloom's taxonomy. *Chemistry Education Research and Practice, 21*, 839–851. https://doi.org/10.1039/D0RP00058B

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse. *Science Education, 88*(6), 915–933. https://doi.org/10.1002/sce.20012

Galloway, K. R., & Bretz, S. L. (2015). Development of an assessment tool to measure students' meaningful learning in the undergraduate chemistry laboratory. *Journal of Chemical Education, 92*(7), 1149–1158. https://doi.org/10.1021/ed500881y

Gilbert, J. K., & Treagust, D. F. (2009). Introduction: Macro, submicro and symbolic representations and the relationship between them: Key models in chemical education. In J.K. Gilbert & D. Treagust (Eds.), *Multiple representations in chemical education, Models and Modeling in Science Education* (pp. 1–8). Springer. https://doi.org/10.1007/978-1-4020-8872-8

Hamerská, L., Matěcha, T., Tóthová, M., & Rusek, M. (2024). Between symbols and particles: Investigating the complexity of learning chemical equations. *Education Sciences, 14*(6), 570. https://doi.org/10.3390/educsci14060570

Hofstein, A., & Lunetta, V. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science Education, 88*(1), 28–54. https://doi.org/10.1002/sce.10106

Hofstein, A., & Mamlok-Naaman, R. (2011). High-school students' attitudes toward and interest in learning chemistry. *Educacion Quimica, 22*(2), 90–102. https://doi.org/10.1016/S0187-893X(18)30121-6

Holman, J. (2017). Good practical science. https://www.gatsby.org.uk/app/uploads/sites/2/2025/07/good-practical-science-report.pdf

Cheng, M. M. W. (2018). Students' visualisation of chemical reactions – insights into the particle model and the atomic model. *Chemistry Education Research and Practice, 19*(1), 227–239. https://doi.org/10.1039/C6RP00235H

Childs, P. E., Hayes, S. M., & O'Dwyer, A. (2015). Chemistry and everyday life: Relating secondary school chemistry to the current and future lives of students. In *Relevant chemistry education* (pp. 33–54). Brill. https://link.springer.com/chapter/10.1007/978-94-6300-175-5_3

Janoušková, S., Teplý, P., Čtrnáctová, H., & Maršák, J. (2019). Vývoj přírodovědného vzdělávání v České republice od roku 1989 [Development of science education in the Czech Republic since 1989]. *Scientia in Educatione, 10*(3), 163–178.
https://doi.org/10.14712/18047106.1254

Kelly, R., & Akaygun, S. (2019). Visualizations and representations in chemistry education. *Chemistry Education Research and Practice, 20*(4), 657–658.
https://doi.org/10.1039/C9RP90009H

Kelly, R. M. (2017). Learning from contrasting molecular animations with a metacognitive monitor activity. *Educacion Quimica, 28*(3), 181–194.
https://doi.org/10.1016/j.eq.2017.02.003

Knox, K. (1990). The H2+ Cl2 explosion as a chemical analogue of the photoelectric effect: A true quantum mechanical demonstration. *Journal of Chemical Education, 67*(10), 897.
https://doi.org/10.1021/ed067p897

Koperová, D., Matěcha, T., Espinosa, A. A., & Rusek, M. (2025). Assessing experimental activities in chemistry instruction: A systematic review of available tools. *Chemistry Teacher International, 7*(4), accepted for publication.

Kuncová, L., & Rusek, M. (2020). V hlavní roli kyslík: experimentální ověření výukové aktivity [Starring Oxygen: Experimental evaluation of a learning activity]. In M. Rusek, M. Tóthová, & K. Vojíř (Eds.), *Project-Based Education And Other Activating Strategies In Science Education XVII* (pp. 88–97).
https://pages.pedf.cuni.cz/pbe/files/2020/05/PBE_2019_final.pdf

Noetel, M., Griffith, S., Delaney, O., Sanders, T., Parker, P., del Pozo Cruz, B., & Lonsdale, C. (2021). Video improves learning in higher education: A systematic review. *Review of Educational Research, 91*(2), 204–236.
https://doi.org/10.3102/0034654321990713

Oliveira, H., & Bonito, J. (2023). Practical work in science education: A systematic literature review. *Frontiers in Education, 8*, 1151641.
https://doi.org/10.3389/feduc.2023.1151641

Osborne, J. (2015). Practical work in science: Misunderstood and badly used? *The School Science Review, 96*, 16–24.
https://nosyevolucion.wordpress.com/wp-content/uploads/2015/10/ssr-june-2015-016-024-osborne.pdf

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching, 41*(10), 994–1020.
https://doi.org/10.1002/tea.20035

Rusek, M., Chroustová, K., Bílek, M., Skřehot, P. A., & Hon, Z. (2020). Conditions for experimental activities at elementary and high schools from chemistry teachers' point of view. *Chemistry-Didactics-Ecology-Metrology, 25*(1-2), 93–100.
https://doi.org/10.2478/cdem-2020-0006

Seibert, J., Kay, C. W. M., & Huwer, J. (2019). EXPlainistry: Creating documentation, explanations, and animated visualizations of chemistry experiments supported by information and communication technology to help school students understand molecular-level interactions. *Journal of Chemical Education, 96*(11), 2503–2509.
https://doi.org/10.1021/acs.jchemed.8b00819

Taber, K. S. (2018). Representations and visualisation in teaching and learning chemistry. *Chemistry Education Research and Practice, 19*(2), 405–409.
https://doi.org/10.1039/C8RP90003E

Talanquer, V. (2010). Exploring dominant types of explanations built by general chemistry students. *International Journal of Science Education, 32*(18), 2393–2412.
https://doi.org/10.1080/09500690903369662

Talanquer, V. (2011). Macro, submicro, and symbolic: The many faces of the chemistry “triplet”. *International Journal of Science Education, 33*(2), 179–195.
https://doi.org/10.1080/09500690903386435

Teplá, M., Sloupová, H., Šrámek, M., & Šarboch, D. (2020). The influence of inquiry activity—electrolysis of aqueous salt solutions—on high-school students’ motivation and performance. In M. Rusek, M. Tóthová, & K. Vojíř (Eds.), *Project-Based Education And Other Activating Strategies In Science Education XVII* (pp. 88–97). Charles University.
https://pages.pedf.cuni.cz/pbe/files/2020/05/PBE_2019_final.pdf

Thompson, J., & Soyibo, K. (2002). Effects of lecture, teacher demonstrations, discussion and practical work on 10th graders’ attitudes to chemistry and understanding of electrolysis. *Research in Science & Technological Education, 20*(1), 25–37.
https://doi.org/10.1080/02635140220130902

van Brederode, M. E., Zoon, S. A., & Meeter, M. (2020). Examining the effect of lab instructions on students’ critical thinking during a chemical inquiry practical. *Chemistry Education Research and Practice, 21*(4), 1173–1182.
https://doi.org/10.1039/d0rp00020e

Velázquez-Marcano, A., Williamson, V. M., Ashkenazi, G., Tasker, R., & Williamson, K. C. (2004). The use of video demonstrations and particulate animation in general chemistry. *Journal of Science Education and Technology, 13*, 315–323.
https://doi.org/10.1023/B:JOST.0000045458.76285.fe

Vojir, K., Honskusová, L., Rusek, M., & Kolář, K. (2018). Aromatic compounds nitration in IBSE. In M. Rusek & K. Vojíř (Eds.), *Project-Based Education And Other Activating Strategies In Science Education XVI* (pp. 131–141). Charles University.
https://pages.pedf.cuni.cz/pbe/files/2019/07/sbornikPBE2018_wos.pdf

Vojíř, K., & Rusek, M. (2020). Vývoj kurikula chemie pro základní vzdělávání v České republice po roce 1989 (Development of chemistry curriculum for lower-secondary education in Czechia after 1989). *Chemické listy, 114*(45), 366–369.
http://chemicke-listy.cz/ojs3/index.php/chemicke-listy/article/view/3606

Vojíř, K., & Rusek, M. (2021). Preferred chemistry curriculum perspective: Teachers’ perception of lower-secondary school textbooks. *Journal of Baltic Science Education, 20*(2), 316–331.
https://doi.org/10.33225/jbse/21.20.316

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It's time to build skyscrapers: A digital task sequence on graphs as representations of covarying quantities

Yosep Dwi Kristanto, Zsolt Lavicza, Alessandro Martinelli

Abstract

This study proposes a digital task sequence, drawing on instruction based on the foundational principles of duality, necessity, and repeated reasoning (DNR-based instruction), designed to support students in developing an understanding of graphs as representations of covarying quantities. It reports on a lesson case involving 22 first-year pre-service mathematics teachers who engaged with the sequence. The findings highlight the potential of the digital task sequence to develop emergent graphical shape thinking (EGST) as a productive way of thinking about graphs. Through tasks that progressively bridge situational quantitative and covariational reasoning and reasoning with graphical representations, students demonstrated their ability to interpret, construct, and refine meanings related to graphs as representations of covarying quantities.

Keywords

Graphs; emergent graphical shape thinking; intellectual need; DNR

INTRODUCTION

Graphs representing covarying quantities are a common tool used to convey information to informed citizens. From illustrating the rise in global sea levels over the years to depicting trends in teen health-related behaviours, graphs effectively convey important messages. Thus, interpreting and constructing graphs are essential skills for students to develop as both consumers and producers of information (Binali et al., 2024; OECD, 2023). However, researchers have reported students' difficulties with graphs (Glazer, 2011; Hadjidemetriou & Williams, 2002; Ivanjek et al., 2017; Van Dooren et al., 2008). In this study, we propose a digital task sequence designed to support students in developing an understanding of graphs as representations of covarying quantities.

Integrating theories for designing a digital task sequence

In designing the digital task sequence, we integrated two perspectives: the DNR (duality, necessity, and repeated reasoning) framework for mathematics curriculum and instruction (Harel, 2008a, 2008b) and emergent graphical shape thinking (EGST, Moore & Thompson, 2015; Paoletti et al., 2023). Drawing on Harel's DNR framework, we articulated a pedagogical stance for teaching and learning mathematics. Drawing on EGST, we promote a productive way of thinking that supports students in interpreting and constructing graphs.

The DNR framework outlines three foundational instructional principles, i.e. duality, necessity, and repeated reasoning (Harel, 2008a, 2008b). The duality principle is based on the view that mathematics consists of two intertwined sets of knowledge: ways of understanding and ways of thinking (Harel, 2008b). The duality principle suggests that students develop ways of thinking through the production of ways of understanding, and the ways of understanding they generate are influenced by the ways of thinking they hold (Harel, 2008a). The second principle is the necessity principle, which states that for students to learn the mathematics intended for instruction, they must have an intellectual need for it. Intellectual need refers to a problematic situation that arises when an individual encounters a situation incompatible with or unsolvable by their current knowledge (Harel, 2013). Lastly, the repeated reasoning principle states that students must engage in reasoning repeatedly to internalize desirable ways of understanding and thinking (Harel, 2008a).

Moore and Thompson (2015) distinguished between two forms of graphical shape thinking: static and emergent. The former refers to viewing a graph as an object in itself, while the latter involves envisioning a graph as being dynamically generated by the trace of a moving point that represents covarying quantities. Researchers emphasize that emergent graphical shape thinking (EGST) is crucial for understanding concepts in advanced mathematics and other STEM disciplines (Paoletti et al., 2024; Thompson & Harel, 2021). Paoletti et al. (2023) developed a framework outlining the key components necessary for students to engage in EGST. According to this framework, students must first engage in situational quantitative reasoning and covariational reasoning as well as reasoning with graphical representations as prerequisites for developing EGST (Paoletti et al., 2024).

Digital task sequence

We applied the instructional design principles of duality, necessity, and repeated reasoning proposed by Harel (2008a, 2008b) in designing the digital task sequence. Guided by the duality principle, the task sequence emphasized both graphs and EGST as central to students' activity. Drawing on the necessity principle, students were prompted to devise their strategies for effectively communicating about two covarying quantities. These student-generated strategies served as an entry point for introducing graphs as representations of covarying quantities. Finally, in alignment with the repeated reasoning principle, the task sequence provided multiple opportunities for students to engage in situational quantitative and covariational reasoning, reasoning with graphical representations, and EGST to interpret and construct graphs.

A digital task sequence titled "It's Time to Build Skyscrapers" was developed using Desmos, which is publicly accessible at `https://s.id/build-skyscrapers`. The sequence consists of four tasks, which are detailed in Table 1.

Table 1: Description of the digital task sequence.

Task	Objective	Description
1	Students generate their own strategies to communicate covarying quantities through text and images.	Students first locate the positions of two buildings and provide reasons for their choices. Next, they drag to adjust the position of a car on the street. They then match the distances between the car and the two buildings with preconstructed segments (Figure 1(a)). Finally, they communicate the relationship between the distances using text and images.
2	Students analyse and evaluate the mathematical thinking and strategies of others to envision a graph both as the trace it creates and as a representation of covarying quantities.	Students analyse a strategy that uses a graph to represent the distances between the car and the two buildings (Figure 2(a)). By observing an animation, they interpreted the graph as dynamically generated by the trace of a moving point constrained by those two covarying quantities (Figure 2(b)). Finally, they define a graph in their own words.
3	Students explore different situations that can produce the same final graph through varying traces.	Given a segment of a graph, students identify different situations that could produce it (Figure 1(b)). They are then presented with another segment of the graph and repeat the process, identifying potential situations that could result in the new segment.
4	Students construct a graph to represent changing quantities within a given context.	Students are first presented with a situation involving a car moving along a straight path between two buildings. They construct a graph representing the distances between the car and the two buildings. Next, they are given a situation where the car moves along a non-straight path, and they construct a corresponding graph for the distances (Figure 1(c)).

Table 1 outlines how the digital task sequence aligns with the EGST framework (Paoletti et al., 2023). It offers opportunities for students to engage in both situational quantitative and covariational reasoning as well as reasoning with graphical representations and further supports engagement with EGST as students interpret and construct graphs.

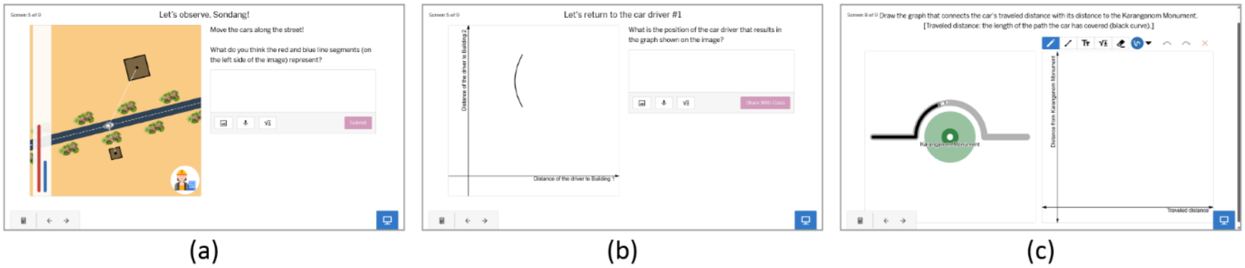

Figure 1: Screens from the digital task sequence.

Task 2 plays an important role in the digital task sequence, as it is the first point where students are expected to construct meaning for graphs as dynamically generated representations. In this task (see Figure 2(a)), students are intended to coordinate two varying quantities, specifically the distances between the car and each of the two buildings, and reason about how these quantities change in relation to each other. They then consider the corresponding variations in the lengths of two orthogonal segments on the coordinate axes, each representing one of the distances. By conceiving a point in the coordinate plane as a multiplicative object that simultaneously represents the magnitudes of both segments, students begin to build connections between the real-world situation and its graphical representation. These situational quantitative and covariational reasoning, along with reasoning with graphical representations, are intended to support students' meanings for EGST, namely their understanding of graphs as traces of moving points, dynamically generated through the interplay of covarying quantities (see Figure 2(b)). This understanding is foundational for engaging with subsequent tasks, where students are expected to interpret a given graph in Task 3 and construct graphs in Task 4.

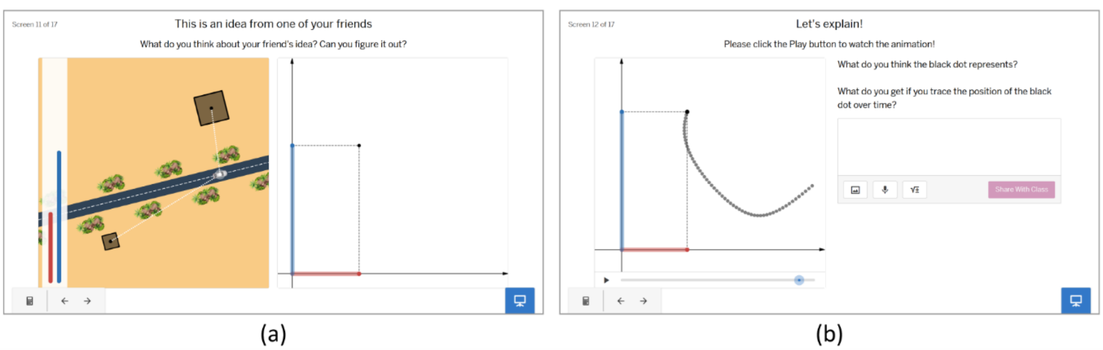

Figure 2: Screens from Task 2.

In summary, the digital task sequence was designed based on instructional principles: duality, to help students develop an understanding of graphs through EGST as a way of thinking; necessity, to present situations that naturally require the use of graphs; and repeated reasoning, to offer students multiple opportunities to revisit and deepen their understanding of graphs throughout the tasks. These principles guided the design of tasks that progressively engage students in reasoning about covarying quantities and in constructing a conceptual understanding of graphs as representations of these relationships.

METHODS

This study aims to propose a digital task sequence designed to support students in developing an understanding of graphs as representations of covarying quantities. The structure and design of the task sequence have been detailed in the preceding section. Accordingly, the central research question guiding this study is: How can the digital task sequence support students in developing EGST as a way of thinking for constructing an understanding of graphs?

This study is part of a larger design research project aimed at transforming mathematics curriculum and instruction related to change and relationships. Specifically, it presents a lesson case showcasing the implementation of a digital task sequence on graphs. The participants were 22 first-year pre-service mathematics teachers enrolled in an algebra and trigonometry course at a private university in Yogyakarta, Indonesia.

The lessons were conducted in two separate sessions, each lasting 100 minutes. The first session took place in late August 2023, followed by the second in early September 2023. Students worked in groups of two or three. In the first session, they completed the first task, generating their strategies to communicate covarying quantities using text and images. In the second session, students worked on the second, third, and fourth tasks.

The data for this study consists of students' work on the digital platform Desmos, which includes both textual and image-based responses that capture their answers and reasoning for the tasks. The analysis was guided by the EGST framework (Paoletti et al., 2023), which served as a lens to examine how the digital task sequence supported students in developing EGST as a way of thinking. The framework consists of situational quantitative and covariational reasoning (M.S.), reasoning with graphical representations of covarying quantities (M.R.), and EGST (M.E.). Using this framework, the first author coded students' works on the digital platform. The coded data were then discussed with the research team to ensure agreement and consistency in the interpretation.

RESULTS AND DISCUSSION

In this section, we present students' work in response to the digital task sequence. We then interpret their responses to examine how the opportunities provided by the sequence supported the development of EGST and contributed to their understanding of graphs as representations of covarying quantities.

In the first task, students developed various strategies to communicate covarying quantities. All strategies involved sketching a literal representation of the situation, depicting a car on the street and two buildings. However, six out of ten groups represented a dynamic process in their sketches by illustrating two or more positions of the car along the street. Figure 3 shows Group 1's work, which illustrates this approach by intentionally selecting two key positions of the car to convey their message.

The students' response in Figure 3 demonstrates that they developed meanings related to M.S. and M.R. They were able to identify the covarying quantities in the given situation and represent their magnitudes through varying segment lengths. Additionally, they coordinated how these quantities change in relation to each other. They divided the situation into three cases based on two key points: the first point, where the car is directly in front of building 2, resulting in the smallest distance between the car and building 2, and the second point, where the car is directly in front of building 1, resulting in the smallest distance between the car and building 1. From their answer (Figure 3), we infer that the students developed an operative image of covariation, at the stage of directional covariation (Carlson et al., 2002).

In Task 2, the students were introduced to a strategy for conveying the relationship between the two distances, i.e. the distance between the car and building 1, and the distance between the car and building 2, using a graph on a rectangular coordinate plane. When asked to analyse the graph, two groups, i.e. Group 1 and 9, demonstrated meanings related to M.E. Below is a translated excerpt of Group 1's interpretation of the graph.

The black point represents the driver's distances from both buildings. The vertical position of the black point represents the driver's distance to the second building. The horizontal position of the black point represents the driver's distance to the first building. If the driver moves from the west until directly in front of the second building, the black point will move to the bottom left. If the driver moves from in front of the second building until directly in front of the first building, the black dot will move to the top left.

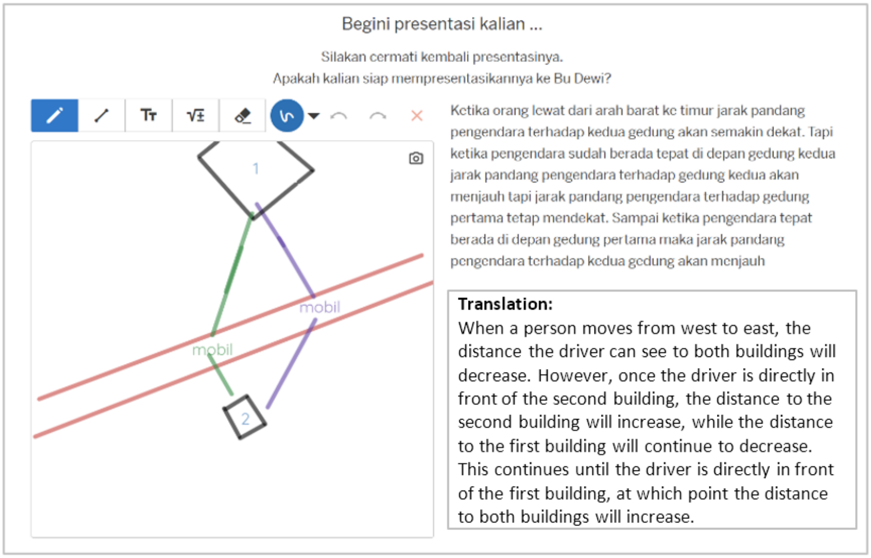

Figure 3: Group 1's response to Task 1.

From this group's interpretation of the graph, we infer that they perceived the motion of a point in the coordinate plane as representing changes in the distances. They also conceptualized the graph as the trace of the point, illustrating how the distances covary.

However, eight groups did not succeed in constructing meanings related to M.E. Group 2, for instance, struggled to interpret the point's movement, as shown in the following translated excerpt.

If the black point moves upward, the driver gets closer to the larger building. If the black point moves downward, the driver gets closer to the smaller building.

Based on the excerpt, it appears that Group 2 interpreted the point on the coordinate plane as representing the driver's literal position. As a result, they stated that the higher the point, the closer the driver is to the larger building, and the lower the point, the closer the driver is to the smaller building.

In Task 3, two groups, i.e. Group 3 and Group 10, successfully identified different situations that could produce the given graph. Figure 4 shows that Group 3 was able to identify two distinct situations represented by the given graph in the first question of Task 3.

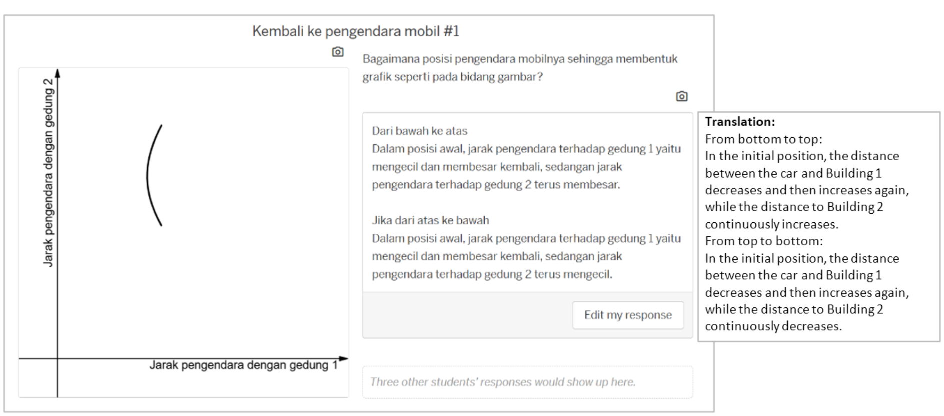

Figure 4: Group 3's response to the first question of the Task 3.

Group 3's response in Figure 4 demonstrates their attempt to describe the relationships between the car's position and its distances to the two buildings. They distinguished two directional movements along the graph, i.e. from bottom to top and from top to bottom and explained how the distances change in each case. From this response, we infer that the group demonstrated meanings related to M.E., as they identified two distinct situations that could produce the given graph by interpreting its traces in different directions.

Five groups interpreted the graph in the first question of Task 3 in only one direction. Group 1, for instance, analysed the graph from the bottom-to-top direction. Their response is presented in the following translated excerpt.

If the point moves to the upper left, it indicates that the car is moving closer to the first building and farther from the second building until a certain point. The point will then move to the upper right, indicating that the car is moving away from both buildings.

In Task 4, most groups successfully answered the first question, constructing a graph to represent covarying quantities from the given situation. A similar pattern was observed in their responses to the second question, which is illustrated in Figure 1(c). Figure 5 displays all groups' answers to the second question.

Figure 5 illustrates that most groups (8 out of 10) constructed appropriate graphs in response to the second question of Task 4, accurately representing the given situation. Their use of linear relationships for segments of their graphs appears appropriate to the context. However, the students' sketches do not provide enough evidence to infer their reasoning behind this choice.

We identified the progression of students' EGST as they engaged with the task sequence. The problem of conveying information about covarying quantities served as a bridge to introduce graphs. The ability of graphs to effectively communicate covarying quantities provided students with a clear rationale to understand and utilize graphs. Using Harel's term (Harel, 2013, 2024), this allowed students to perceive an epistemological justification for the necessity of graphs. These features reflect key principles of project-based instruction, particularly the use of a strong guiding problem and the active engagement of students (Rusek & Becker, 2011) in exploring and constructing mathematical ideas within a purposeful context.

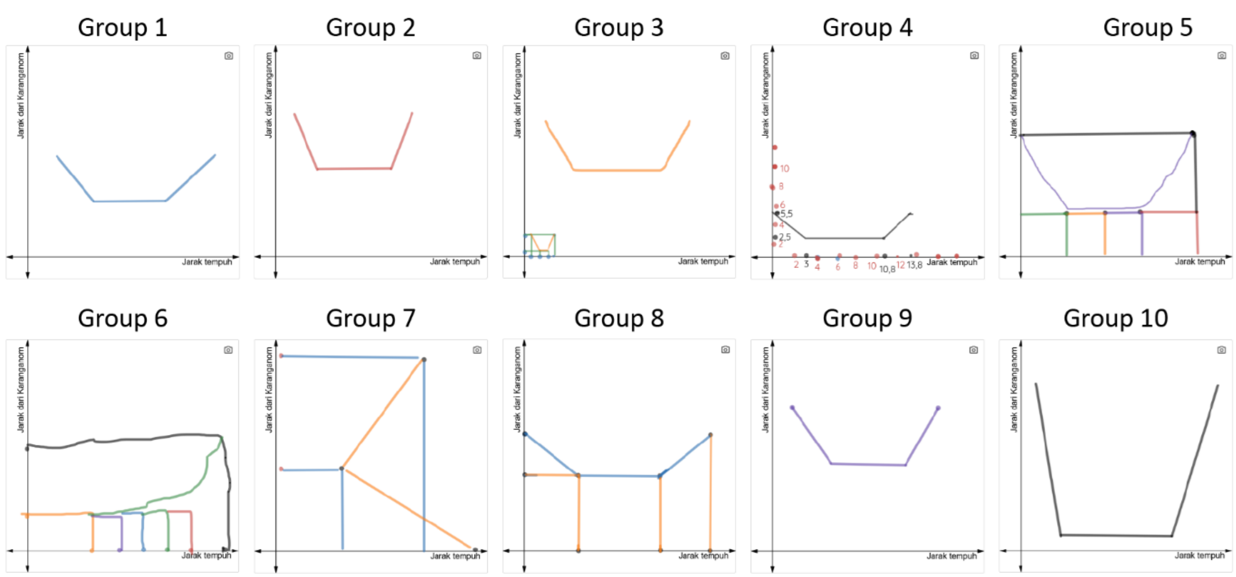

Figure 5: Sketches created by all groups in response to the second question of Task 4.

We found that most students were not successful in completing Task 2, which is particularly noteworthy given that this task was designed to serve as a conceptual foundation of graphs for the subsequent activities. Drawing on cognitive load theory (Sweller, 1988; Sweller et al., 2019), we suspect that this difficulty may be attributed to a split-attention effect, as students were required to integrate related information presented across two separate screens (see Figure 2(a) and 2(b)). To address this, we plan to revise the task into a single-screen format that presents both visualizations concurrently. This strategy is supported by previous research showing that integrated designs can reduce cognitive load (Kueker & Moore, 2024). Additionally, we will incorporate the segmentation principle to manage cognitive load by gradually introducing information (Lusk et al., 2009). As a result, in the revised task, students will first see the changing lengths of orthogonal segments on each axis, which represent the distances to the two buildings, as they manipulate the car on the street. Next, they will be shown a point on the coordinate plane that corresponds to these distances. Finally, they will observe how the trace of that point forms a graph, allowing for a more coherent and scaffolded understanding of the covarying relationship.

We also found that providing students with repeated opportunities to engage in situational quantitative and covariational reasoning, reasoning with graphical representations of covarying quantities, and EGST, helped them refine their understanding of graphs. This result aligns with findings from previous studies (Moore, 2014; Paoletti et al., 2024). For example, Group 2, which initially struggled with interpreting graphs in Task 2, was able to construct meaningful interpretations of graphs by Task 4. These findings highlight the importance of repeated practice for developing fluency, aligning with conclusions from other studies (Harel, 2021; Soto et al., 2022). However, we acknowledge that some students were still unable to construct graphs successfully by the end of the task sequence. This raises important questions about how to best support students in developing EGST through repeated reasoning: How many tasks are needed for students to achieve understanding? What types of tasks, and how should they be sequenced? These questions offer valuable insight for further studies. For example, further studies could incorporate tasks that encourage the use of multiple representations for interpreting and constructing graphs, as suggested by previous studies (Johnson, 2022; Moore et al., 2013).

The findings of this study underscore the significance of EGST as a productive way of thinking for students to develop a meaningful understanding of graphs. This study offers a lens to organize and frame curricular approaches to teaching graphs and their functions. For example, we align with Moore and Thompson's (2015) hypothesis on function transformations, suggesting that a solid understanding of graphs as representations of covarying quantities is essential for students to develop a meaningful and productive understanding of function transformations.

While this study provides valuable insights into students' learning through the digital task sequence, there are some limitations to consider. First, the methods relied on interpreting students' learning based on their works in the platform, which offers limited evidence and does not capture a complete picture of their cognitive processes. Second, the technology used for the digital task sequence is primarily optimized for tablets and computers, and its functionality is limited on mobile devices. This restricts its potential for widespread use in schools, where access to appropriate devices may vary.

CONCLUSION

The findings of this study highlight the potential of the digital task sequence to support students in developing EGST as a productive way of thinking about graphs. Through tasks that progressively bridge situational quantitative and covariational reasoning and reasoning with graphical representations, students demonstrated their ability to interpret, construct, and refine meanings related to graphs as representations of covarying quantities. While many students successfully developed a robust understanding of graphs, the study also identified challenges faced by some students, underscoring the importance of providing repeated opportunities and carefully sequenced tasks to support the development of fluency.

LITERATURE

Binali, T., Chang, C.-H., Chang, Y.-J., & Chang, H.-Y. (2024). High school and college students' graph-interpretation competence in scientific and daily contexts of data visualization. *Science & Education, 33*(3), 763–785.
https://doi.org/10.1007/s11191-022-00406-3

Carlson, M., Jacobs, S., Coe, E., Larsen, S., & Hsu, E. (2002). Applying covariational reasoning while modeling dynamic events: A framework and a study. *Journal for Research in Mathematics Education, 33*(5), 352.
https://doi.org/10.2307/4149958

Glazer, N. (2011). Challenges with graph interpretation: A review of the literature. *Studies in Science Education, 47*(2), 183–210.
https://doi.org/10.1080/03057267.2011.605307

Hadjidemetriou, C., & Williams, J. (2002). Children's graphical conceptions. *Research in Mathematics Education, 4*(1), 69–87.
https://doi.org/10.1080/14794800008520103

Harel, G. (2008a). A DNR perspective on mathematics curriculum and instruction. Part II: With reference to teacher's knowledge base. *ZDM, 40*(5), 893–907.
https://doi.org/10.1007/s11858-008-0146-4

Harel, G. (2008b). DNR perspective on mathematics curriculum and instruction, Part I: Focus on proving. *ZDM, 40*(3), 487–500.
https://doi.org/10.1007/s11858-008-0104-1

Harel, G. (2013). Intellectual need. In K. R. Leatham (Ed.), *Vital directions for mathematics education* (pp. 119–151). Springer New York.
https://doi.org/10.1007/978-1-4614-6977-3_6

Harel, G. (2021). The learning and teaching of multivariable calculus: A DNR perspective. *ZDM – Mathematics Education, 53*(3), 709–721.
https://doi.org/10.1007/s11858-021-01223-8

Harel, G. (2024). Epistemological justification. *ZDM – Mathematics Education, 56*(7), 1489–1501.
https://doi.org/10.1007/s11858-024-01603-w

Ivanjek, L., Planinic, M., Hopf, M., & Susac, A. (2017). Student difficulties with graphs in different contexts. In K. Hahl, K. Juuti, J. Lampiselkä, A. Uitto, & J. Lavonen (Eds.), *Cognitive and affective aspects in science education research* (Vol. 3, pp. 167–178). Springer International Publishing.
https://doi.org/10.1007/978-3-319-58685-4_13

Johnson, H. L. (2022). Task design for graphs: Rethink multiple representations with variation theory. *Mathematical Thinking and Learning, 24*(2), 91–98.
https://doi.org/10.1080/10986065.2020.1824056

Kueker, D., & Moore, J. (2024). Learning from screencast software tutorials: A comparison of cognitive load in dual and single-monitor learning environments. *Journal of Computer Assisted Learning, 40*(1), 118–135.
https://doi.org/10.1111/jcal.12875

Lusk, D. L., Evans, A. D., Jeffrey, T. R., Palmer, K. R., Wikstrom, C. S., & Doolittle, P. E. (2009). Multimedia learning and individual differences: Mediating the effects of working memory capacity with segmentation. *British Journal of Educational Technology, 40*(4), 636–651.
https://doi.org/10.1111/j.1467-8535.2008.00848.x

Moore, K. C. (2014). Quantitative reasoning and the sine function: The case of Zac. *Journal for Research in Mathematics Education, 45*(1), 102–138. `https://doi.org/10.5951/jresematheduc.45.1.0102`

Moore, K. C., Paoletti, T., & Musgrave, S. (2013). Covariational reasoning and invariance among coordinate systems. *The Journal of Mathematical Behavior, 32*(3), 461–473. `https://doi.org/10.1016/j.jmathb.2013.05.002`

Moore, K. C., & Thompson, P. W. (2015). Shape thinking and students' graphing activity. In T. Fukawa-Connelly, N. E. Infante, K. Keene, & M. Zandieh (Eds.), *Proceedings of the 18th Annual Conference on Research in Undergraduate Mathematics Education* (pp. 782–789). West Virginia University. `https://pat-thompson.net/PDFversions/2015MooreShapeThinking.pdf`

OECD. (2023). *PISA 2022 assessment and analytical framework*. OECD. `https://doi.org/10.1787/dfe0bf9c-en`

Paoletti, T., Gantt, A. L., & Corven, J. (2023). A local instruction theory for emergent graphical shape thinking: A middle school case study. *Journal for Research in Mathematics Education, 54*(3), 202–224. `https://doi.org/10.5951/jresematheduc-2021-0066`

Paoletti, T., Stevens, I. E., Acharya, S., Margolis, C., Olshefke-Clark, A., & Gantt, A. L. (2024). Exploring and promoting a student's covariational reasoning and developing graphing meanings. *The Journal of Mathematical Behavior, 74*, 101156. `https://doi.org/10.1016/j.jmathb.2024.101156`

Rusek, M., & Becker, N. (2011). "Projectivity" of projects and ways of its achievement. In M. Rusek (Ed.), *Project-Based Education in Chemistry and Related Fields* (pp. 12–22). Charles University. `https://pages.pedf.cuni.cz/pbe/files/2011/11/proceedings.pdf`

Soto, O., Siy, K., & Harel, G. (2022). Promoting a set-oriented way of thinking in a U.S. high school discrete mathematics class: A case study. *ZDM – Mathematics Education, 54*(4), 809–827. `https://doi.org/10.1007/s11858-022-01337-7`

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*(2), 257–285. `https://doi.org/10.1207/s15516709cog1202_4`

Sweller, J., Van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive architecture and instructional design: 20 years later. *Educational Psychology Review, 31*(2), 261–292. `https://doi.org/10.1007/s10648-019-09465-5`

Thompson, P. W., & Harel, G. (2021). Ideas foundational to calculus learning and their links to students' difficulties. *ZDM – Mathematics Education, 53*(3), 507–519. `https://doi.org/10.1007/s11858-021-01270-1`

Van Dooren, W., De Bock, D., Janssens, D., & Verschaffel, L. (2008). The linear imperative: An inventory and conceptual analysis of students' overuse of linearity. *Journal for Research in Mathematics Education, 39*(3), 311–342. `https://doi.org/10.2307/30034972`

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Artificial Intelligence in the Preparation of Chemistry Student Teachers

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Abstract

This contribution describes the implementation of artificial intelligence (AI) in chemistry education of student teachers at Masaryk University in spring 2024. It discusses AI tools like text generators (ChatGPT, Gemini), graphics generators (Midjourney, DALL-E, Canva), and lesson preparation applications (ScioBot). The results of a questionnaire survey on student teachers' experiences and interests in AI applications before AI classes highlight that most student teachers used the free version of ChatGPT-3.5 (77 %) and were eager to learn more about it and Gemini (76 %), while many (88 %) sought to enhance their skills in Canva. The results of the post-course survey indicated that the most students (71 %) interested in Microsoft Copilot text generator and Image Creator and AI Czech textbooks.

Keywords

Artificial intelligence; chemistry; student teachers; preservice teachers; AI tools

INTRODUCTION

The rapid advancements in the field of so-called generative artificial intelligence (AI), particularly since 2018 and marked by a breakthrough in 2022, have ushered in a new era of innovation across various sectors, including education (Bendel, 2023). AI is rapidly moving from the lab to daily life, it becomes more efficient, affordable, and accessible (Stanford University Human-centred Artificial Intelligence, 2025).

AI and computer science education is worldwide expanding – Africa and Latin America making the most progress (Stanford University Human-centred Artificial Intelligence, 2025). But gaps in access and readiness persist, yet access remains limited in many African countries due to basic infrastructure gaps like electricity (Stanford University Human-centred Artificial Intelligence, 2025).

In the U.S., 81 % of K-12 Computer Science (CS) teachers say AI should be part of foundational CS education, but less than half feel equipped to teach it (Stanford University Human-centred Artificial Intelligence, 2025). As AI continues to be integrated into education (Inamdar, 2024) affecting primary and secondary schools (Hyunsoo, 2022), it is essential for future teachers—not just those teaching chemistry—to learn how to work with this technology.

Educational research has been investigating the effectiveness of various teaching methods, including inquiry-based teaching, project-based education, and using educational digital tools and sources (Šarboch & Teplá, 2022; Teplá et al., 2021). In recent years, the involvement of AI in the educational process has become an important topic (Abualrob, 2025; Iyamuremye et al., 2024; Sun et al., 2024; Yildirim & Akcan, 2024). However, integrating AI into education brings not only opportunities but also concerns and challenges (Alasadi & Baiz, 2023).

COURSE TEACHING MATERIALS IN CHEMISTRY

"Teaching Materials in Chemistry" is an optional course of chemistry teacher training at the Faculty of Science, Masaryk University. The course is primarily devoted to master's degree students. The course aims to develop students' digital competencies and introduces them to the theory and practice of creating teaching materials in chemistry. The emphasis is mainly on creating their own electronic teaching materials that can be practically used in teaching chemistry at secondary schools. In 2023/2024, 17 students completed the course (Švandová et al., 2024).

In the spring of 2024, the course covered six topics. Students received theoretical knowledge, which they then applied through practical tasks. Due to the inclusion of two new topics ("AI in Chemistry Teaching" and

“Virtual Reality in Chemistry Teaching”) some earlier, less relevant topics had to be removed from the course plan (Švandová et al., 2024). For example, the topics ”Chemical Experiments” (which focused on a database of school chemical experiments and measurement systems such as Vernier and Pasco) and ”Popularisation of Chemistry” (which involved training in writing popular science articles) were discontinued.

AI in the course

The inclusion of AI in chemistry teaching, as part of the Teaching Materials in Chemistry course, covered several key areas, as briefly described in Švandová et al. (2024):

1. **Text Generators:** This section involved the presentation and comparison of various applications, including ChatGPT-3.5 and 4, Microsoft Copilot, and Deeply (nowadays renamed to Editee). Students engaged in practical work using these applications.

2. **Graphic Generators:** In this portion, students explored and compared applications such as Copilot Designer, Midjourney, DALL-E in ChatGPT-4, and Deeply / Editee). The focus was on understanding the advantages and disadvantages of each tool.

3. **Preparing for Chemistry Teaching:** This area included a presentation and comparison of ScioBot, ChatGPT, Canva Write applications, as well as the Magic School application (in English) and their usage in the context of lesson planning. A practical task involved creating a teaching preparation using ScioBot.

4. **Chemical Didactic Software:** Students (among others) learned to work with the Canva application and AI graphic generators in this application, the training was realised on chemical topics.

Overall, the course provided students with valuable insights into using AI tools for chemistry teaching and its preparation.

RESEARCH OBJECTIVE

The primary objective of our research was to explore the experiences of students regarding the use of AI in teaching chemistry. We aimed to understand their experiences before they joined our course, as well as to identify their areas of interest and the specific skills they would like to develop. After completing the course, we gathered participants’ opinions on the inclusion of AI within the course. We also explored their views on the use of AI in education as a whole, as well as whether and how they utilize artificial intelligence in their teaching (in the context of pedagogical practice) or to enhance student learning. The investigation aimed to gain initial insights into AI and chemistry education issues, providing a foundation for potential future extensive research.

The research method was a questionnaire focused on future chemistry teachers. The questionnaire completed after the course was inspired by part of the instrument used in the TALIS 2024 survey – the Teaching and Learning International Survey (OECD, n.d.). The TALIS is an international project by the OECD (Organisation for Economic Cooperation and Development), allowing participation of member countries and other non-member countries and economic regions (MŠMT ČR, 2024). The project aims to map the learning environment and the working conditions of teachers and principals (OECD, n.d.). In the Czech Republic, the Česká školní inspekce (ČŠI) is responsible for preparing, implementing, and evaluating the TALIS 2024 survey (Česká školní inspekce, 2024). The results are set to be published in October 2025 and are typically used by policymakers to enhance teaching and learning globally (OECD, n.d.). The TALIS 2024 study covered 55 education systems and focused on teachers and school leaders at ISCED 2 (The International Standard Classification of Education is defined by UNESCO, in the Czech Republic this level corresponds to the second stage of primary schools and the lower level of multi-year grammar schools) (OECD, n.d.). The study also included additional modules that focused e.g. on ISCED 1 and 3, but the Czech Republic did not participate in those modules (MŠMT ČR, 2024).

METHODS

Research type

Quantitative descriptive research was selected to gain initial insights into issues surrounding AI in chemistry teaching.

Target group

The research target group was future chemistry teachers (student teachers). The group consisted of chemistry student teachers who enrolled in the course Teaching Materials in Chemistry at the Faculty of Science, Masaryk University, in spring 2024, totalling 17 students. Participants gave informed consent to be a part of the research, and according to Masaryk University's rules of the Research Ethics Committee, anonymous survey research in adults does not require ethics approval (Masaryk University, 2025).

Research questions

The research focused on the following 3 questions:

RQ1: What experiences do student chemistry teachers have with AI, mainly in the area of lesson preparation?

RQ2: In which applications are student chemistry teachers interested in improving?

RQ3: What are the opinions and experiences of student chemistry teachers about AI related to teaching after completing the course?

The research questions were explored in relation to the topics covered in the course: AI Text Generators (applications such as ChatGPT-3.5 and 4, Microsoft Copilot, and Gemini), AI Graphic Generators (applications such as Copilot Designer, Midjourney, DALL-E in ChatGPT-4, and Canva), Preparing for Chemistry Teaching (applications such as ScioBot, ChatGPT, Canva Write, and Magic School).

Research tool

In this research, a questionnaire was used as a research method. We designed our own questionnaire in two versions, administered before and after the course they attended. The questionnaire contained both closed-ended items (such as dichotomous and multiple-choice) and open-ended items, which allow respondents to create their own answers. Some of the items included sub-items. The inquiry covered nominal, ordinal, and interval data (scale items). Questionnaires before and after classes are described below in detail. All questionnaires were distributed electronically using the Microsoft Forms tool.

Survey for student chemistry teachers -– before classes

The questionnaire consisted of two parts. Part 1 included nine items that focused on experiences with AI, particularly in the realm of AI text generators. It explored interest in improving skills related to specific applications such as ChatGPT-3.5 and 4, Microsoft Copilot, and Gemini, as well as the use of AI for preparing chemistry teaching (applications such as ScioBot, ChatGPT, Canva Write, and Magic School). Part 2 explored the experiences of student teachers and their interests in AI Graphic Generators (such as Copilot Designer, Midjourney, DALL-E in ChatGPT-4, and Canva).

Survey for student chemistry teachers -– after classes

The questionnaire consisted of nine items, which explored chemistry students' opinions about AI related to the course and their views on the use of AI in education generally. The second part could be in future compared to the TALIS 2024 survey (Česká školní inspekce, 2024) after the TALIS results are published in October 2025.

Implementation period, research sample, return and study limitations

In the spring of 2024, the inquiry involving chemistry preservice teachers was conducted with 17 participants. Each of them completed questionnaires both before and after receiving instruction on artificial intelligence (AI), achieving a 100 % return rate for both questionnaires. As the number of participants was low (17), special methods for small sample analysis were used (e. g. Wilson confidence interval identification).

The inquired participants weren't chosen randomly from the population of preservice chemistry teachers, but we inquired about those who had chosen the Teaching Materials in Chemistry course as their voluntary choice. Volunteer sampling is vulnerable to self-selection bias: people who choose to volunteer may differ from those who don't in important ways (e.g. their attitude to AI in our case), which is limiting for generalizability. Therefore, the inductive analysis results are not referenced to all chemistry preservice students at Masaryk University but describe attitudes and opinions of the course graduates and are input for subsequent deeper research. On the other hand, 90 % of chemistry preservice teachers for whom the course is recommended chose the course, so the results in the population could be close to those described.

Data analysis

Data from the completed questionnaires were exported to Microsoft Office Excel for initial analysis. In Excel, we calculated the absolute and relative frequencies for the basic variables. Following this, we utilized IBM SPSS Statistics software (International Business Machines Corporation Statistical Product and Service Solutions Statistics) to verify the results obtained from Excel and to conduct a more in-depth statistical analysis of both basic and derived variables. We performed basic descriptive statistics, which included determining the absolute and relative frequencies of responses, calculating position characteristics (such as mode, median, and mean), and assessing data variability.

From the perspective of inductive statistics, univariate analysis (the examination of a single variable) was conducted. We calculated confidence intervals for both the means and the relative frequencies of responses. Additionally, we assessed whether the observed frequency distribution differed from the theoretical distribution using the Chi-square goodness-of-fit test for polytomous variables and the Binomial test for dichotomous variables. ChatGPT, Perplexity and NotebookLM AI applications were used to work, check, organize and present the inquiry data. In this paper, the initial results of a survey for student chemistry teachers are presented.

RESULTS

Respondents

In a research survey of chemistry student teachers, 17 respondents participated, comprising 13 women (76 %) and 4 men (24 %). Therefore, the modal category is "Woman".

Survey before classes

The **RQ1** examined students' experiences. Most students (60 %) have not actively used AI during their primary or secondary education practice. Only a minority (12 %) have encountered AI in other subjects at university (e.g. in mathematics).

In the field of AI text generators, such as ChatGPT-3.5, ChatGPT-4.0, Microsoft Copilot, and Gemini, students primarily reported using ChatGPT-3.5, with 77 % of respondents indicating familiarity with this application. In contrast, most respondents had little to no experience with the other text generators: 94 % had not used Microsoft Copilot, 88 % had not used ChatGPT-4.0, and 77 % had not used Gemini. Respondents rated their experience with each application on a scale from -1 (indicating "I do not use this program") to 2 (indicating "I use this program often"). Figure 1 illustrates the average ratings for each application: ChatGPT-3.5 received an average rating of 1, Gemini received 0.12, Microsoft Copilot received -0.29, and ChatGPT-4.0 received -0.47. The figure also includes 95 % confidence intervals for the mean, represented by lines.

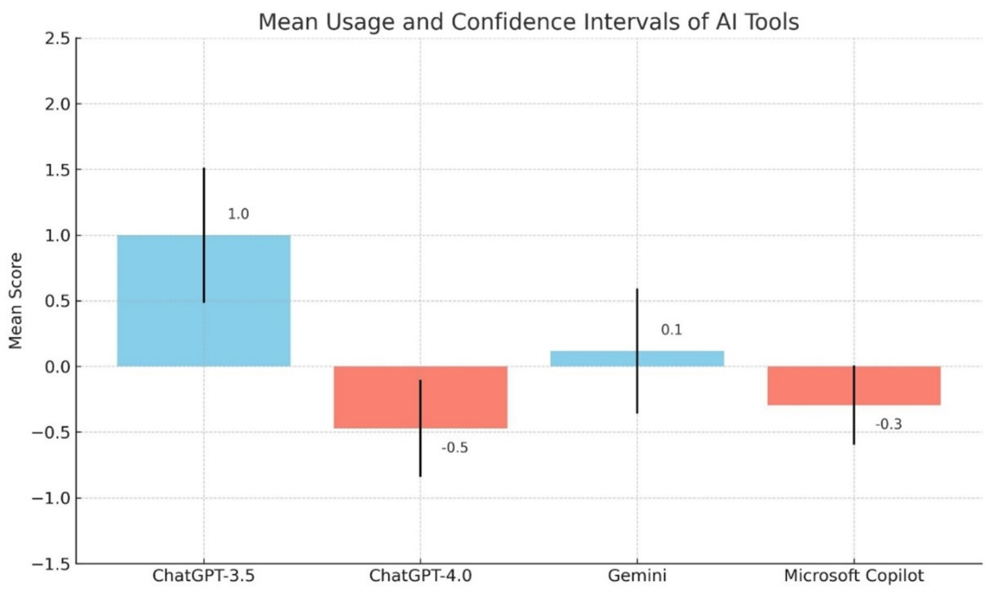

Figure 1: Mean usage and confidence intervals of AI Tools among student teachers of chemistry.

Among graphic AI programs, students reported the most experience with Canva Free (47 %), while none had any experience with Midjourney or Dall-E (0 %).

In the context of lesson preparation, only a minority of students (35 %) reported having experience using AI. Specifically, 35 % had experience with lesson planning, while only 29 % had created materials with AI. In an open-ended question, they specifically mentioned using ChatGPT-3.5 as part of their experience.

The areas of interest examined in **RQ2** and the specific skills they would like to develop were identified firstly in the field of AI text generators. Most respondents showed interest in learning about Gemini (76 %) and ChatGPT-3.5 (71 %), less respondents were interested in ChatGPT-4.0 (47 %) and Copilot (35 %). An overview of individual applications' learning interest is shown in Figure 2.

Among graphic AI programs, most students wanted to improve in Canva (41 % Canva Free, 41 % Canva Edu, 18 % Canva Pro, 88 % in some type of Canva), less than 18 % of respondents were interested in other applications.

Data on students' opinions about AI was not gathered prior to the course being taught.

Survey after classes

This part of the survey answered the **RQ3**. As they evaluated AI related to the course (Figure 3), 76 % of students stated that they valued the course innovation based on the integration of AI into teaching, and they felt more confident in using AI in relation to teaching after completing the course (65 %). They thought they had acquired new skills related to the use of AI in teaching (71 %), they had learned new information about the use of AI in teaching (76 %). After the course 71 % preservice teachers found the topic of using AI in teaching useful and 76 % interesting.

Respondents rated work with each application in the course on a scale from – (indicating "The application didn't interest me, I don't see its benefit for teachers") to ++ (indicating "The application interested me very much, I find it very useful for teachers"). The results are shown in the Table 1. The most students (71 %) interested in Microsoft Copilot text generator, Microsoft Bing/Copilot Image Creator and AI in Vividbooks and Fraus Czech textbooks.

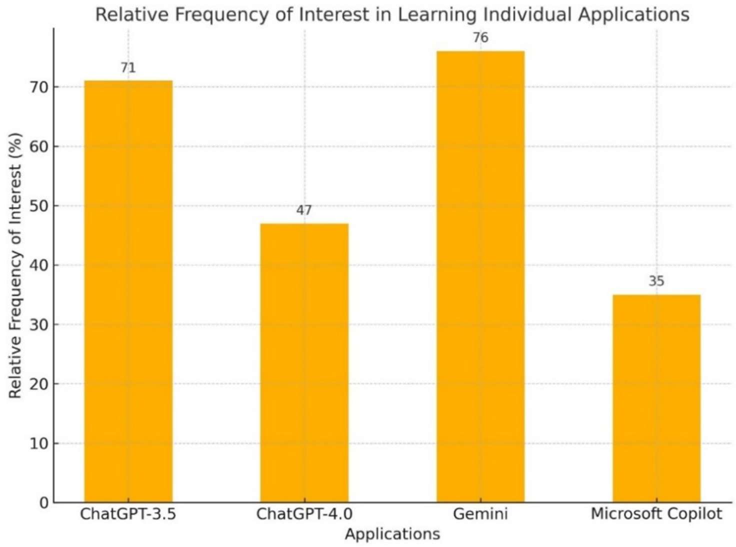

Figure 2: Relative frequency of interest in learning individual applications.

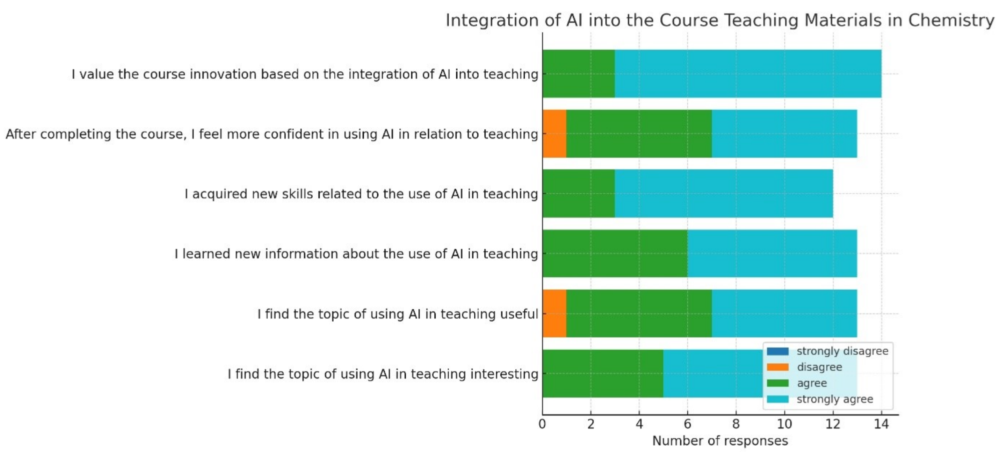

Figure 3: Frequency of opinions on integrating AI into the Teaching Materials in Chemistry course.

DISCUSSION

As AI is integrated into education (Inamdar, 2024), it is essential for future teachers to learn how to work with this technology. From the results presented above, there were several consequences.

Based on the identified experience (**RQ1**) and interest (**RQ2**) in learning ChatGPT-3.5 and Canva, detailed instruction on these subjects was included in the course.

Additionally, based on the identified interest (**RQ2**) in learning Gemini and the lowest experience with this application, teaching alternative chat applications (to the already known ChatGPT-3.5), including Gemini, was prepared for the course. Generative AI chatbots, such as ChatGPT and Gemini, have become increasingly popular as educational tools as they have the potential to enhance learning (Baidoo-Anu & Owusu Ansah, 2023). They have significant implications for teachers, especially pre-service science teachers: they can use them to support the teaching-learning process, focusing on preparing lesson plans and teaching aids, developing authentic assessment tools, creating tables and pictures, and determining instructional strategies that engage all students in the lesson (Abualrob, 2025). A comprehensive study (Iyamuremye et al., 2024) found that these applications enhance students' problem-solving skills, especially in the area of material sci-

Table 1: Various selection of choices about interest and usefulness of the AI applications (frequencies).

AI application	**- -**	**-**	**0**	**+**	**++**
ChatGPT-3.5 (free version)	0	0	3	8	2
ChatGPT-4.0 (paid version)	0	2	3	3	5
Microsoft Copilot	0	0	1	5	7
Canva – Magic Media Application	0	1	1	3	8
Midjourney	0	2	6	2	3
Microsoft Bing/Copilot image creator	0	0	1	6	6
DALL · E	0	1	3	7	2
Adobe Firefly	0	0	8	4	1
DeepL	0	0	7	4	2
Deeply	0	0	5	6	2
Lesson preparation with the ScioBot application	0	1	1	9	2
Lesson preparation using foreign application	0	2	6	4	0
AI in Vividbooks and Fraus textbooks	0	1	0	10	2

ence; they help in understanding the boiling points of organic compounds and significantly improve students' performance in topics like chemical bonding and atomic structure. According to another study of Czech pupils (Křížková Hronová, 2024), ChatGPT is the most favourite AI application among them, followed by Photomath, Google Gemini, and Microsoft Copilot. The post-course survey (RQ3) also indicated that most of the preservice teachers (71 %) saw potential in Microsoft Copilot text generator, Microsoft Bing/Copilot Image Creator. To ensure the success of future educators, it is crucial to prioritize these applications in the training of student teachers.

A large-scale survey by Canva (Wilmot, 2023) of 1,000 teachers in the US found that 78 % of educators expressed interest in implementing AI in their teaching, with the main motivation to create visual materials more efficiently. While the study does not explicitly mention future chemistry teachers, it covers general pedagogical trends. Key barriers include a lack of technical knowledge (93 % of respondents) and concerns about the ethical implications of automated design. Responsibly integrating AI into Canva (which is, according to the authors, many times the first interaction of teachers with AI) and by guaranteeing free access to Canva for Education, the education could be more tailored to students' needs.

Due to respondents' limited experience with teaching preparations, this topic was thoroughly studied and incorporated into the course. The after-course data shows that most of the students (65 %) were interested in creating a preparation course in the Czech application Sciobot. It is crucial to develop this student teachers' competence during their studies at universities because teachers in practice also don't have this competence on an adequate level (Yildirim & Akcan, 2024). In this area, AI can help, for example, visualize and solve chemistry problems, analyse chemical reactions, and conduct chemistry experiments (Yildirim & Akcan, 2024).

Preservice teachers, who are currently in training to become educators, play a crucial role in shaping the future of education. Their willingness to incorporate AI technologies into the classroom and their eagerness to explore, master, and utilize various AI tools are paramount for their effectiveness as future educators (Sun et al., 2024).

CONCLUSION

This contribution shared experiences from the implementation of AI in teaching chemistry for student teachers at the Faculty of Science of Masaryk University in 2024. It described the courses Teaching Materials in Chemistry for student teachers as well as a questionnaire survey that focused on participants' experiences, interests in AI applications, and their attitudes towards AI in teaching before and after the courses. Initial data from the survey of student teachers were presented, highlighting their interest in learning about tools like Gemini, ChatGPT-3.5, and Canva, as well as their limited experience with teaching preparations with AI. Based on these results, related parts of the course were prepared.

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LITERATURE

Abualrob, M. M. (2025). Innovative teaching: How pre-service teachers use artificial intelligence to teach science to fourth graders. *Contemporary Educational Technology, 17*(1), ep547. https://doi.org/10.30935/cedtech/15686

Alasadi, E. A., & Baiz, C. R. (2023). Generative AI in education and research: Opportunities, concerns, and solutions. *Journal of Chemical Education, 100*(8), 2965–2971. https://doi.org/10.1021/acs.jchemed.3c00323

Baidoo-Anu, D., & Owusu Ansah, L. (2023). Education in the era of generative artificial intelligence (AI): Understanding the potential benefits of ChatGPT in promoting teaching and learning (SSRN Scholarly Paper 4337484). Social Science Research Network. https://doi.org/10.2139/ssrn.4337484

Bendel, O. (2023). Image synthesis from an ethical perspective. *AI & SOCIETY, 40*, 437–446. https://doi.org/10.1007/s00146-023-01780-4

Česká školní inspekce. (2024, November 15). O šetření TALIS. Česká Školní Inspekce. https://www.csicr.cz/cz/Mezinarodni-setreni/TALIS/O-setreni-TALIS

Hyunsoo, K. (2022). Suggestions on teaching and learning AI ethics using cooperative learning method in elementary and secondary education. *Robotics & AI Ethics, 7*(1), 65–75. https://doi.org/10.22471/ai.2022.7.1.65

Inamdar, S. (2024). Ethical reflections in the use of AI for teaching and learning. *Anvesak*. https://www.academia.edu/125034384/ETHICAL_REFLECTIONS_IN_THE_USE_OF_AI_FOR_TEACHING_AND_LEARNING

Iyamuremye, A., Niyonzima, F. N., Mukiza, J., Twagilimana, I., Nyirahabimana, P., Nsengimana, T., Habiyaremye, J. D., Habimana, O., & Nsabayezu, E. (2024). Utilization of artificial intelligence and machine learning in chemistry education: A critical review. *Discover Education, 3*(1), 95. https://doi.org/10.1007/s44217-024-00197-5

Křížková Hronová, M. (2024, November 12). Čeští žáci a umělá inteligence. Jak AI mění vzdělávání? https://www.zurnal.upol.cz/nc/en/news/clanek/cesti-zaci-a-umela-inteligence-jak-al-meni-vzdelavani

Masaryk University. (2025, May 15). Research Ethics Committee: Ethics review. https://www.muni.cz/en/about-us/organizational-structure/boards-and-committees/research-ethics-committee/ethics-review

MŠMT ČR. (2024, November 12). OECD: Informace o zapojení České republiky do vzdělávacích projektů OECD. MŠMT ČR. https://msmt.gov.cz/mezinarodni-vztahy/organizace-pro-ekonomickou-spolupraci-a-rozvoj-oecd

OECD. (2024, December 28). TALIS. OECD. https://www.oecd.org/en/about/programmes/talis.html

Šarboch, D., & Teplá, M. (2022). The role of the interactive animations in science education and their impact on the students' motivation and knowledge. In M. Rusek & M. Tóthová (Eds.), *Project-based Education and Other Student-activation Strategies and Issues in Science Education XIX* (pp. 144–153). Charles

University.
https://pages.pedf.cuni.cz/pbe/files/2022/10/ProceedingsPBE2021_final.pdf

Stanford University Human-centered Artificial Intelligence. (2025, May 15). Artificial Intelligence Index Report 2025. Stanford University Human-centered Artificial Intelligence.
https://hai-production.s3.amazonaws.com/files/hai_ai_index_report_2025.pdf

Sun, F., Tian, P., Sun, D., Fan, Y., & Yang, Y. (2024). Pre-service teachers' inclination to integrate AI into STEM education: Analysis of influencing factors. *British Journal of Educational Technology, 55*(6), 2574–2596.
https://doi.org/10.1111/bjet.13469

Švandová, V., Sáblík, L., & Klebanová, K. (2024). Využití umělé inteligence v přípravě budoucích učitelů chemie. In R. Maršálek (Ed.), *DIDSCI+ 2024: 12th International Conference on Research in Didactics of the Sciences* (pp. 74–75). Ostravská univerzita.
https://doi.org/10.15452/DIDSCI.2024

Teplá, M., Šmejkal, P., Šrámek, M., Šarboch, D., & Teplý, P. (2021). The influence of 3D models and animations on students' motivation in chemistry and biology – The results of the pilot study. In M. Rusek, M. Tóthová, & K. Vojíř (Eds.), *Project-based Education and other activating Strategies in Science Education XVIII* (pp. 140–148). Charles University.
https://pages.pedf.cuni.cz/pbe/files/2021/05/ProceedingsPBE2020_final.pdf

Wilmot, J. (2023, October 23). Canva's AI in Education Study: Teachers embrace power of AI. Newsroom - Latest Canva News Announcements, Brand Guidelines and Media Kit.
https://www.canva.com/newsroom/news/ai-education-survey/

Yildirim, B., & Akcan, A. T. (2024). AI-Professional Development Model for Chemistry Teacher: Artificial Intelligence in chemistry education. *Journal of Education in Science, Environment and Health*, 161–182.
https://doi.org/10.55549/jeseh.741

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Pilot Study on the Impact of Innovative Educational Approaches on Students' Knowledge and Attitudes Toward Plants: Insights into Addressing Plant Blindness

Tereza Brčáková, Renata Ryplová

Abstract

This study explores how two distinct educational approaches influence 8th and 9th grade students' understanding of the cooling effects of plants and their related attitudes, particularly in the context of addressing the phenomenon known as "plant blindness." The quasi-experimental study was conducted in the South Bohemia region with a control and an experimental group of students (N = 211) in June 2024, using a pre-post-test design. Results suggest that with modern technologies, project-based learning increased students' knowledge and positive attitudes toward the subject matter significantly more than traditional teaching methods, which resulted in only small changes. There is growing evidence, such as that presented here, on how modern educational technologies with proper instructional design can potentially improve students' understanding of plants and their ecological roles, especially concerning climate change. This study adds to the literature on the use of modern educational technologies and how these different teaching methodologies influence students' perception and appreciation of plants.

Keywords

Plant awareness; knowledge about plants; attitudes towards plants; concept maps

INTRODUCTION

The term "plant blindness," first described in the 1990s, has gained widespread attention in recent decades. It encompasses people's inability to notice plants in their surroundings and the ecological roles and beauty they add (Wandersee & Schussler, 1999). This phenomenon affects people of all ages and backgrounds worldwide and has been frequently examined in educational contexts. Consequently, there is a plethora of literature on the phenomenon, its occurrence at different levels of schooling, and its effect on people's environmental consciousness (Amprazis & Papadopoulou, 2020; Marcos-Walias et al., 2023; Ryplová & Pokorný, 2020; Stagg & Dillon, 2022).

Studies tend to show more interest in animals than plants (Jose et al., 2019; Balas & Momsen, 2014). During biology classes, animals are prioritized over plants, something which extends out of the classroom. In fact, society has a general bias toward animals as well. Teachers use animals as the main focal point in biology classes, resulting in little work with plants (Wandersee, 1986). In addition, an interest in plants goes hand in hand with a lack of basic knowledge essential to fostering sustainable development and environmental concerns (Jose et al., 2019).

This is associated with a phenomenon described as "plant illiteracy," where people lack the knowledge and understanding of plant biology, ecology, and their significance in the ecosystem (Ryplová & Pokorný, 2020). The causes of plant blindness are multidimensional, ranging from a lack of formal education about plants to cultural and cognitive biases that prioritize animals over plants in both media and science (Balding & Williams, 2016).

The teaching modules of this research stem from the global issue of plants cooling the climate. Understanding this key process is essential for sustainable development, as it directly impacts climate regulation and environmental preservation. The cooling effect of plants, through processes like transpiration, plays a significant role in mitigating urban heat islands and combating climate change (Ellison et al., 2017). The relevance of this issue in relation to the European Green Deal is also notable, which aims for carbon neutrality and biodiversity restoration by 2050 (European Commission, 2019). Understanding the role of vegetation in climate regulation will be crucial for upcoming generations to give urban environments and ecosystems the attention and care they deserve through proper planning and conservation. This calls for understanding the cooling effect of vegetation as a powerful tool for promoting environmental protection, as emphasized by Ryplová & Pokorný (2020). It highlights how far-reaching and effective pedagogical approaches to engineering ecological awareness need to be, especially when it comes to tackling plant blindness.

Contextually, the infusion of such themes into the teaching programs should help students cope with the worrying issues of climate change in connection with the sustainable development goals (United Nations, 2015). Through active learning methods and project-based learning, as proposed in this study, it is expected that students will gain knowledge and potentially develop attitudes that support environmental sustainability.

Why knowledge and attitudes?

The phenomenon of "plant blindness" remains relatively theoretical, albeit there have been developments to measure it. For instance, Parsley et al. (2022, p. 9) introduced the term 'plant awareness disparity' (PAD) to divide plant blindness into four significant dimensions. These are: Attention, which is also divided into General Attention and Attention to Food Plants; Attitude, which is divided into Positive Affect and Caring for or Investment in Plants; Relative Interest, which comprises Plants Better than Animals and Animals Better than Plants; Knowledge, which deals with Necessity or Importance of Plants (Parsley et al., 2022).

Pany et al. (2022, p. 4) further classify Plant blindness into four groups: Visual Perception of Plants; Categorizing Plants as Living Organisms; Knowledge About Plants, and Attitudes Towards Plants. They explain that these domains are related to one another, and they demonstrate an intricate relationship between perception, knowledge, and attitudes towards plants.

Both Parsley et al. (2022) and Pany et al. (2022) recognize two main pillars: knowledge and attitudes towards plants. Building on these theories, this pilot study seeks to address the following research questions:

1. How does students' knowledge of plants influence their attitudes toward them?

2. How do students' attitudes toward plants influence their plant knowledge?

By investigating these questions, this study aims to build our understanding of plant blindness and its influence on the way people engage with nature, in particular plants. This study will enhance the broader knowledge base on environmental education and will help inform future projects that work towards increasing awareness within learning settings.

METHODOLOGY

This study was conducted in June 2024 among 211 8th and 9th grade primary school pupils and equivalent grades of secondary schools in the South Bohemia region. The research aimed to answer the following question: "Does modified knowledge of the cooling function of plants in the human environment impact students' attitudes toward plants?"

Participants were assigned to control and experimental groups based on existing class units due to the impossibility of random assignment. For comparability, groups were selected from the same grade level and comparable school environments. The study compares the impact of an active teaching approach with the use of digital technologies to traditional frontal teaching. Both methods were designed to transmit the same information on the cooling ability of plants. The control group participated in classroom-based lessons using a pre-recorded presentation supported by a worksheet, with sufficient time allocated for completing exercises (45 minutes). The experimental group engaged in project-based learning in a school garden, working with infrared thermometers, thermal cameras, and solarimeters. Students measured surface temperatures, visited theoretical stations, and designed urban cooling projects (e.g., reducing the thermal impact of parking lots). Lessons averaged 60 minutes due to additional time spent explaining digital tools.

Both groups completed identical pre-test and post-test questionnaires. The knowledge section consisted of nine modified questions from a valid survey (Ryplová & Pokorný, 2018), combining open-ended and multiple-choice formats. The attitudinal section also included nine questions, three from the validated questionnaire of attitudes toward plants (Dünser et al., 2024) and six adapted from another survey (Kaur & Zhao, 2017). For an assessment of students' attitudes, a Likert scale was used in the survey, from 1 (most negative) to 100 (most positive), and reasons for ratings were requested from students. For the exact wording of the questionnaires, please address the author.

In the final section of the questionnaire survey, students were asked to create concept maps related to the cooling role of plants. Six keywords were provided to the students: solar radiation, cooling of the surroundings, water, stomata, roots, and water evaporation. The concept map structure was pre-designed and required students to incorporate these keywords and connect them appropriately.

Figure 1 illustrates the fill-in-the-map method used in the survey. This method asks students to complete a partially structured concept map by filling in missing concepts or relationships. The exercise prompted the students to engage actively with the content by recalling and classifying appropriate information regarding the cooling effect of plants.

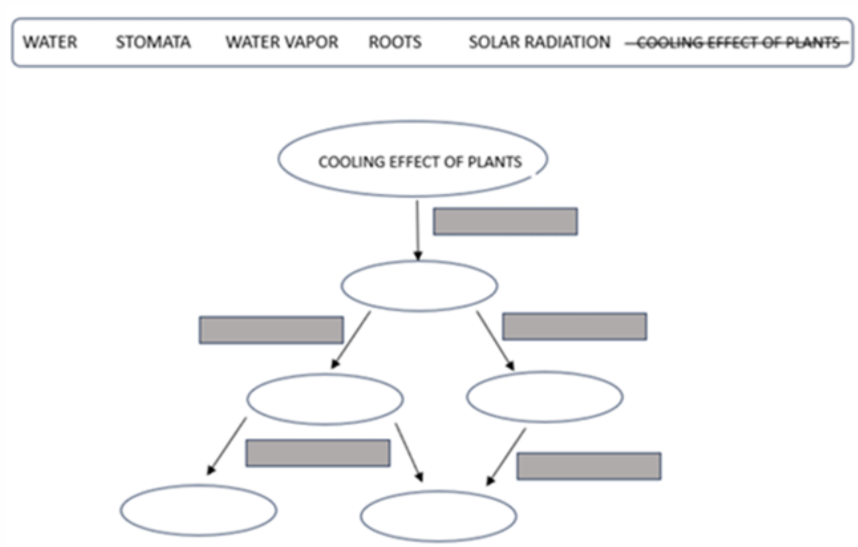

Figure 1: Fill-in-the-box concept map used in the survey.

The use of concept maps in this study aimed to assess students' understanding of complex plant processes. However, it should be noted that concept maps were employed as a methodological tool, and some challenges arose during the implementation. A brief introduction to the technique was provided, but students' unfamiliarity with the creation of concept maps may have impacted the quality of the results. For future research, it will be necessary to provide more comprehensive training on how to create concept maps, ensuring that students are adequately prepared to use this tool effectively.

RESULTS

The results indicate a weak positive correlation between knowledge and attitudes which was observed in both the control and experimental groups. Figure 2 illustrates the correlation between knowledge and attitudes in the control group, which underwent intervention through traditional frontal teaching. Spearman's correlation analysis for the control group revealed a significant but weak positive relationship between knowledge about plants' cooling role and attitudes toward plants ($R = 0.24$, $p = 0.02$, $N = 95$). Wilcoxon's test, conducted on the knowledge section of the questionnaire, demonstrated a statistically significant increase in knowledge about the cooling role of plants ($p < 0.001$, $N = 95$). However, for the attitudinal section, which exhibited a normal distribution as confirmed by the normality test, a T-test was applied. This analysis did not show a statistically significant change in attitudes toward plants ($p = 0.79$, $t = 0.27$, $N = 95$).

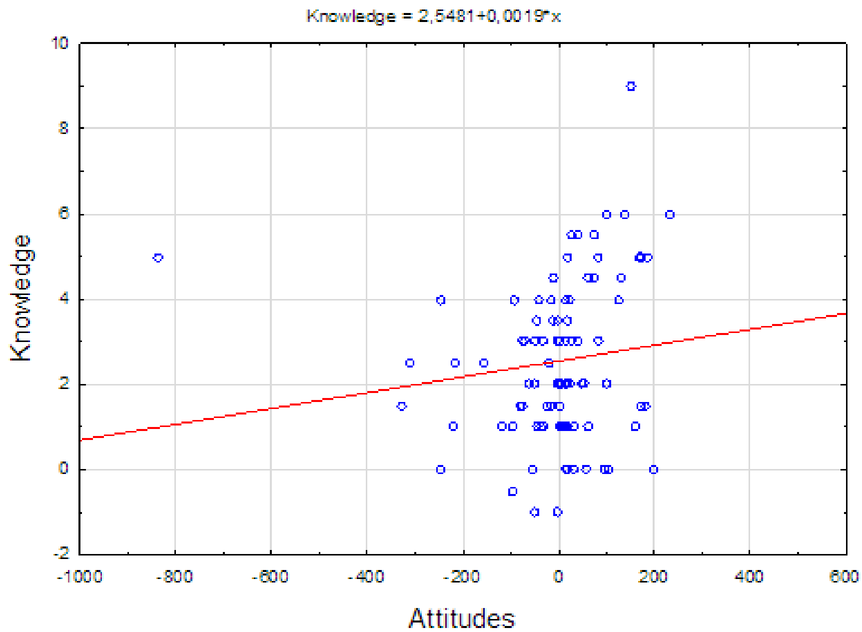

Figure 2: Correlation of knowledge and attitudes towards plants for a control group (R = 0.24; p = 0.02; N = 95).

Figure 3 shows the correlation between knowledge and attitudes in the experimental group, which participated in project-based learning using modern digital tools. Spearman's correlation analysis for the experimental group revealed a significant but weak positive relationship between knowledge about the cooling effect of plants and attitudes toward plants (R = 0.32; $p < 0.001$; N = 116). Wilcoxon's test indicated a statistically significant improvement in knowledge ($p < 0.001$, N = 116). This statistical test was used because of non-normally distributed data. Additionally, Wilcoxon's test for the attitudinal part demonstrated a statistically significant increase in attitudes ($p < 0.001$, N = 116).

Project-based learning using modern technologies was enjoyed by 81 % of respondents, while transmissive teaching was enjoyed by 58 % of respondents. The responses from the attitude scales were coded. For negative attitudes toward plants, respondents most commonly mentioned that plants were unnecessary for life, the subject was taught in a boring manner, and that plants were not needed. Positive attitudes were most often based on aesthetic appreciation, such as beauty and fragrance. Mentions of photosynthesis, plants' cooling effects, and air purification were relatively rare.

This pilot study shows a very weak positive correlation between knowledge and attitudes, which was similar in both groups. It is therefore impossible to assert that the type of educational program contributed significantly to the relationship between these two variables. Nevertheless, statistically significant changes in attitudes and knowledge were found in the experimental group that received project-based learning with the application of digital technology. While the project-based approach was rated as more enjoyable by students (81 % of respondents compared to 58 % in the control teaching group), this aspect alone may not entirely explain the attitude changes observed. Attitude development is a complex process that likely requires a longer time frame. These results are thus to be interpreted with some caution with due regard to methodological limitations inherent in pilot studies. This study can serve as a basis for upcoming and more detailed studies intended to evaluate the effectiveness of various learning approaches in facilitating the familiarity of students with plants.

DISCUSSION

This pilot study provides an initial insight into the knowledge-attitude relationship toward plants in an ecological context – namely their cooling role via transpiration, which is a subset of the broader phenomenon

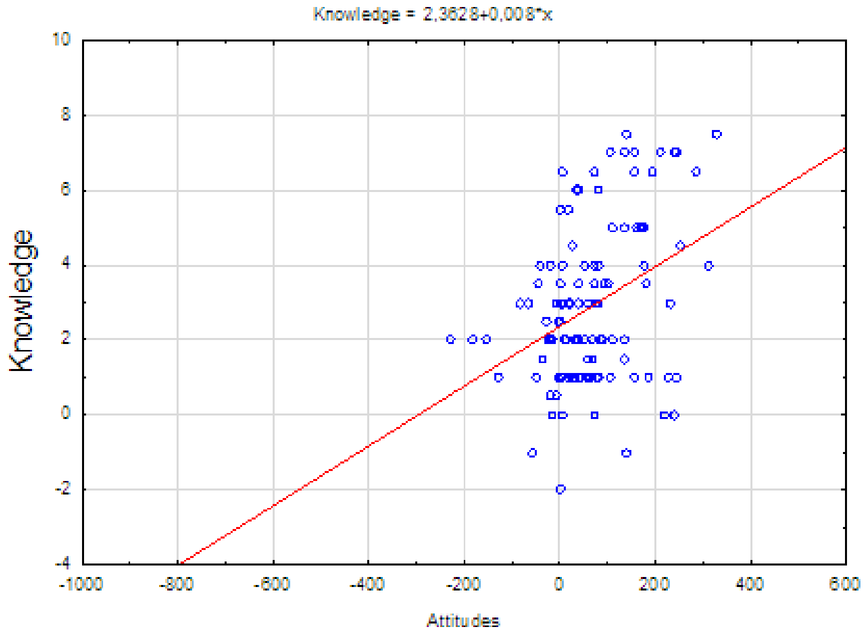

Figure 3: Correlation of knowledge and attitudes towards plants for an experimental group (R = 0.32; $p < 0.001$; N = 116).

of plant blindness. Although the relationship observed was weak, it was statistically significant, suggesting a possible connection between students' cognitive and affective domains in plant-related topics.

Both the control and experimental groups showed a statistically significant increase in knowledge about plant cooling (caused by transpiration, for more details see Ryplová & Pokorný, 2018). However, a significant positive change in attitude was observed just in the experimental group with project-based learning supported by modern digital tools in comparison with traditional teaching methods used in the control group. This result would suggest that not only the content but also the form of instruction plays an important role in shaping students' attitudes. Stagg & Dillon (2022) emphasize that people's awareness of plants develops when they engage with plants in meaningful and relevant contexts. In line with this. Thomas et al. (2022) and Uno (2009) present an argument that the inclusion of plant biological processes in education is critical for building plant awareness and science literacy. The role of digital technologies and their impact on knowledge acquisition is also addressed by Ryplová et al. (2023).

Other scholars have also raised the relationship between cognitive knowledge and affective qualities. For instance, Dünser et al. (2024) discussed a possible link between knowledge of ecosystem service knowledge and pro-plant attitudes. Similarly, a study by Gabela et al. (2022) conducted with undergraduate agricultural students also identified a weak but positive correlation between these variables. These findings support the results of this pilot study and confirm the benefits of including both cognitive and affective learning outcomes in plant education.

Concept maps were used in this study to gain a deeper insight into students' comprehension of the complex process of the cooling role of plants. Although concept maps are considered a promising tool in science education (Ruiz-Primo & Shavelson, 1996; Choudhary & Bano, 2022), their application in this study also demonstrated several limitations. Despite prior agreements with teachers regarding students' familiarity with concept maps, the results reflected severe difficulties in their correct construction. Students lacked the necessary skills to structure meaningful connections among the concepts, which led to inconsistent and distorted outputs.

Although students were briefly familiarized with the process before the pre-test, it was not adequate to ensure credible outcomes. For future studies, it will be required to include an instructional block focused on developing concept mapping skills before data collection takes place. This finding is in line with recommendations by Ruiz-Primo & Shavelson (1996) emphasizing the need to train students in building concept maps in order to achieve valid and reliable results. While the method is extremely promising, the problems experienced in this study illustrate how a lack of preparation can reduce its utility as a research tool. These limitations should be carefully considered when interpreting the findings.

Despite these constraints, the use of concept maps in this pilot study identified gaps in student knowledge and gave valuable insight into instructional needs for this method. Future research should explore how concept mapping can be more effectively integrated into biology education, particularly in topics related to ecosystem services and plant awareness.

The findings of this study also align with broader educational concerns regarding plant blindness. Marcos-Walias et al. (2023) point out that, despite education, plant blindness persists, and students routinely fail to recognize or appreciate plant life. Their research in Spain showed that animals are far more likely to be recognized than plants, pointing to the importance of including learning experiences that increase both knowledge along with emotional engagement. The present study confirms this recommendation and supports the use of experiential and digitally supported learning as one possible tool for increasing plant awareness and reducing plant blindness.

In conclusion, this pilot study contributes to the understanding of how students' knowledge and attitudes towards plants can develop within an educational intervention, and it underlines the importance of methodological considerations when using tools such as concept maps. With suitable instructional support and well-designed interventions, such strategies can be instrumental in fostering both cognitive and affective aspects of plant literacy.

CONCLUSIONS

This pilot study aimed to evaluate the impact of different instructional approaches on students' knowledge and attitudes toward plants, with a specific focus on the cooling effect of plants, as a component of the broader phenomenon of plant blindness. The findings showed that both the control and experimental groups improved their knowledge after the intervention. However, a statistically significant improvement in attitudes was observed only in the experimental group, which was exposed to an innovative educational approach combining modern technologies and project-based learning. The findings suggest that although both traditional and modern methods can enhance students' knowledge, fostering positive attitudes towards plants may demand more immersive and student-driven instructional strategies. The experimental program appeared to support not only knowledge acquisition but also emotional engagement and relevance to students' lives — elements often emphasized in the literature on plant awareness (e.g. Thomas et al., 2022; Stagg & Dillon, 2022). Similar findings were reported by Gabela et al. (2022) and Dünser et al. (2024), who documented a positive relationship between students' knowledge and attitudes in contexts involving plant-related topics and ecosystem services. Although our data point to a weak correlation, it is important to consider that only the experimental group showed significant changes in both domains.

Although a weak but statistically significant correlation between knowledge and attitudes was observed overall, the results imply that such a relationship may only manifest when the educational approach effectively connects content with students' lived experiences. This aligns with previous research by Gabela et al. (2022) and Dünser et al. (2024), who reported a positive association between students' knowledge of ecosystem services and their attitudes toward plants. Moreover, Marcos-Walias et al. (2023) emphasize the persistent problem of plant blindness and advocate for instructional strategies that simultaneously foster plant interest and understanding, echoing the value of the experimental approach used in this study. Given the ongoing challenge of plant blindness, particularly in younger students, integrating innovative teaching strategies — such as those employed in the experimental program — may represent a promising direction for future interventions. These strategies, when aligned with national curricula, have the potential to enhance both plant literacy and appreciation of plants' ecological roles. Future studies should further refine these approaches and explore their long-term effects on students' perceptions and behaviours.

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LITERATURE

Amprazis, A., & Papadopoulou, P. (2020). Plant blindness: a faddish research interest or a substantive impediment to achieve sustainable development goals? *Environmental Education Research, 26*(2), 1-24.
https://doi.org/10.1080/13504622.2020.1768225

Balas, B., & Momsen, J. (2014). Attention "blinks" differently for plants and animals. *CBE—Life Sciences Education, 13*(3), 437-43.
https://doi.org/10.1187/cbe.14-05-0080

Balding, M., & Williams, K. J. H. (2016). Plant blindness and the implications for plant conservation. *Conservation Biology, 30*(6), 1192–1199.
https://doi.org/10.1111/cobi.12738

Choudhary, F., & Bano, R. (2022). Concept maps as an effective formative assessment tool in biology at the secondary level. *Journal of Education and Educational Development, 9*(1), 157-175.
https://doi.org/10.22555/joeed.v9i1.454

Dünser, B., Moeller, A., Fondriest, V., Boeckle, M., Lampert, P., & Pany, P. (2024). Attitudes towards plants – Exploring the role of plants' ecosystem services. *Journal of Biological Education, 59*(1), 124-138.
https://doi.org/10.1080/00219266.2024.2308293

Ellison, D., Morris, C. E., Locatelli, B., Sheil, D., Cohen, J., Murdiyarso, D., Gutierrez, V., Van Noordwijk, M., Creed, I. F., Pokorny, J., Gaveau, D., Spracklen, D., Tobella, A. B., Ilstedt, U., Teuling, A., Gebrehiwot, S. G., Sands, D. C., Muys, B., Verbist, B., … Sulivan, C. (2017). Trees, forests and water: Cool insights for a hot world. *Global Environmental Change, 43(51)*, 51-61.
https://doi.org/10.1016/j.gloenvcha.2017.01.002

European Commission. (2019). *The European Green Deal.* European Commission.
https://ec.europa.eu/green-deal

Gabela, C. D., Trejos, B., Jaramillo, P. L., & Boren-Alpizar, A. (2022). Sustainable agriculture: Relationship between knowledge and attitude among university students. *Sustainability, 14*(23).
https://doi.org/10.3390/su142315523

Jose, S. B., Wu, C.-H., & Kamoun, S. (2019). Overcoming plant blindness in science education and society. *Plants, People, Planet, 1*(3), 169-172.
https://doi.org/10.1002/ppp3.51

Kaur, D., & Zhao, Y. (2017). Development of physics attitude scale (PAS): An instrument to measure students' attitudes toward physics. *The Asia-Pacific Education Researcher, 26*(5), 291-304.
https://doi.org/10.1007/s40299-017-0349-y

Marcos-Walias, J., Bobo-Pinilla, J., Inglesias, J. D., & Reinoso-Tapia, R. (2023). Plant awareness disparity among students of different educational levels in Spain. *European Journal of Science and Mathematics Education, 11*(2), 234-248.
https://doi.org/10.30935/scimath/12570

Pany, P., Meier, F. D., Dünser, B., Yanagida, T., Kiehn, M., & Möller, A. (2022). Measuring students' awareness: A prerequisite for effective botany education. *Journal of Biological Education, 58*(5), 1103-1116.
https://doi.org/10.1080/00219266.2022.2159491

Parsley, K. M., Daigle, B. J., & Sabel, J. L. (2022). Initial development and validation of the plant awareness disparity index. *CBE – Life Sciences Education, 21*(4). https://doi.org/10.1187/cbe.20-12-0275

Ruiz-Primo, M. A., & Shavelson, R. J. (1996). Problems and issues in the use of concept maps in science assessment. *Journal of Research in Science Teaching, 33*(6), 569–600. https://doi.org/10.1002/(SICI)1098-2736(199608)33:6%3C569::AID-TEA1%3E3.0.CO;2-M

Ryplova, R., & Pokorny, J. (2018). Using project-based education to develop pre-service biology teachers' knowledge of the cooling effect of vegetation. In M. Rusek & K. Vojíř (Eds.), *Project-based Education and other activating strategies in Science Education XVI* (pp. 105–113). Pedagogická fakulta Univerzity Karlovy.

Ryplova, R., & Pokorny, J. (2020). Saving water for the future via increasing plant literacy of pupils. *European Journal of Sustainable Development, 9*(3), 313-323. https://doi.org/10.14207/ejsd.2020.v9n3p313

Ryplova, R., Pokorny, J., & Baxa, M. (2023). Education for sustainability: Innovative teaching on photosynthesis of aquatic plants in ecological context. *European Journal of Sustainable Development, 12*(4), 69-82. https://doi.org/10.14207/ejsd.2023.v12n4p69

Stagg, B. C., & Dillon, J. (2022). Plant awareness is linked to plant relevance: A review of educational and ethnobiological literature (1998–2020). *Plants, People, Planet, 4*(6), 579–592. https://doi.org/10.1002/ppp3.10323

Thomas, H., Ougham, H., & Sanders, D. (2022). Plant blindness and sustainability. *International Journal of Sustainability in Higher Education, 23*(1), 41–57. https://doi.org/10.1108/IJSHE-09-2020-0335

United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development.* United Nations.

Uno, G. E. (2009). Botanical literacy: What and how should students learn about plants. *American Journal of Botany, 96*(10), 1753-1759. https://doi.org/10.3732/ajb.0900025

Wandersee, J. H. (1986). Plant or animals—which do junior high school students prefer to study? *Journal of Research in Science Teaching, 23*(5), 415-426. https://doi.org/10.1002/tea.3660230504

Wandersee, J. H., & Schussler, E. E. (1999). Preventing plant blindness. *The American Biology Teacher, 61*(2), 84-86. https://doi.org/10.2307/4450624

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School Principals' Perspectives on the Role of Artificial Intelligence in Education

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Abstract

This study examines school principals' general attitudes towards artificial intelligence (AI). A survey model, one of the quantitative research methods, was used in the study. The sample consists of 82 school principals working in an international private school chain. The general Attitudes Toward Artificial Intelligence scale developed by Schepman and Rodway (2020) was used as a data collection tool in the study. The collected data were analysed descriptively. Frequency tables were created for school principals' responses to the items. School principals frequently expressed positive views on certain aspects of AI. However, they showed greater hesitation when it came to items comparing humans with AI. While many principals acknowledged some negative aspects of AI, they largely disagreed with the notion that AI is inherently dangerous. At the same time, they expressed concerns about AI's potential to violate human privacy. These findings suggest that school principals' perceptions of AI are nuanced, reflecting a balance of both positive and negative views influenced by the specific context of each question.

Keywords

Artificial intelligence; AI; attitudes toward AI; school principals

INTRODUCTION

The use of artificial intelligence (AI) powered educational technologies has increased in recent years. In many countries worldwide, including China, the US, and South Korea, efforts are being made to integrate AI into the K-12 curriculum (Steinbauer et al., 2021). These efforts have led researchers to investigate the effectiveness of AI-supported technologies at many different points in the learning and education processes (Elmas et al., 2024). Researchers are exploring various applications of AI technologies in education, including adaptive learning (Minn, 2022; Kabudi et al., 2021), scaffolded learning (Gobert et al., 2024; Kim et al., 2022), personalized learning (Pratama et al., 2022; Somasundaram et al., 2020), automated feedback systems (Naseer et al., 2024; Yang et al., 2024), classroom management and planning (Yugandhar & Rao, 2024), and measurement and evaluation processes (Owan et al., 2023; Khan et al., 2021). Considering the potential of AI tools to enable students to participate in their own learning process actively, it is closely compatible with project-based education. AI tools are valuable in facilitating students ' research processes, especially in project-based environments focused on STEAM (Science, Technology, Engineering, Arts, and Mathematics). Considering all these research studies and trends, integrating AI into education has become an increasingly popular subject (Bulus & Elmas, 2024). In this regard, it is necessary to evaluate the perspectives of teachers, students, school principals, and parents regarding the use of AI in education. There are various studies related to AI conducted with teachers (Park et al., 2023; Lin et al., 2022; Lindner & Romeike, 2019), pre-service teachers (Pokrivcakova, 2024; Sanusi et al., 2024; Zhang et al., 2023), and students (Przybyła-Kasperek, 2023; Shin et al., 2018). However, the number of studies conducted with school principals is relatively low. Principals are crucial change agents (Fios et al., 2024) in encouraging educational reform and innovation. Given the role of school principals in integrating educational technologies into the classroom, more studies are needed to determine their perspectives. Indeed, according to Waxman et al. (2013), school principals' perceptions of technology can affect the success of embedding these applications in practice. According to Tołwińska (2021), school principals who use digital technologies and integrate them into their profession play a key role in integrating these applications into the school environment. Gulpan and Raja (2020) emphasized that leading the use of AI is expected from school principals more than curricular leadership. Accordingly, it can be said that the principal is a vital facilitator in the drive to incorporate technology into the school. Indeed, evaluating the relationship between school principals' attitudes and student achievement, as well as overall school performance (Shen et al., 2021; Sebastian et al., 2016; Wu et al., 2020) highlights the importance of principals' attitudes toward AI. To address this gap, this study examined school principals' general attitudes toward AI. Given the key role of principals in the school ecosystem, their perspectives on AI

Table 1: Demographic information about science teachers.

School Principals	Variable	N
Gender	Male	52
	Female	29
Region	Asia Pacific	25
	Africa (Francophone)	18
	Europe	15
	Africa (Anglo-Saxon)	14
	Middle East	9
Education Level	4 Year University	49
	Master's Degree	27
	Doctorate – PhD	5
Years of Experience	0–10	58
	11–20	18
	21–30	3
	31 and above	2
International Accreditation System Experience	Yes	29
	No	52

technologies can directly impact the integration of AI technologies into educational environments designed for both STEM Education and Project-Based Education Approaches. Understanding principals' perspectives toward AI is essential for effectively integrating AI tools into academic environments.

METHODOLOGY

In this study, a descriptive research design, one of the qualitative research designs, was used. Descriptive research provides a general picture of the need, subject, or phenomenon under consideration (Willis et al., 2016).

Sample

The study research group consists of 82 school principals working in different regions. Table 1 shows demographic information about school principals.

Data collection tools

The General Attitudes Toward Artificial Intelligence Scale (GAAIS), developed by Schepman & Rodway (2020), was used as a data collection tool. Permission to use the scale has been granted. The scale includes twelve positively and eight negatively worded items. The scale consists of 20 items and is a 5-point Likert-type scale (strongly disagree, disagree, neutral, agree, strongly agree). The scale exhibited strong internal consistency reliability, with a = 0.88 for Positive GAAIS and a = 0.83 for Negative GAAIS (Schepman & Rodway, 2020).

Data analysis

The scale items were transferred to Google Forms and sent to school principals via Google Forms, emails, and group messaging. The collected data were analysed using frequency analysis and demographic data. A frequency table was created for school principals' responses to the items.

RESULTS

The research analysed the general attitudes of the school principals toward AI. The results are shown below. The Figure 1 shows that the school principal endorsed some positive items with high frequency. However, the school principals were more reluctant to endorse AI for items comparing humans with AI. It is seen (Figure 2) that school administrators mostly agreed with some of the negative items related to AI. However, while they mostly disagreed with the item stating that AI is dangerous, they agreed with the possibility of AI taking control of the population.

	DISAGREE (f)	NEUTRAL (f)	AGREE (f)
FOR ROUTINE TRANSACTIONS, I WOULD RATHER INTERACT WITH AN ARTIFICIALLY INTELLIGENT SYSTEM THAN WITH A HUMAN.	29	33	20
ARTIFICIAL INTELLIGENCE CAN PROVIDE NEW ECONOMIC OPPORTUNITIES FOR THIS COUNTRY.	10	22	50
ARTIFICIALLY INTELLIGENT SYSTEMS CAN HELP PEOPLE FEEL HAPPIER.	18	29	35
I AM IMPRESSED BY WHAT ARTIFICIAL INTELLIGENCE CAN DO.	10	19	53
I AM INTERESTED IN USING ARTIFICIALLY INTELLIGENT SYSTEMS IN MY DAILY LIFE.	22	24	36
ARTIFICIAL INTELLIGENCE CAN HAVE POSITIVE IMPACTS ON PEOPLE'S WELLBEING.	12	34	36
ARTIFICIAL INTELLIGENCE IS EXCITING.	8	13	61
AN ARTIFICIALLY INTELLIGENT AGENT WOULD BE BETTER THAN AN EMPLOYEE IN MANY ROUTINE JOBS.	29	28	25
THERE ARE MANY BENEFICIAL APPLICATIONS OF ARTIFICIAL INTELLIGENCE.	11	17	54
ARTIFICIALLY INTELLIGENT SYSTEMS CAN PERFORM BETTER THAN HUMANS.	29	25	28
MUCH OF SOCIETY WILL BENEFIT FROM A FUTURE FULL OF ARTIFICIAL INTELLIGENCE	14	19	49
I WOULD LIKE TO USE ARTIFICIAL INTELLIGENCE IN MY OWN JOB.	14	28	40

Figure 1: The frequency of responses to positive statements in the General Attitudes to Artificial Intelligence Scale.

	DISAGREE (f)	NEUTRAL (f)	AGREE (f)
ORGANIZATIONS USE ARTIFICIAL INTELLIGENCE UNETHICALLY.	22	36	24
I THINK ARTIFICIALLY INTELLIGENT SYSTEMS MAKE MANY ERRORS.	30	32	20
I FIND ARTIFICIAL INTELLIGENCE SINISTER.	34	34	14
ARTIFICIAL INTELLIGENCE MIGHT TAKE CONTROL OF PEOPLE.	27	26	29
I THINK ARTIFICIAL INTELLIGENCE IS DANGEROUS.	37	25	20
I SHIVER WITH DISCOMFORT WHEN I THINK ABOUT FUTURE USES OF ARTIFICIAL INTELLIGENCE.	27	28	27
PEOPLE LIKE ME WILL SUFFER IF ARTIFICIAL INTELLIGENCE IS USED MORE AND MORE.	36	30	26
ARTIFICIAL INTELLIGENCE IS USED TO SPY ON PEOPLE.	21	26	35

Figure 2: The frequency of responses to negative statements in the General Attitudes to Artificial Intelligence Scale

DISCUSSION AND CONCLUSION

The survey revealed that school principals commonly backed positive items. These results indicate that school principals' positive perceptions of educational technologies can be a potential support element in the integration process of AI technologies. These results are seen as valuable in the context of their facilitating role in integrating artificial intelligence technologies into the educational environment.

Chang (2012) discovered that school principals' technological leadership encourages teachers to integrate technology into their practice. Laouni (2023) found a moderate relationship between the level of technology integration in education and the self-efficacy of school principals. Hao et al. (2021) examined school principals' willingness to adopt AI training. The study found that school principals can adopt AI education, but only

16.3 % of schools have implemented AI education. There is a contradiction between a high willingness to adapt and a low development rate.

The research also revealed that school principals are hesitant to approve things that compare humans to AI. This situation is thought to be because AI is a new concept, and school principals mostly do not have enough knowledge and competency related to this subject. Afshari et al. (2019) revealed that school principals have moderate levels of information technology competency. Cheng & Wang (2023) conducted a study with school principals and management-level teachers to examine the barriers to teachers in Hong Kong incorporating AI into primary education.

They emphasize that internal and external barriers (unclear curriculum guidelines, ethical concerns, limited technological resources, teachers' perceptions, attitudes, pedagogical beliefs, and confidence levels) significantly affect the use of AI. Tyson & Sauers (2021) wanted to look at how school leaders adopted and used AI technology in their schools. They used ALEKS as an AI tool. They found that school principals actively participated in discussions about adopting and implementing AI. The leaders realized that many of their students, staff, and parents had been extensively exposed to technology. When describing implementation, one school principal contended, "if the quality isn't there, if the interface is weird or it looks sold, or if it looks too generic."

In conclusion, the study's findings indicate that comprehensive training programs for school principals and teachers are crucial to empower them with the skills to utilize AI tools effectively. School principals must be equipped to guide classroom practices with these technologies.

Furthermore, collaboration and continued research are essential for effectively integrating AI applications in education. As key leaders in the education system, school principals play a pivotal role in shaping the adoption and implementation of AI technologies. Their attitudes, awareness, and willingness to engage with AI-driven innovations can significantly influence the broader school community, including teachers, students, and parents. Therefore, targeted professional development programs and initiatives are crucial to increase school principals' understanding of AI. AI's role in enhancing educational outcomes and transforming the education system can be significantly strengthened by fostering awareness among all stakeholders, especially school principals. The findings of this study are based solely on the perceptions of the school principals in the sample. The results need to be supported by studies conducted in different regions and with larger samples to make broader generalizations.

LITERATURE

Afshari, M., Bakar, K. A., Luan, W. S., Samah, B. A., & Fooi, F. S. (2009). Technology and school leadership. *Technology, Pedagogy and Education, 18*(2), 235-248. https://doi.org/10.1080/14759390902992527

Bulus, B., & Elmas, R. (2024). The use of artificial intelligence applications as alternative tools in chemistry education. *Journal of Turkish Chemical Society Section C: Chemistry Education, 9*(1), 1-28. https://doi.org/10.37995/jotcsc.1366999

Chang, I. H. (2012). The effect of principals' technological leadership on teachers' technological literacy and teaching effectiveness in Taiwanese elementary schools. *Journal of Educational Technology & Society, 15*(2), 328-340.

Cheng, E. C. K., & Wang, T. (2023). Leading digital transformation and eliminating barriers for teachers to incorporate artificial intelligence in basic education in Hong Kong. *Computers and Education: Artificial Intelligence, 5*, 100171. https://doi.org/10.1016/j.caeai.2023.100171

Elmas, R., Adiguzel-Ulutas, M., & Yılmaz, M. (2024). Examining ChatGPT's validity as a source for scientific inquiry and its misconceptions regarding cell energy metabolism. *Education and Information*

Technologies, 29, 25427–25456.
https://doi.org/10.1007/s10639-024-12749-1

Fios, F., Marzuki, M., Ibadurrahman, I., Renyaan, A. S., & Telaumbanua, E. (2024). Innovative leadership strategies for school principals: Building a holistic educational environment focused on student achievement in the era of technology and globalization. *International Journal of Teaching and Learning, 2*(1), 266-281.

Gobert, J. D., Li, H., Dickler, R., & Lott, C. (2024). Can AI-based scaffolding promote students' robust learning of authentic science practices? In X. Zhai & J. Krajcik (Eds.), *Uses of artificial intelligence in STEM education* (pp. 250–268). Oxford University Press.

Gulpan, J., & Baja, R. M. (2020). Technological leadership of 21st century principals of private secondary schools. *International Journal of Advances Research and Publications, 4*(4), 66-69.

Hao, Z., Miao, E., & Yan, M. (2021, December). Research on school principals' willingness to adopt artificial intelligence education and related influencing factors. In 2021 Tenth International Conference of Educational Innovation through Technology (EITT) (pp. 356-361). IEEE.
https://doi.org/10.1177/02666669241257206

Kabudi, T., Pappas, I., & Olsen, D. H. (2021). AI-enabled adaptive learning systems: A systematic mapping of the literature. *Computers and Education: Artificial Intelligence, 2*, 100017.
https://doi.org/10.1016/j.caeai.2021.100017

Khan, I., Ahmad, A. R., Jabeur, N., & Mahdi, M. N. (2021). An artificial intelligence approach to monitor student performance and devise preventive measures. *Smart Learning Environments, 8*(1), 1-18.
https://doi.org/10.1186/s40561-021-00161-y

Kim, M. K., Kim, N. J., & Heidari, A. (2022). Learner experience in artificial intelligence-scaffolded argumentation. *Assessment & Evaluation in Higher Education, 47*(8), 1301-1316.

Laouni, N. (2023). School principals' self-efficacy beliefs and level of technology integration in Moroccan public schools. *International Journal of Educational Leadership and Management, 11*(1), 25-61.
http://dx.doi.org/10.17583/ijelm.2023.9154

Lin, X. F., Chen, L., Chan, K. K., Peng, S., Chen, X., Xie, S., ... & Hu, Q. (2022). Teachers' perceptions of teaching sustainable artificial intelligence: A design frame perspective. *Sustainability, 14*(13), 7811.
https://doi.org/10.1080/02602938.2022.2042792

Lindner, A., & Romeike, R. (2019). Teachers' perspectives on artificial intelligence. In E. Jasutė & S. Pozdniakov (Eds.), *Informatics in schools: Situation, evolution, and perspectives* (pp. 22–29). Springer.

Minn, S. (2022). AI-assisted knowledge assessment techniques for adaptive learning environments. *Computers and Education: Artificial Intelligence, 3*, 100050.
https://doi.org/10.1016/j.caeai.2022.100050

Naseer, F., Khalid, M. U., Ayub, N., Rasool, A., Abbas, T., & Afzal, M. W. (2024). Automated assessment and feedback in higher education using generative AI. In R. C. Sharma & A. Bozkurt (Eds.), *Transforming education with generative AI: Prompt engineering and synthetic content creation* (pp. 433–461). IGI Global.

Owan, V., Abang, K. B., Idika, D. O., Etta, E. O., & Bassey, B. A. (2023). Exploring the potential of artificial intelligence tools in educational measurement and assessment. *EURASIA Journal of Mathematics, Science and Technology Education, 19*(8), 1-15.
https://doi.org/10.29333/ejmste/13428

Park, J., Teo, T. W., Teo, A., Chang, J., Huang, J. S., & Koo, S. (2023). Integrating artificial intelligence into science lessons: Teachers' experiences and views. *International Journal of STEM Education, 10*(1), 61.
https://doi.org/10.1186/s40594-023-00454-3

Pokrivcakova, S. (2024). Pre-service teachers' attitudes towards artificial intelligence and its integration into EFL teaching and learning. *Journal of Language and Cultural Education, 11*(3), 100-114.
https://doi.org/10.2478/jolace-2023-0031

Pratama, M. P., Sampelolo, R., & Lura, H. (2023). Revolutionizing education: Harnessing the power of artificial intelligence for personalized learning. *Klasikal: Journal of Education, Language Teaching and Science, 5*(2), 350-357.
https://doi.org/10.52208/klasikal.v5i2.877

Przybyła-Kasperek, M. (2023). Factors enhancing students' views on artificial intelligence. *International Journal of Research in E-learning, 9*(2), 1-42.
https://doi.org/10.31261/IJREL.2023.9.2.03

Sanusi, I. T., Ayanwale, M. A., & Tolorunleke, A. E. (2024). Investigating pre-service teachers' artificial intelligence perception from the perspective of planned behavior theory. *Computers and Education: Artificial Intelligence, 6*, 100202.
https://doi.org/10.1016/j.caeai.2024.100202

Schepman, A., & Rodway, P. (2020). Initial validation of the general attitudes towards artificial intelligence scale. *Computers in Human Behavior Reports, 1*, 100014.
https://doi.org/10.1016/j.chbr.2020.100014

Sebastian, J., Allensworth, E., & Huang, H. (2016). The role of teacher leadership in how principals influence classroom instruction and student learning. *American Journal of Education, 123*(1), 69-108.
https://doi.org/10.1086/688169

Shen, J., Ma, X., Mansberger, N., Wu, H., Palmer, L. A. B., Poppink, S., & Reeves, P. L. (2021). The relationship between growth in principal leadership and growth in school performance: The teacher perspective. *Studies in Educational Evaluation, 70*, 101023.
https://doi.org/10.1016/j.stueduc.2021.101023

Shin, S., Ha, M., & Lee, J. K. (2018). Exploring elementary school students' image of artificial intelligence. *Journal of Korean Elementary Science Education, 37*(2), 126-146.
https://doi.org/10.15267/keses.2018.37.2.126

Somasundaram, M., Junaid, K. A. M., & Mangadu, S. (2020). Artificial intelligence (AI) enabled intelligent quality management system (IQMS) for personalized learning path. *Procedia Computer Science, 172*, 438-442.
https://doi.org/10.1016/j.procs.2020.05.096

Steinbauer, G., Kandlhofer, M., Chklovski, T., Heintz, F., & Koenig, S. (2021). A differentiated discussion about AI education K-12. *Kunstliche Intelligenz, 35*(2), 131-137.
https://doi.org/10.1007/s13218-021-00724-8

Tołwińska, B. (2021). The role of principals in learning schools to support teachers' use of digital technologies. *Technology, Knowledge and Learning, 26*(4), 917-930.
https://doi.org/10.1007/s10758-021-09496-4

Tyson, M. M., & Sauers, N. J. (2021). School leaders' adoption and implementation of artificial intelligence. *Journal of Educational Administration, 59*(3), 271-285.
https://doi.org/10.1108/JEA-10-2020-0221

Waxman, H. C., Boriack, A. W., Lee, Y. H., & MacNeil, A. (2013). Principals' perceptions of the importance of technology in schools. *Contemporary Educational Technology, 4*(3), 187-196. https://doi.org/10.30935/cedtech/6102

Willis, D. G., Sullivan-Bolyai, S., Knafl, K., & Cohen, M. Z. (2016). Distinguishing features and similarities between descriptive phenomenological and qualitative description research. *Western Journal of Nursing Research, 38*(9), 1185-1204. https://doi.org/10.1177/0193945916645499

Wu, H., Shen, J., Zhang, Y., & Zheng, Y. (2020). Examining the effect of principal leadership on student science achievement. *International Journal of Science Education, 42*(6), 1017-1039. https://psycnet.apa.org/doi/10.1080/09500693.2020.1747664

Yang, H., Gao, C., & Shen, H. Z. (2024). Learner interaction with, and response to, AI-programmed automated writing evaluation feedback in EFL writing: An exploratory study. *Education and Information Technologies, 29*(4), 3837-3858. https://doi.org/10.1007/s10639-023-11991-3

Yugandhar, K., & Rao, Y. R. (2024). Artificial intelligence in classroom management: Improving instructional quality of English class with AI tools. *Educational Administration: Theory and Practice, 30*(4), 2666-2672. https://doi.org/10.53555/kuey.v30i4.1914

Zhang, C., Schießl, J., Plößl, L., Hofmann, F., & Gläser-Zikuda, M. (2023). Acceptance of artificial intelligence among pre-service teachers: A multigroup analysis. *International Journal of Educational Technology in Higher Education, 20*(1), 49. https://doi.org/10.1186/s41239-023-00420-7

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The impact of using the interactive electronic textbook Biomass in Sustainable Landscapes on secondary school students

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Abstract

This study describes the results of the impact of the e-textbook Biomass in Sustainable Landscapes in a secondary school. From a cognitive perspective, the impact of the textbook on the development of knowledge of photosynthetic biomass production, energy flows and ecological contexts was evaluated. The evaluation also focused on validating the affective goals of education. The investigation was conducted in three secondary schools, and 185 second-year students participated. Data collection was based on a controlled pre-test - post-test system. The results indicate that the electronic textbook is a suitable supplement in teaching photosynthetic issues to achieve cognitive but mainly affective learning objectives.

Keywords

E-textbook; biomass; photosynthesis; secondary school

INTRODUCTION

Biomass is all organic matter derived from the bodies of living organisms, i.e. plants, animals, fungi or micro-organisms. Plant biomass production is closely linked to photosynthesis, which is rightly considered one of the most important processes on planet Earth. Research conducted in primary and secondary school settings shows that students' knowledge of these issues is not very high (Vidal & Membiel, 2014). Teaching involving photosynthetic issues is even considered one of the critical points in the biology curriculum from the perspective of both students and teachers (Vágnerová et al., 2019). It is one of the most challenging topics in biology (Carlson, 2002). In the course of teaching, students' misconceptions are often formed, including, for example: the main principle of photosynthesis is the production of oxygen (Köse, 2008; Ryplová, 2014); photosynthesis is the respiration of plants (Keleş & Kefeli, 2010); plants take in food from the soil (Köse, 2008); or plants only breathe at night when no light is available (Al Olaimat, 2010). Students often do not enjoy teaching about similar topics because it is too abstract for them (Martín-López et al., 2007; Fančovičová & Prokop, 2010; Jose et al., 2019). Previous didactic work has pointed out that the use of activating interdisciplinary approaches (currently, e.g. STEM - Science, Technology, Engineering and Mathematics) can have a significant impact on increasing the attractiveness of botanical topics by reducing the abstraction of the curriculum through the implication of examples from practical and everyday life, increased interaction with model natural environments, or the use of a variety of computer technology and adequate applications (Lohr & Pearsoon-Mins, 2005; Balding & Williams, 2016; Robinson et al., 2016). The newly developed interactive textbook Biomass in Sustainable Landscapes was incorporated into the teaching process for this research (Ryplová et al., 2023). Electronic texts have several advantages over printed texts, including interactivity that allows live podcasts, hyperlinks, audio-visual elements, simulations of phenomena or events, and various quizzes. Including QR codes is also popular (Millar & Schreier, 2015). Another benefit of e-textbooks is that learners are routinely sent additional supplementary information about the topic at the click of a button, which can be particularly beneficial for engaged learners (Dobler, 2015). The use of electronic textbooks has been steadily increasing over the last decade (Rodríguez-Regueira & Rodríguez-Rodríguez, 2022). The disadvantages of electronic interactive resources include that they cannot be used in education without the need for exceptional reading equipment or specific software (Bouck et al., 2016), which can be very costly and often unaffordable for schools. Software also becomes rapidly obsolete and needs to be upgraded (Lee et al., 2013).

MAIN GOAL

The main goal of this study was to test, through a controlled experiment, the effect of using an electronic textbook on the development of cognitive and affective goals of secondary school students in photosynthetic biomass production, energy flows and their ecological context. The authors' partial goal was to make the discussed topic more attractive to students. For this reason, an electronic textbook with interactive content was included in the teaching, which contains several interdisciplinary overlaps between biology, chemistry, physics, mathematics and environmental science.

METHODOLOGY

The Research Process

The e-textbook was first piloted with 451 lower secondary and 128 secondary school students (Chmelová et al., 2023, Vácha et al., 2023). At the same time, practising teachers commented on the text and the graphic design. Based on the feedback from the described investigations, the final version of the textbook was created (available from `https://fotosyntezavkrajine.cz/`).

Data were collected through a controlled experiment. The research investigation was conducted in three secondary schools that expressed interest in participating in the testing. Thus, it was an 'available sample' of respondents (Skutil, 2011), which may represent a limiting factor of the research, and the results obtained cannot be fully generalized. The research included two classes of second graders at each school - an experimental group (N = 94) and a control group (N = 91). A total of 185 pupils participated in the research. The lessons in both groups lasted three lessons and were taught by the same teacher.

Before the actual teaching, the pupils were always given a pre-test to determine the starting level of their knowledge. The topics covered were photosynthetic biomass production, energy flows and their ecological context. Based on the pre-test results, two homogeneous groups were formed in each school and then subjected to the experiment. In the experimental group, the teaching was carried out using an electronic textbook; students had tablets and could use individual interactive schemes within the education. In the control group, typical conventional teaching was carried out using a regular printed textbook and pictures in the presentation, which provided more space for frontal teaching by the teacher. Immediately after the end of the lesson, the students were tested using a uniform knowledge test (post-test), which was identical to the pre-test. One more post-test, retention test, was included in the experiment and was implemented 2 weeks after the teaching. The knowledge tests contained nine questions (the maximum test score was 19). The test questions were validated before use through a pilot survey involving 53 second-year secondary school students. The items were then edited into their final form. A Likert-type questionnaire was used to verify the achievement of affective goals as part of the post-test 1. The questionnaire contained two subjective items: (1) I enjoyed today's teaching, and (2) I would include a similar type of teaching more often (repeatedly). In addition, students in the experimental group could verbally express the positives and negatives of the electronic textbook.

Data analysis

The impact of teaching using the e-textbook on student knowledge was evaluated using Mann Whitney U test, utilising group (experimental versus control) as a variable. To compare the differences in knowledge level among pre-tests, post-test1 and post-tests2 of the experimental and control group, the Wilcoxon test was used. Students' Likert scale assessment of their subjective enjoyment and willingness to learn using the same approach were evaluated using a t-test for independent samples. These parametric tests were selected for analysis due to their robustness, as proven by previous research (Carifio & Perla, 2008; Norman, 2010; Blanca et al., 2023).

RESULTS

Based on the pre-test results, it can be concluded that students of both groups entered the study with the same level of knowledge. No significant differences between the mean pre-test score of control (mean score 6.47 ± 0.23 St. dev.) and experimental (mean score 6.38 ± 0.22 St. dev.) were found using the Mann Whitney U test ($Z = -0.22932$, $p = 0.9817$). Wilcoxon tests indicated significant increase in the mean scores of the knowledge tests in pre-test 1 of the control (mean score 13.01 ± 0.41 St. dev., $p < 0.001$) as well as the experimental group (mean score 13.57 ± 0.4 St. dev., $p < 0.001$). After two weeks, post-test 2 values revealed a statistically significant decrease in knowledge compared to post-test 1 in both groups (control group mean score 11.58 ± 0.41 St. dev., $p < 0.001$, experimental group mean score 12.00 ± 0.4 St. dev. $p < 0.001$). Despite the mean test scores of the experimental group being slightly higher in both post-tests compared to the control group, the differences were not statistically significant ($Z = 0.124$, $p = 0.900$ for post-test 1, $Z = 0.869$, $p = 0.384$ for post-test 2) – Figure 1.

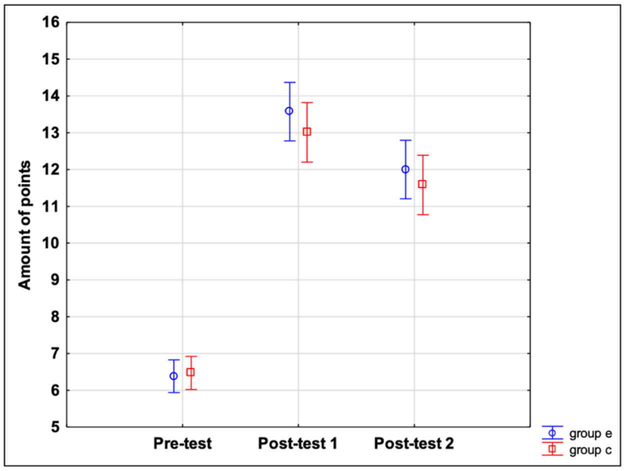

Figure 1: Analysis of students' knowledge as influenced by teaching utilizing new interactive e-book (group e = experimental group, group c = control group). Mean test score values, line segments = 1.96*St. Dev., N = 185).

The students of the experimental group assessed their subjective enjoyment of teaching using the interactive e-book significantly better (Median 2, Mean 2.11 ± 1.03 Std. dev.) than the control group (Median 3, Mean 2.92 ± 1.09 St. dev.) and the differences between both groups were statistically significant ($t = -5.24$, $p < 0.001$) – Figure 2. Students consider interactive animations, diagrams, clarity, a more enjoyable learning style, and the ecological aspect of the textbook and its connection to real life to be the main positives of the e-textbook. Among the negatives was that too much technical terminology appears in the text or that they prefer a paper textbook.

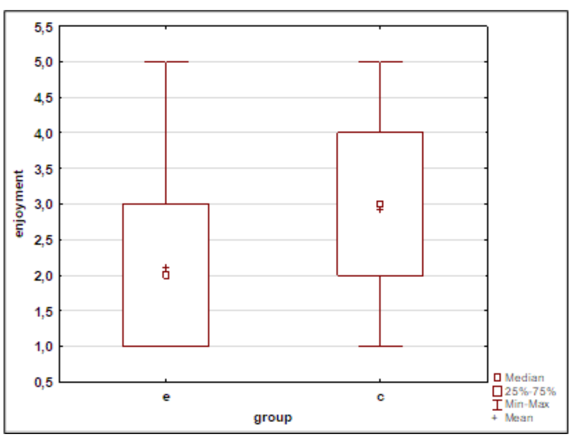

Figure 2: Subjective assessment of students' enjoyment of teaching, 5 grade Likert scale (school-like assessment, 1= excellent, 5= inadequate), e= experimental group, c = control group, N = 185.

Also, the willingness to undergo the same type of learning was higher in the case of the experimental group using the interactive e-book (Median 2, Mean 2.25 ± 1.1 Std. Dev.) compared to the control group taught by conventional teaching (Median 3, Mean 3.19 ± 1.14 Std. Dev.) Student t-test of independent samples revealed a statistically significant difference among both groups ($t = -5.65$, $p < 0.001$) – Figure 3.

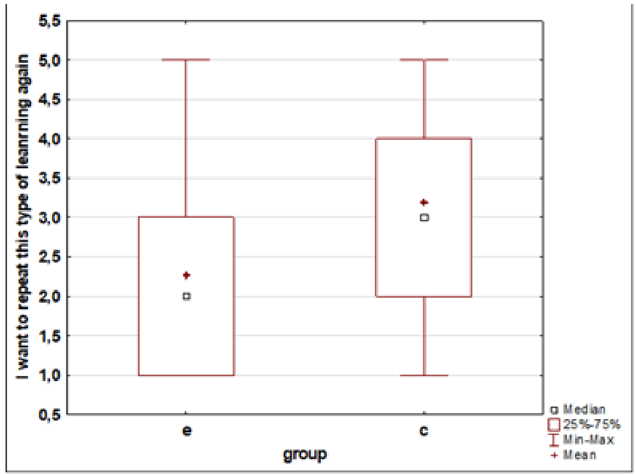

Figure 3: Subjective assessment of students' willingness to learn by the same way of teaching, 5 grade Likert scale, 1 = definitely yes, 5 = definitely no, e= experimental group, c = control group, N = 185.

CONCLUSION

A controlled experiment was used to test the impact of an electronic textbook, Biomass in Sustainable Landscapes, on cognitive and affective goal development in second-year secondary school students. The results show a statistically significant increase in knowledge in both control and experimental groups.

Statistically significant differences in the formation of affective goals were observed between the tested groups. The students found the lessons in which the electronic textbook and tablets were more enjoyable. On the other hand, in the control group, where conventional teaching using a frontal approach, picture presentation, and a printed textbook took place, the participating pupils did not enjoy the teaching so much (see Figure 2). Similar results can be seen if the pupils would like to receive a similar type of teaching more often (see Figure 3). Pupils in the experimental group wanted to receive similar teaching more often than pupils in the control group. Again, the differences between the groups are statistically significant.

We can debate whether it is more important to emphasize results or fun in teaching. However, it is indisputable that factual knowledge is one of the fundamental pillars that also influence students' interest and attitudes towards different topics (e.g. Kubiatko et al., 2021) or Nyberg and Sanders (2014). So, it is essential to strike a balance between facts and fun. This fact can be one way of making topics that are primarily uninteresting and abstract to students more attractive. Of course, the learning environment in which the learning takes place and the tools available to students are also important (Rusek et al., 2017). In this case, linking tablets with an interactive electronic textbook proved a good idea. The incorporation of various activating teaching strategies, which certainly include the use of computer technology, can positively affect the growing interest in even primarily unpopular botanical topics.

LITERATURE

Al Olaimat, M. (2010). The contribution of conceptual change texts accompanied by concept mapping to eleventh-grade students understanding of cellular respiration concepts. *Journal of Science Education and Technology, 19*(2), 115-125.
`https://doi.org/10.1007/s10956-009-9185-z`

Balding, M., & Williams, K. J. (2016). Plant blindness and the implications for plant conservation. *Conservation Biology, 30*(6), 1192–1199.
`https://doi.org/10.1111/cobi.12738`

Blanca, M. J., Arnau, J., García-Castro, F. J., Alarcón, R., & Bono, R. (2023). Non-normal data in repeated

measures ANOVA: Impact on type I error and power. *Psicothema, 35*, 21-29.
https://doi.org/10.7334/psicothema2022.292

Bouck, E. C., Weng, P., & Satsangi, R. (2016). Digital versus traditional: Secondary students with visual impairments' perceptions of a digital algebra textbook. *Journal of Visual Impairment & Blindness, 110*(1), 41–52.
https://doi.org/10.1177/0145482X1611000105

Carifio, J., & Perla, R. J. (2008). Resolving the 50-year debate around using and misusing Likert scales. *Medical Education, 42*, 1150–1152.
https://doi.org/10.1111/j.1365-2923.2008.03172.x

Carlsson, B. (2002). Ecological understanding 1: Ways of experiencing photosynthesis. *International Journal of Science Education, 24*, 681–699.
https://doi.org/10.1080/09500690110098868

Dobler, E. (2015). E-textbooks. *Journal of Adolescent & Adult Literacy, 58*(6), 482–491.
https://doi.org/10.1002/jaal.391

Fančovičová, J., & Prokop, P. (2011). Plants have a chance: Outdoor educational programmes alter students' knowledge and attitudes towards plants. *Environmental Education Research, 17*(4), 537–551.
https://doi.org/10.1080/13504622.2010.545874

Chmelová, Š., Ryplová, R., Vácha, Z., Brčáková, R., & Novák, M. (2023). Testování interaktivní učebnice pro výuku fotosyntézy na základních školách. In R. Ryplová & T. Brčáková (Eds.), *Biomasa v trvale udržitelné krajině – digitální technologie, aktuální trendy a výzvy ve výuce* (pp. 55-61). Jihočeská univerzita.

Jose, S. B., Wu, C. H., & Kamoun, S. (2019). Overcoming plant blindness in science, education, and society. *Plants, People, Planet, 1*(3), 169–172.
https://doi.org/10.1002/ppp3.51

Keleş, E., & Kefeli, P. (2010). Determination of student misconceptions in "photosynthesis and respiration" unit and correcting them with the help of CAI material. *Procedia-Social and Behavioral Sciences, 2*(2), 3111-3118.
https://doi.org/10.1016/j.sbspro.2010.03.474

Köse, S. (2008). Diagnosing student misconceptions: Using drawings as a research method. *World Applied Sciences Journal, 3*(2), 283-293.

Kubiatko, M., Fančovičová, J., & Prokop, P. (2021). Factual knowledge of students about plants is associated with attitudes and interest in botany. *International Journal of Science Education, 43*(9), 1426-1440.
https://doi.org/10.1080/09500693.2021.1917790

Lee, H. J., Messom, C., & Yau, K. A. (2013). Can an electronic textbook be part of K-12 education? Challenges, technological solutions and open issues. *Turkish Online Journal of Educational Technology – TOJET, 12*(1), 32–44.

Lohr, V. I., & Pearson-Mims, C. H. (2005). Children's active and passive interactions with plants influence their attitudes and actions toward trees and gardening as adults. *Hort Technology, 15*(3), 472–476.
https://doi.org/10.21273/HORTTECH.15.3.0472

Martín-Lopez, B., Montes, C., Ramírez, L., & Benayas, J. (2009). What drives policy decision-making related to species conservation? *Biological Conservation, 142*(7), 1370–1380.
https://doi.org/10.1016/j.biocon.2009.01.030

Millar, M., & Schrier, T. (2015). Digital or printed textbooks: Which do students prefer and why? *Journal of Teaching in Travel & Tourism, 15*(2), 166–185. https://doi.org/10.1080/15313220.2015.1026474

Norman, G. (2010). Likert scales, levels of measurement and the "laws" of statistics. *Advances in Health Sciences Education, 15*, 625-632. https://doi.org/10.1007/s10459-010-9222-y

Nyberg, E., & Sanders, D. (2014). Drawing attention to the 'green side of life'. *Journal of Biological Education, 48*(3), 142–153. https://doi.org/10.1080/00219266.2013.849282

Robinson, B. S., Inger, R., & Gaston, K. J. (2016). A rose by any other name: Plant identification knowledge & socio-demographics. *PLOS ONE, 11*(5), 1-13. https://doi.org/10.1371/journal.pone.0156572

Rodríguez-Regueira, N., & Rodríguez-Rodríguez, J. (2022). Analysis of digital textbooks. *Educational Media International, 59*(2), 172–187. https://doi.org/10.1080/09523987.2022.2101207

Rusek, M., Slavík, J., & Najvar, P. (2017). Obsahová konstrukce a didaktické uplatnění přírodovědného edukačního experimentu ve výuce na příkladu chemie. *Orbis Scholae, 10*, 71–91. https://doi.org/10.14712/23363177.2017.3

Ryplová, R. (2014). *Fyziologie rostlin: Skriptum pro studující Učitelství přírodopisu pro 2. stupeň ZŠ.* Jihočeská univerzita.

Ryplová, R., Pokorný, J., Borkovcová, M., Baxa, M., Brčáková, T, Hesslerová, P., Chmelová, Š., Kröpfelová, L., Novák, M., Vácha, Z., & Valenta, M. (2023). *Biomasa v trvale udržitelné krajině – výuka fotosyntézy ve vodě a na souši k poznání úlohy rostlin v krajině pro střední školy.* Jihočeská univerzita v Českých Budějovicích.

Skutil, M. (2011). *Základy pedagogicko-psychologického výzkumu pro studenty učitelství.* Portál.

Vácha, Z., Chmelová, Š., Ryplová, R., Brčáková, R., & Novák, M. (2023). Evaluace elektronické učebnice fotosyntézy v prostředí středních škol. In R. Ryplová & T. Brčáková (Eds.), *Biomasa v trvale udržitelné krajině – digitální technologie, aktuální trendy a výzvy ve výuce* (pp. 50-54). Jihočeská univerzita.

Vágnerová, P., Benediktová, L., & Kout, J. (2019). Kritická místa ve výuce přírodopisu – jejich identifikace a příčiny. *Arnica, 9*(1), 39–50. https://www.arnica.zcu.cz/images/casopis/2019/Arnika_2019_1-4-Vagnerova-Benediktova-Kout-web.pdf

Vidal, M., & Membiela, P. (2014). On teaching the scientific complexity of germination: A study with prospective elementary teachers. *Journal of Biological Education, 48*(1), 34–39. https://doi.org/10.1080/00219266.2013.823881

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Drawing Surfaces: AR App for Learning Geometry

Alessandro Martinelli, Yosep Dwi Kristanto, Andri Setiyawan, Zsolt Lavicza

Abstract

Emphasizing direct interaction with teaching materials, as Dewey suggested in the early 20th century, reveals ongoing gaps in higher education. This research tests the effectiveness of an AR application, *GeoTry*, designed to catalogue and visualize 3D geometries for secondary education. Using a PBL approach, the app includes a feature that challenges students to draw geometries themselves. Working solo or in groups, students build knowledge through hands-on design, comparing their work with example catalogues. Tested in higher education, the app has shown positive effects on engagement, as well as the speed and quality of learning: about 300 higher education students from different faculties participated in tests and surveys on the impact of the app, of which over 90 % showed improved learning compared to traditional learning, positive expectations towards the use of AR in the classroom, and in particular an appreciation for the interactive 3D drawing function in a virtual environment.

Keywords

AR; geometry education; geometry visualization; design-based education; 3D geometry

INTRODUCTION

Digital technologies continue to transform traditional education, offering new opportunities to bridge theoretical knowledge with practical application. This study analyses and experiments the application of an AR app dedicated to teaching spatial geometry, focusing on the case study of the ruled surfaces: a complex yet fundamental topic in mathematics and architecture. By leveraging immersive technology, *GeoTry* aims to make abstract concepts more tangible and accessible. The research objectives include:

1. Exploring AR's capabilities in visualizing and interacting with 3D geometries.

2. Integrating creative tools and gamification into geometry education to foster engagement.

3. Proposing a new method for cataloguing ruled surfaces, emphasizing clarity and ease of exploration.

The app addresses gaps in traditional educational methods by combining interactive visualization with hands-on creation. This dual approach enhances students' understanding of theoretical principles while encouraging active participation and curiosity.

STATE OF THE ART

Recent research highlights the potential of educational AR apps, which have demonstrated positive contributes to learning outcomes, engagement, and understanding of complex geometric concepts (Rossano et al., 2020). These applications often incorporate gamification and collaborative features to support STEM learning in primary schools (Yegorina et al., 2021). AR technology enables situated learning, allowing students to interact with 3D geometric objects in a physical environment. Other recent studies have demonstrated positive student perceptions and successful problem-solving using AR-based tools in descriptive geometry courses (Ignatiev et al., 2020). The development of user-friendly AR applications, such as Geo+ and Learn Geometry with AR, has facilitated the integration of this technology into classroom settings (Dhukka et al., 2023). While challenges remain in widespread adoption, AR shows significant potential for revolutionizing geometry education by making abstract concepts more tangible and engaging for students.

In this context, the research on *GeoTry* seeks to distinguish itself through the complex cataloguing of geometries (which is not limited to a few case studies), a menu design specifically conceived to facilitate understanding, and the use of complex and creative mechanics.

METHODOLOGY

GeoTry was conceived to provide an innovative learning experience by integrating AR and interactive tools into geometry education. To achieve this, the app was designed with the following core functionalities:

- AR-Driven Visualization: Users can explore 3D geometries within their physical environment, bridging abstract theoretical models and tangible real-world examples.
- Interactive Camera Control: Device movement allows users to orbit and examine geometries from various perspectives, fostering an active, kinaesthetic learning process.
- Layered Visualization: Users can toggle and overlay specific geometric properties (such as directrices and generatrixes) enhancing their understanding of spatial relationships.
- Creative Mode: A drawing feature (Figure 1) empowers users to draw custom ruled surfaces, encouraging hands-on exploration of the principles behind their mathematical generation. In the creative mode, users can draw ruled surfaces by tracing curves on a transparent collider.

This process involves: sampling touch inputs at regular intervals, projecting a ray from the touch point to a predefined collider, and interpolating intersection points into Bézier curves to generate the surface. The resulting surface is parametric, enabling users to activate geometric properties such as tangent planes and generatrixes.

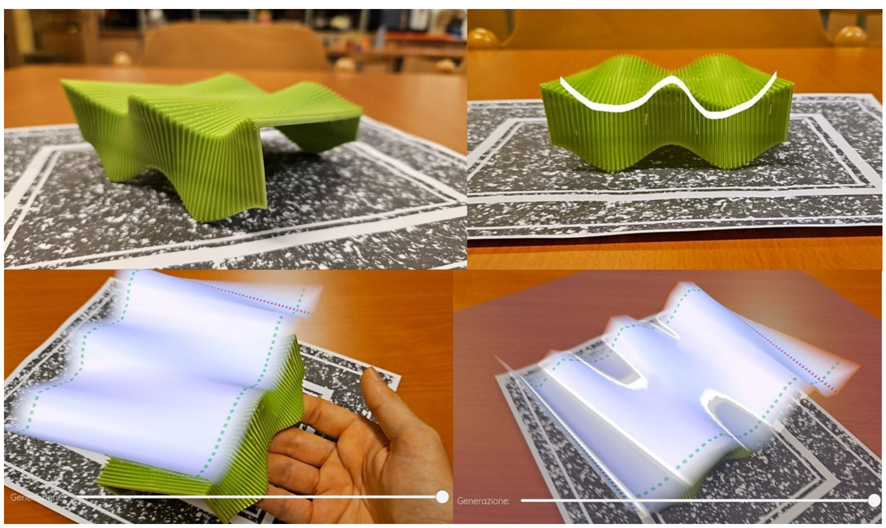

Figure 1: Example of AR function of drawing on reality, to generate a digital geometry and study it.

Drawing Features and Project-Based Education

The drawing functionalities of *GeoTry* were designed with project-based education (PBE) in mind, an approach that emphasizes learning through active participation and problem-solving. Project-based learning (PBL) has emerged as an effective pedagogical approach in modern education, enhancing student engagement, critical thinking, and collaboration skills (Shi, 2024). Research indicates that PBL positively impacts learning outcomes across various educational levels, from high school to higher education (Tulungagung, 2023; Guo et al., 2020). Studies have shown that PBL improves students' cognitive abilities, problem-solving skills, and real-world application of knowledge (Wahyudin, 2023). Moreover, PBL fosters active learning, cultural awareness, and prepares students for future career opportunities. Compared to traditional teaching methods, PBL and other collaborative learning approaches have demonstrated superior results in developing critical thinking and communication skills (Hafeez, 2021). However, challenges remain in teacher preparation, assessment strategies, and curriculum alignment (Nasution et al., 2022). *GeoTry*'s creative mode reflects this philosophy by allowing users to:

1. Experiment with geometry through hands-on design tasks.

2. Analyse and refine their creations using the app's analytical tools.

3. Compare their custom surfaces with predefined examples in the catalogue.

This workflow aligns with PBE principles by placing students in the role of active creators rather than passive learners. By working through the process of surface generation (identifying errors, revising inputs, and analysing outcomes) students internalize core concepts of geometry.

Technical development

Several challenges arose during development: complexity and usability, gradual exposition of concepts, adaptation to various expertise, effective representation of complex geometries, expression of three-dimensional properties, but above all addressing the limits of interaction in space. In fact, touch-based inputs cannot inherently convey depth, complicating 3D modelling tasks. This limitation was addressed by using colliders (Figure 2) to constrain user inputs to specific classes of ruled surfaces. A collider is a virtual element in game engines designed to detect interactions and serve as intuitive tools for managing user input. For instance:

- Touch inputs are captured by the transparent collider, which acts as a reference plane for drawing directrices.

- Generated surfaces are parameterized, allowing users to activate geometric properties like tangent planes and generatrixes for further exploration.

- The app employs AR-based rendering to integrate these surfaces into the user's real-world environment, creating a seamless blend of physical and virtual learning spaces.

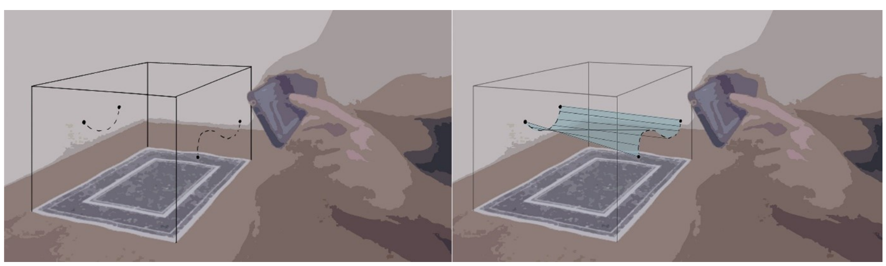

Figure 2: Mechanics by which the drawing is traced in three-dimensional space, intercepting a collider.

Gamification and Engagement

To sustain engagement, *GeoTry* incorporates gamification elements inspired by popular educational tools such as ClassCraft, HP Reveal or Zapworks. These include:

- Progress Indicators and Prizes: The app incorporates completion bars and badges, encouraging users to explore its entire catalogue and rewarding curiosity. This feature, inspired by successful gamified learning platforms, fosters a sense of achievement and motivates further exploration, in line with modern educational methodologies to foster engagement.

- Custom Surface Creation: As explained above, users design their own ruled surfaces, reinforcing the mathematical principles behind their formation. This feature contributes the PBE experience by introducing students to problem-solving activities, possibly in groups. In this way, students are not merely consumers of content but active participants in their own learning journey, building a deeper connection to the subject matter.

Data collection method and survey approach

To validate the effectiveness of the AR application *GeoTry*, a structured research methodology was designed, incorporating both qualitative and quantitative research methods. The study aimed to assess the app's usability, its impact on learning outcomes, and its potential for integration into university-level geometry courses. The research followed a mixed-methods approach, combining experimental testing, structured surveys, and statistical analysis. Testing was conducted in three main phases:

1. Preliminary Testing: A small-scale evaluation with 10 participants, including professors and doctoral students, to refine usability and technical aspects before broader implementation.

2. Controlled Classroom Experiments: The app was introduced in structured classroom settings, where students engaged with the AR environment under guided conditions. A total of 302 students participated in surveys—51 in the first phase and 251 in the second.

3. Wider Field Testing: The final phase involved independent use by students, with surveys conducted post-experiment to collect data on usability, engagement, and educational impact.

These phases allowed researchers to assess both immediate user experiences and long-term effectiveness in learning retention.

The research team employed structured questionnaires on Google Forms (28 questions, accessible via QR code) and observational metrics, divided into four primary areas:

- Background Analysis: Assessed participants' prior knowledge of geometry and experience with AR applications.

- Qualitative Feedback: Measured perceived learning improvements and engagement levels.

- Technical Performance Evaluation: Examined app usability, interface intuitiveness, and device compatibility.

- User Suggestions and Feature Requests: Collected insights into potential improvements and additional functionalities.

Data collection was conducted through digital surveys (88 % of responses), in-class observational studies (conducted in 12 different university settings), and direct feedback interviews (conducted with a smaller subset of 30 participants). Survey results were processed using statistical tools (Microsoft Excel) to identify trends in user engagement and educational benefits. Key metrics analysed included:

- Engagement Rates: Percentage of students who preferred AR-based learning over traditional methods.

- Knowledge Retention Scores: Performance comparisons between students using *GeoTry* and those learning through conventional lectures.

- User Satisfaction Levels: Ratings on usability, interface design, and overall effectiveness.

The study's findings provided a comprehensive evaluation of how AR technology can enhance geometric visualization and problem-solving skills in an academic setting.

The tests (on the second and final version) were made on university students from disciplines such as Architecture, Design, and Engineering with an age average of 20, and no preparation on ruled surfaces, but with a small portion (15 %) prepared in app development. Professors pre-approved the use of the app in their courses to ensure its educational relevance. The diversity of participants helped to validate the tool across different levels of education, with students from introductory geometry courses to advanced computational design programs. The app's effectiveness was assessed across these different groups, and interesting trends emerged regarding the varying ways students engaged with *GeoTry* based on their background knowledge.

RESULTS

Among the 302 students surveyed, 78 % reported that the app made it easier to visualize geometric concepts that were previously difficult to grasp. Interestingly, students with prior exposure to AR tools had a slightly better learning curve (an average of 15 % faster in completing exercises) than those using such a system for the first time. However, 22 % of respondents mentioned needing additional explanations from their professors alongside the app's guidance, indicating that while AR can be a powerful tool, it should complement rather than replace traditional instruction.

Moreover, 82 % of students believed that using *GeoTry* improved their spatial visualization skills, an essential aspect of geometry learning. However, 18 % of participants either saw no improvement or felt overwhelmed by the technology, suggesting a need for adaptive learning settings to accommodate different levels of digital fluency.

Further analysis showed that 69 % of participants felt that the interactive exercises helped them retain information better than traditional lecture-based instruction. Meanwhile, 21 % preferred traditional methods, indicating that while AR is highly effective, a blended learning approach may be most beneficial.

While, based on the data above, students responded positively to the immersive and gamified nature of *GeoTry*, the study identified some challenges:

- Usability Issues: Some users found the menus complex, particularly as more features were added. About 34 % of students struggled with navigating the UI (User Interface) initially but adapted after repeated use. Introducing a guided tutorial mode could significantly improve initial user experience.

- Engagement Levels: The app was more appreciated by students with prior knowledge of geometry, while those with less experience required additional guidance. Notably, 65 % of users preferred learning through interactive exercises rather than static diagrams, reinforcing the importance of experiential learning.

- Device Performance: In 11 % of total cases, technical limitations were observed, such as lag in augmented reality rendering depending on the device's capability. Devices older than 2019 experienced an average frame rate drop of 25 %, affecting the fluidity of the experience. Future updates should focus on optimization for lower-end devices.

Additionally, 45 % of students expressed interest in expanding the app's content, particularly with polyhedral, geodesics, and minimal surfaces. This demand indicates a broader potential for AR in mathematical education beyond its initial scope.

Feedback from participants (in the form of open suggestions on the online form) also highlighted the need for an offline mode. Currently, the app requires an internet connection to load models, which was cited as a limitation by 28 % of users who faced connectivity issues.

The data (Figure 3) suggest that AR significantly improves engagement and comprehension, while gamification encourages deeper exploration of the content. When asked to indicate which aspect of the app contributed the most to learning, features such as property visualization and creative shape drawing were much more popular (higher yellow lines), while traditional text and slides had less impact (higher red lines).

The study confirmed *GeoTry*'s potential for widespread use in educational environments. However, improvements in onboarding, device compatibility, and content expansion would enhance its adoption.

A particularly notable request came from 40 % of students who suggested a multi-user mode for collaborative learning. This could be especially useful in engineering and design courses where teamwork is integral to problem-solving. Implementing this feature would likely increase engagement and practical application of geometric concepts.

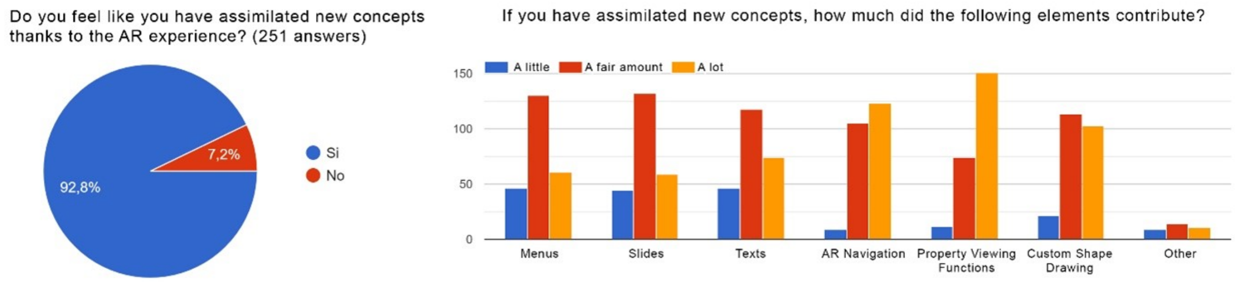

Figure 3: Graphs of the collected data.

Interestingly, 58 % of participants reported increased motivation in studying geometry when using *GeoTry* compared to traditional methods. This supports existing research on gamification, indicating that interactive elements can enhance learning outcomes. However, 12 % of students found the gamified elements distracting, suggesting that customization options for different learning styles could be beneficial.

In synthesis, the most significant key findings are:

- AR Potential: 95 % of participants agreed AR could be a vital component of future education.
- App Value: 98 % found *GeoTry*'s AR features enhanced their learning experience.
- Educational Integration: 98 % believed the app could complement traditional coursework effectively.

Comparing the data collected with similar experiments such as those of Rossano et al. (2020) or Thamrongrat & Law (2019), this one aligns itself with them in terms of appreciation found towards digital technologies and the interactive teaching approach, while it stands out both for bringing new evidence of the educational validity of drawing functions, and for collecting data on complex topics usually dedicated to higher education. Future experiments on larger samples and across educational levels are therefore desirable for a complete comparison, which can experiment with additional creative functions such as VR Tilt Brush or Google VR Blocks.

DISCUSSION AND CONCLUSIONS

The present study demonstrates that immersive technologies, specifically AR, can substantially bridge the persistent gaps in traditional geometry education. Through *GeoTry* users are enabled to visualize, interact with, and generate complex surfaces within real-world environments, thus transforming abstract mathematical concepts into tangible learning experiences. The highly positive feedback from participants highlights the broader educational potential of AR technologies, which could be extended beyond geometry to disciplines such as physics, biology, or engineering. Survey data confirming improvements in student engagement, comprehension, and motivation suggest that the *GeoTry* framework may serve as a model for future interdisciplinary educational applications, particularly if complemented by the development of advanced collaborative tools.

Rossano et al. (2020) emphasized that AR significantly enhances students' understanding of complex geometric constructs through dynamic visualization: an observation that finds a direct continuation in *GeoTry*'s approach, where the visualization is not only dynamic but also actively constructed by the learners themselves through creative drawing features. This shift from passive observation to active creation allows students to internalize mathematical principles more profoundly, offering a richer and more participatory learning experience than previously documented.

Similarly, the study by Ignatiev et al. (2020), which demonstrated that AR improves problem-solving capabilities in descriptive geometry by enabling dynamic manipulation of models, finds resonance in the *GeoTry* results; however, *GeoTry* further advances this concept by engaging students in the design and generation of novel ruled surfaces, thereby fostering not only the ability to manipulate but also to invent and critically evaluate geometrical forms through an intuitive and immersive process.

Moreover, the emphasis placed by Yegorina et al. (2021) on the value of collaborative and gamified AR applications in enhancing engagement and supporting learning outcomes in STEM fields finds a strong parallel in the *GeoTry* project. Although initially designed for individual use, *GeoTry*'s creative features, such as the drawing mode and the gamified catalogue exploration, automatically encouraged collaborative behaviours among students, who often worked in groups to solve design challenges. This spontaneous collaboration suggests that the app inherently supports the kind of peer interaction and motivational dynamics described by Yegorina et al., reinforcing the idea that AR platforms benefit from embedding mechanisms that stimulate both individual exploration and collective problem-solving. For these reasons, this research aims to innovate pedagogical practice by proposing a system that merges dynamic visualization with creative construction. Future studies should aim to broaden the sample size, diversify educational contexts, and integrate multi-user collaborative features to further enhance the educational impact of AR-based geometry learning platforms.

LITERATURE

Blocks by Google. (n.d.). Blocks by Google [VR software]. *Steam.*
`https://store.steampowered.com/app/533970/Blocks_by_Google/`

Dewey, J. (1916). *Democracy and education.*
`https://nsee.memberclicks.net/assets/docs/KnowledgeCenter/BuildingExpEduc/BooksReports/10.%20democracy%20and%20education%20by%20dewey.pdf`

Dhukka, H., Mahamunkar, O., Makwana, H., & Patel, D. (2023). Augmented reality for learning 3D geometry. *SSRN.*
`https://doi.org/10.2139/ssrn.4409458`

Guo, P., Saab, N., Post, L. S., & Admiraal, W. F. (2020). A review of project-based learning in higher education: Student outcomes and measures. *International Journal of Educational Research*, *102*( ), 101586.
`https://doi.org/10.1016/j.ijer.2020.101586`

Hafeez, M. (2021). Systematic review on modern learning approaches, critical thinking skills and students learning outcomes. *Indonesian Journal of Educational Research and Review*, *4*, 167.
`https://doi.org/10.23887/ijerr.v4i1.33192`

HMH. (n.d.). Classcraft. *HMH.*
`https://www.hmhco.com/programs/classcraft`

Ignat'ev, S., Tret'yakova, Z., & Voronina, M. V. (2020). Augmented reality in descriptive geometry. *Geometry & Graphics*, *8*, 41–50.
`https://doi.org/10.12737/2308-4898-2020-41-50`

Nasution, T., Ambiyar, & Lubis, A. L. (2022). Project-based learning model to improve learning outcomes in higher education. *American Research Journal of Humanities & Social Science*, *5*(1), 69–79.
`https://www.arjhss.com/wp-content/uploads/2022/01/I516979.pdf`

Rossano, V., Lanzilotti, R., Cazzolla, A., & Roselli, T. (2020). Augmented reality to support geometry learning. *IEEE Access*, *8*, 107772–107780.
`https://doi.org/10.1109/ACCESS.2020.3000990`

Shi, X. (2024). Research on project-based learning in practical English education. *The Educational Review,*

USA, *8*(3), 433–437.
https://doi.org/10.26855/er.2024.03.017

Thamrongrat, P., & Law, E. L. C. (2019, August). Design and evaluation of an augmented reality app for learning geometric shapes in 3D. In D. Lamas, H. Loos, L. Nunes, & J. Zhang (Eds.), *Human–Computer Interaction – INTERACT 2019* (pp. 364–385). Springer.
https://doi.org/10.1007/978-3-030-29390-1_20

The PaperLab. (2019, June 17). HP Reveal. *The PaperLab*.
https://www.thepaperlab.it/2019/06/17/hp-reveal/

Tilt Brush. (n.d.). Tilt Brush [VR software]. *Steam*.
https://store.steampowered.com/app/327140/Tilt_Brush/

Trustha, T. (2023). A systematic literature review: The impact of project-based learning model implementation on high school students' learning outcomes assessed through VOSViewer in the Google Scholar database. *Jurnal Pelita Pendidikan*, *11*(1), Articolo 40656.
https://doi.org/10.24114/jpp.v11i1.40656

Wahyudin, Y. (2023). Application of the project-based learning model to improve student learning outcomes. *Beginner: Journal of Teaching and Education Management*, *1*(2), 37–49.
https://doi.org/10.61166/bgn.v1i2.37

Wilson, A. B., Bay, B. H., Byram, J. N., Carroll, M. A., Finn, G. M., Hammer, N., ... Organ, J. M. (2024). Journal recommended guidelines for survey-based research. *Anatomical Sciences Education*, *17*(7), 1389–1391.
https://doi.org/10.1002/ase.2499

Yegorina, D., Armstrong, I., Kravtsov, A., Merges, K., & Danhoff, C. (2021). Multi-user geometry and geography augmented reality applications for collaborative and gamified STEM learning in primary school. *Review of Education*, *9*(3), e3319.
https://doi.org/10.1002/rev3.3319

ZapWorks. (n.d.). ZapWorks. *ZapWorks*.
https://zap.works/

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Design the Orthographic Projection on Engineering Drawing module based on Project-based with 3D Printing and Modelling Mechanical Object

Andri Setiyawan, Zsolt Lavicza, Yosep Dwi Kristanto, Alessandro Martinelli

Abstract

This study aims to design a lesson plan for engineering drawing in orthographic projection. The lesson plan combines mechanical object modelling and printed objects. The lesson plan was designed with project-based learning principles to encourage active student participation through hands on engagement with real objects. The lesson plan was subjected to expert validation by experienced vocational education teachers and lecturers in engineering education to evaluate its relevance and effectiveness. Feedback was gathered on the appropriateness of the content, pedagogical approaches, and alignment with the Merdeka Curriculum. The results of the expert validation indicate that the module is pedagogically sound, engaging, and applicable in vocational high school settings. This lesson plan provides a modernized approach to teaching engineering, drawing in line with contemporary industrial needs.

Keywords

Engineering drawing; orthographic projection; project-based; 3d modelling; printing

INTRODUCTION

Engineering drawings are communication tools in engineering (Kosky et al., 2021; Lille & Ruus, 2019). For example, new products have approved drawings before mass production. The design team provides the final drawing for management to use in projection views. Orthographic projection in engineering drawings represents designs in different views. It represents three-dimensional objects in two dimensions, providing essential visual information for designing, manufacturing, and maintaining mechanical components.

Understanding orthographic projections is important for vocational students in machining and automotive technology. Orthographic projection is learned by students in the first year. This material supports the skills required for job-ready graduates. For example, being a mechanic, operator, or technician requires skills in spatial reasoning. However, in classroom learning, students still need help understanding the concept of orthographic projection. Students often struggle to grasp the spatial relationships between different projection views (Sotsaka & Singh-Pillay, 2020). This problem is especially prevalent in vocational high schools, where students must acquire technical knowledge and practical skills for future employment.

The latest technology is expected to support learning, especially in technical vocational education. The integration of 3D modelling and printing offers significant potential to address existing challenges in teaching orthographic projection (Awuor et al., 2022). Students can see all sides of mechanical objects by modelling in three dimensions. For example, students model the components of a 4-stroke engine. They then generate orthographic views such as front, top, and right-side projections based on the three-dimensional model. Afterward, they can reconstruct the three-dimensional object from these two-dimensional projections, reinforcing their spatial understanding and illustrating how orthographic drawings represent physical forms. This process enhances students' ability to interpret and produce technical drawings with greater accuracy and confidence. The technology provides a more intuitive understanding of the relationship between different views in orthographic projections.

Moreover, students can convert their digital designs into physical models with 3D printing. This point enables them to see and touch the object they have studied. This hands-on experience helps bridge the gap between theoretical knowledge and practical application, making engineering drawing more relevant and engaging for students.

Merdeka Curriculum emphasizes student-centred learning, flexibility, and hands-on activities (Hunaepi & Suharta, 2024; Rachman et al., 2024). Indonesia Ministry of Education developed the Merdeka Curriculum in 2022 (Wisudawati & Barke, 2024). It encourages innovative teaching methods that move away from traditional rote learning. Schools and universities implement the curriculum through the ministry's instruction. In vocational education, the curriculum supports critical thinking, problem-solving, and creativity, essential skills in the modern workforce.

Project-based learning (PBL) is a teaching approach that can be both realistic and motivational (Jeon et al., 2014). Students are tasked with solving a real-world problem. For instance, students design a mechanical object, create orthographic projections, and produce a 3D model. This process fosters critical thinking as students are required to analyse mechanical components, interpret technical drawings, and solve spatial problems throughout the design and prototyping stages. Moreover, in this context, project-based learning encourages collaboration by allowing students to work in teams where they contribute different areas of expertise. For example, one student may focus on 3D modelling, another on technical drawing, and another on operating the 3D printer. This arrangement promotes peer learning and the exchange of knowledge. This collaborative approach helps develop important soft skills, such as communication, teamwork, and problem-solving (Andriyani & Anam, 2022).

This study proposes a lesson plan specifically designed to support teachers in delivering orthographic projection in engineering drawing. By integrating project based learning with modern technologies such as 3D modelling and 3D printing, the plan aims to provide teachers with a practical and innovative instructional tool to enhance student understanding and engagement.

METHODOLOGY

This study adopts a qualitative approach within a developmental research framework, aiming to design, validate, and evaluate a lesson plan and instructional module for teaching orthographic projection in vocational education (Großmann & Krüger, 2024; Pasani et al., 2021). The methodology was structured into four main phases. The first phase involved conducting a needs analysis and identifying learning objectives based on the Merdeka Curriculum and the specific instructional demands of engineering drawing. The lesson plan was developed as a proposed teaching resource for vocational teachers to integrate technology into engineering drawing instruction. Through a project-based learning framework, the design incorporates 3D modelling and 3D printing activities to guide teachers in supporting students' spatial reasoning, practical skills, and conceptual understanding of orthographic projection.

In the second phase, a project-based instructional module was designed and developed, incorporating 3D modelling and 3D printing to support students' spatial reasoning and active learning. The instructional design was grounded in constructivist learning theory and supported by a self-regulated learning approach. The third phase focused on the expert validation of the developed materials, which is central to the qualitative nature of this study. Four subject-matter experts (Table 1) were selected as validators: two vocational high school (VHS) teachers specializing in mechanical engineering and two university lecturers in engineering and technology education.

Table 1: Demographic of Experts

EXPERT ID	ROLE	GENDER	AGE	WORK EXPERIENCE	AREA EXPERTISE	INSTITUTION
E1	Vocational Teacher	Male	42	18	Mechanical Engineering Education	Vocational High School
E2	Vocational Teacher	Female	39	15	Engineering Drawing	Vocational High School
E3	University Lecturer	Male	47	20	Engineering Education and Technology	University
E4	University Lecturer	Female	44	17		University

Table 2: Item of expert lesson plan evaluation

INITIAL	STATEMENTS	ASPECTS
S1	This module accurately teaches the principles of orthographic projection	Content
S2	3D modelling tasks are relevant for understanding the projection of mechanical objects	
S3	3D printing activities are suitable for visualising mechanical components in real-world applications	
S4	The project-based learning (PBL) approach enhances students' understanding of orthographic projection	Pedagogical soundness
S5	This module encourages critical thinking and problem-solving skills through its activities	
S6	The step-by-step instructions in the lesson plan are clear and easy for vocational school students to follow.	
S7	This module is in line with the Merdeka Curriculum's emphasis on student-centred learning	Alignment with the Merdeka Curriculum
S8	This module supports the development of student independence and creativity as required by the Merdeka Curriculum	
S9	The project-based approach is effectively integrated into the Merdeka Curriculum framework	
S10	The resources required to implement the module (e.g., 3D printer, modelling software) are available to most vocational secondary schools.	Practical Applicability
S11	The level of difficulty in the 3D modelling tasks is appropriate for vocational secondary school students.	
S12	The time allocation for completing the activities in this module is sufficient.	
S13	The 3D modelling and printing activities in this module will increase student engagement in technical drawing lessons.	Student Engagement and Motivation
S14	Project-based tasks will motivate students to take an active role in learning.	

Data were collected through a validation questionnaire that included both closed-ended and open-ended items. Closed-ended questions used a five-point Likert scale to assess five key aspects of the lesson plan: content accuracy, pedagogical soundness, alignment with the Merdeka Curriculum, practical applicability, and student engagement. A robust lesson-plan evaluation commonly considers five interlinked aspects as shown in Table 2. Content quality and representation hinge on teachers' pedagogical content knowledge, ensuring concepts are selected and presented for learnability (Shulman, 1986). Pedagogical soundness reflects evidence-informed design that blends content, pedagogy, and appropriate methods (McComas, 2014). Alignment with the Merdeka Curriculum requires constructive alignment of outcomes, activities, and assessment alongside policy expectations specific to Indonesia's reforms (Hailikari et al., 2022; Wardani et al., 2023; Widianti et al., 2024). Practical applicability is strengthened by authentic, problem/project-based tasks that foster transfer and real-world performance (Hmelo-Silver, 2004). Student engagement and motivation are supported when plans cultivate autonomy, competence, and relatedness and address behavioural, emotional, and cognitive engagement (Fredricks et al., 2004; Ryan & Deci, 2000).

Meanwhile, the open-ended questions invited qualitative feedback, allowing the experts to elaborate on strengths, weaknesses, and suggestions for improvement. The final phase involved revising the instructional module based on the experts' feedback and conducting a qualitative analysis of the data. Quantitative responses from the Likert-scale items were summarized using basic descriptive statistics to support interpretation (Sarmento & Costa, 2017; Starbuck, 2023). This process ensured that the lesson plan was pedagogically robust, contextually relevant, and practically applicable in vocational education settings.

RESULTS AND DISCUSSION

Needs analysis and identification of learning objectives

This process involves identifying the specific learning needs of students within the context of engineering drawing. The analysis begins with understanding the current curriculum gaps and assessing student proficiency in basic engineering drawing concepts. Based on the needs analysis, clear learning objectives are established to guide the lesson development. These objectives will ensure that students gain technical skills in creating orthographic projections and develop critical thinking and problem-solving abilities by engaging in project-based learning. The learning objectives include: (1) Understand the concept of orthographic projection drawing, (2) Create a 3D design of a mechanical object model using Shapr3D software, (3) Provide a 3D model that is ready to be printed using a 3D printing machine, and (4) Drawing orthographic projection based on the 3D model that has been printed. These objectives will provide a clear roadmap for the lesson content, ensuring students gain practical experience while aligning with the broader goals of the curriculum.

Design and Development of Lesson Plans

The lesson plan will be structured to integrate theoretical knowledge and practical applications (see Figure 1). The lesson plans are designed with project-based learning, where students choose one of the parts of the mechanic or automotive spare parts for 3D modelling, print the model, and draw the projection views. The lessons were divided into four meetings: understanding the concept of orthographic projection, designing a mechanical object model using shapr3D, printing the model, and providing orthographic projection.

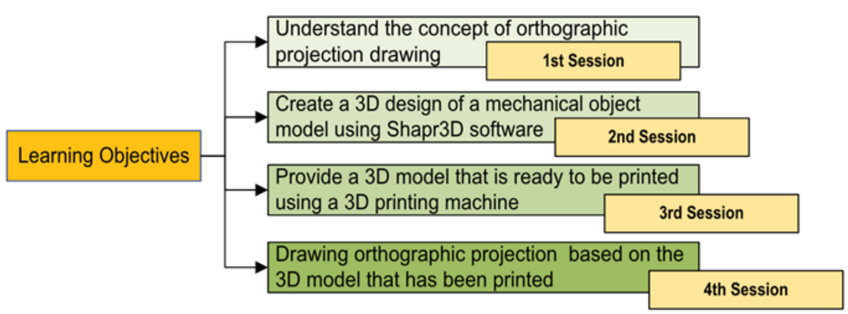

Figure 1: Project-based learning sequence to support orthographic projection in engineering drawing.

Expert Validation of the Lesson Plan

In this step, the expert validated the lesson plan, including gathering feedback on the quality, relevance, and effectiveness of the lesson plan in meeting the learning objectives. Experts assess the content, pedagogical soundness, alignment with the Merdeka Curriculum, practical applicability, and student engagement. The gathered feedback allows for refinement of the lesson plan and ensures it is suitable for effective teaching. Figure 2 shows the result of expert validation on content, pedagogical soundness, alignment with the Merdeka Curriculum, practical applicability, and student engagement and motivation.

The findings reveal consistently high ratings across all aspects, suggesting strong performance in each category. Content, pedagogical soundness, and alignment with the Merdeka Curriculum show particularly robust ratings. This indicates well-structured materials and adherence to curriculum guidelines. Practical applicability and student engagement also score favourably, reflecting the material's relevance to real-world contexts and its ability to motivate learners. The results underscore a well-rounded and practical approach to school curriculum implementation.

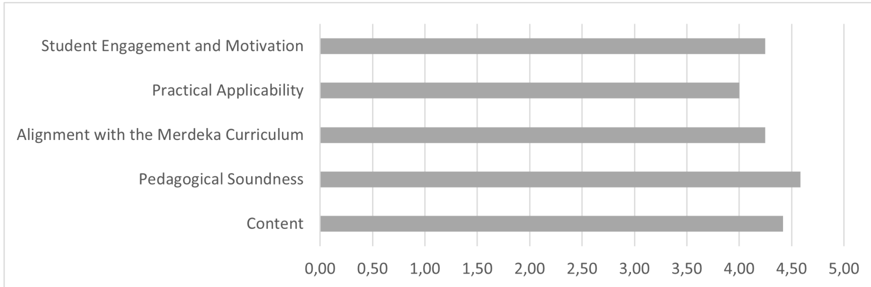

Figure 2: Expert rating of the lesson plan.

Revisions Based on Feedback

This feedback is important to ensuring the lesson plan is comprehensive and ready for implementation. The experts have provided several valuable suggestions that have been incorporated into the revised version of the lesson plan. The revisions focus on improving the content, aligning it more closely with educational goals, and ensuring that the lesson plan is practical and engaging for students.

The lesson plan was revised to include the steps for operating the 3D printer in response to expert feedback. The expert 1 said, "We must ensure that students understand the process of preparing their models for 3D printing". This will enhance the practical applicability of the lesson in the 3rd session. The concept of first quadrant and third quadrant projection will be introduced in the 3D model design activity. Moreover, Expert 2 stated, "The module should provide clear steps for operating the 3D printing machine so that students can understand the process of preparing and producing their models." Based on feedback from Expert 2, the module was revised to include explicit steps for operating the 3D printing machine, ensuring that students clearly understand the process of preparing and producing their models.

Furthermore, based on the feedback suggesting that students should choose their mechanical object models, the revised lesson plan incorporates flexibility, allowing students to select a model of interest for the 3D printing project. Lastly, the feedback highlighted that the structured guidelines facilitate teaching in a project-based learning environment. This element is emphasized to ensure students remain proactive and engaged throughout the learning process. These revisions strengthen the lesson plan's ability to meet its learning objectives and provide a more enriching experience for students and instructors.

Discussion

Lesson planning plays a crucial role in structuring teaching practices and ensuring that instructional goals are met. Farhang et al. (2023) emphasize that a well-designed lesson plan provides clarity for both educators and students, supporting the delivery of targeted and meaningful learning experiences. The design and development of the lesson plan in this study are aligned with contemporary educational goals that prioritize hands-on engagement, learner autonomy, and practical relevance to real-world engineering contexts. The integration of 3D modelling and printing technologies serves as a pedagogical tool to facilitate spatial understanding and prepare students for technological developments in engineering practice.

Expert validation highlighted high ratings in the dimensions of pedagogical soundness and content accuracy, suggesting that the module supports student participation and promotes critical thinking. These findings are consistent with prior studies showing that project-based instructional approaches encourage active involvement and higher-order cognitive skills (Fadhil et al., 2021; Yu, 2024). The emphasis on student-centred activities is particularly important in vocational education, where learners benefit from tasks that simulate professional practices.

Nonetheless, the dimension of practical applicability revealed implementation challenges. Experts noted that constraints such as class time, access to 3D printing equipment, and limited instructional support may hinder adoption in typical school environments. These concerns are consistent with previous literature that highlights logistical barriers in integrating emerging technologies into vocational and secondary education (Iversen et al., 2015; Malik et al., 2013; Richard et al., 2023). To address this, the lesson plan should include operational guidance on 3D printing equipment, simplified design workflows, and contextual adaptations for schools with limited infrastructure.

Expanding the lesson content by incorporating both first-angle and third-angle projection systems could enrich students' understanding of orthographic drawing standards. Such inclusion allows learners to explore multiple representational methods used in global engineering practices, enhancing their technical literacy and awareness of industry conventions (Murthy et al., 2015; Yuhenita et al., 2021). This adjustment aligns well with the goal of deepening student competencies in engineering graphics.

Moreover, expert feedback emphasized the importance of giving students choice within the project-based framework, such as selecting their own mechanical models for 3D printing. This recommendation supports findings by Yu (2024), who notes that student autonomy in task selection fosters motivation, creativity, and problem-solving skills. Allowing learners to model and print real-world objects based on personal interest can also cultivate ownership and investment in the learning process. Structured guidance remains essential to maintain instructional coherence, but the integration of flexible project components offers room for differentiation and innovation.

The expert feedback supports the module's alignment with current pedagogical and curriculum goals in vocational education. Although the module demonstrates potential for promoting deeper learning and real-world skill development, revisions are necessary to address classroom constraints. Incorporating additional technical supports, expanding projection techniques, and integrating opportunities for student choice can strengthen its relevance and usability in diverse educational contexts.

CONCLUSION

By combining project-based learning with 3D printing and mechanical object modelling, the Orthographic Projection lesson plan can improve vocational education. The expert validation results show that the lesson plan is pedagogically sound and connected with the Merdeka Curriculum, making it suitable for vocational high schools. Students learn modern engineering skills using 3D modelling software and 3D printing technology to bridge the gap between theory and practice. The lesson plan's engagement and application have been praised and deepen engineering drawing knowledge. This modernized engineering drawing style meets industrial needs and prepares students for engineering jobs. This research therefore presents a proposed lesson plan that teachers can adopt to strengthen the teaching of orthographic projection in engineering drawing. By embedding project-based learning with 3D modeling and 3D printing, the plan equips educators with a structured yet flexible approach that connects theory with practice, supports the Merdeka Curriculum, and prepares students for future technological and industrial demands.

LITERATURE

Andriyani, S., & Anam, S. (2022). Exploring the relationship between project-based learning and collaborative skills: EFL learners' voices. *Al-Lisan, 7*(1), 51–63.
`https://doi.org/10.30603/al.v7i1.2413`

Fadhil, M., Kasli, E., Halim, A., Evendi, Mursal, & Yusrizal. (2021). Impact of project-based learning on creative thinking skills and student learning outcomes. *Journal of Physics: Conference Series, 1940*(1), 012114.
`https://doi.org/10.1088/1742-6596/1940/1/012114`

Farhang, Q., Hashemi, S. S. A., & Ghorianfar, S. M. (2023). Lesson plan and its importance in teaching process. *International Journal of Current Science Research and Review, 06*(08).
`https://doi.org/10.47191/ijcsrr/V6-i8-57`

Großmann, L., & Krüger, D. (2024). Assessing the quality of science teachers' lesson plans: Evaluation and application of a novel instrument. *Science Education, 108*(1), 153–189. https://doi.org/10.1002/sce.21832

Hunaepi, H., & Suharta, I. G. P. (2024). Transforming education in Indonesia: The impact and challenges of the Merdeka Belajar curriculum. *Path of Science, 10*(6), 5026–5039. https://doi.org/10.22178/pos.105-31

Iversen, O. S., Smith, R. C., Blikstein, P., Katterfeldt, E.-S., & Read, J. C. (2015). Digital fabrication in education: Expanding the research towards design and reflective practices. *International Journal of Child-Computer Interaction, 5*, 1–2. https://doi.org/10.1016/j.ijcci.2016.01.001

Jeon, K., Jarrett, O., & Ghim, H. (2014). Project-based learning in engineering education: Is it motivational? *International Journal of Engineering Education, 30*, 438.

Kosky, P., Balmer, R., Keat, W., & Wise, G. (2021). Elements of engineering analysis. In *Exploring Engineering* (pp. 23–55). https://doi.org/10.1016/B978-0-12-815073-3.00002-8

Lille, H., & Ruus, A. (2019). Composition of engineering drawing through communication skills and social/material interactions from the semiotic aspect. *IOP Conference Series: Materials Science and Engineering, 660*(1), 012011. https://doi.org/10.1088/1757-899X/660/1/012011

Malik, M. E., Ghafoor, M. M., & Iqbal, H. K. (2013). Importance of brand awareness and brand loyalty in assessing purchase intentions of consumer. *International Journal of Business and Social Science, 4*(5), 167–171. https://www.ijbssnet.com/journals/Vol_4_No_5_May_2013/18.pdf

Murthy, M., Mallikharjuna Babu, K., Martin Jebaraj, P., Ravi Maddinapudi, L., Sunkari, V., & Reddy, D. V. (2015). Augmented reality as a tool for teaching a course on elements of engineering drawing. *Journal of Engineering Education Transformations, 0*(0), 295. https://doi.org/10.16920/ijerit/2015/v0i0/59362

Pasani, C. F., Yulinda, R., Putri, R. F., & Amelia, R. (2021). The validity of lesson plan with scientific approach: Building curiosity and responsibility character. *Journal of Physics: Conference Series, 1760*(1), 012048. https://doi.org/10.1088/1742-6596/1760/1/012048

Rachman, A., Putro, H. Y. S., Rusandi, M. A., & Situmorang, D. D. B. (2024). The development and validation of the "Kuesioner Tema Proyek Penguatan Profil Pelajar Pancasila" (KT P5): A new tool for strengthening the Pancasila student profile in Indonesian pioneer schools. *Heliyon, 10*(16), e35912. https://doi.org/10.1016/j.heliyon.2024.e35912

Richard, G. S., Joseph, A., Elikem, K., & Edem, B. K. (2023). Technology integration in technical and vocational education and training (TVET): The role of the art teacher. *Journal of Technical Education and Training, 15*(4). https://doi.org/10.30880/jtet.2023.15.04.007

Sarmento, R., & Costa, V. (2017). Comparative approaches to using R and Python for statistical data analysis. IGI Global. https://doi.org/10.4018/978-1-68318-016-6

Sotsaka, D., & Singh-Pillay, A. (2020). Meeting the challenges first year engineering graphic design preservice teachers encounter when they read and interpret assembly drawing. *Journal of Education, 80.*

https://doi.org/10.17159/2520-9868/i80a04

Starbuck, C. (2023). Descriptive statistics. In *The Fundamentals of People Analytics* (pp. 97–120). Springer International Publishing.
https://doi.org/10.1007/978-3-031-28674-2_7

Wisudawati, A. W., & Barke, H.-D. (2024). Systems thinking approach to understand Indonesia's ocean acidification. *Sustainable Chemistry and Pharmacy, 37*, 101384.
https://doi.org/10.1016/j.scp.2023.101384

Yu, H. (2024). Enhancing creative cognition through project-based learning: An in-depth scholarly exploration. *Heliyon, 10*(6), e27706.
https://doi.org/10.1016/j.heliyon.2024.e27706

Yuhenita, N. N., Majid, Y. M., Murat, A. R., Muliyani, R., Alfahmi, R. A., & Abdillah, M. Z. (2021). Pendampingan dalam menghadapi pembelajaran di masa pandemi bagi warga Dusun Macanan [Assistance in facing learning during the pandemic for the residents of Macanan Hamlet]. *Selaparang. Jurnal Pengabdian Masyarakat Berkemajuan, 4*(2).
https://download.garuda.kemdikbud.go.id/article.php?article=2033569&val=12074&title=PENDAMPINGAN%20DALAM%20MENGHADAPI%20PEMBELAJARAN%20DI%20MASA%20PANDEMI%20BAGI%20WARGA%20DUSUN%20MACANAN

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Chemical Experiments in Preschool: Observation Children's Manual Skills and Their Interest in STEM

Jana Prášilová, Kamila Petrželová

Abstract

This preliminary study explores the integration of chemical experiments into a kindergarten environment, focusing on children's manual skills and their ability to self-evaluate their work. During several experiments, children practised basic chemical operations, including mixing, measuring liquids, and weighing solids. Their skills were observed as they worked with tools such as measuring cylinders, beakers, spoons, and scales. Self-reflection was encouraged by inviting the children to evaluate their own performance. Discussions and questionnaires revealed a lively interest among the children in understanding how different substances are created and the processes behind everyday phenomena. This approach not only enhanced their scientific literacy but also fostered curiosity and excitement about science, laying a foundation for future learning in STEM fields.

Keywords

Preschool; STEM; chemical experiments; manual skills

INTRODUCTION

A growing body of international research highlights the importance of fostering interest in science, technology, engineering, and mathematics (STEM) from the earliest stages of education. Positive experiences with STEM in childhood can influence later academic choices, professional aspirations, and the development of critical thinking and problem-solving skills (Spektor-Levy et al., 2013). Preschool education, in particular, plays a crucial role in establishing the foundations for later STEM engagement, as young children are naturally curious, eager to explore, and responsive to discovery-based learning (Fleer & Veresov, 2019).

The Czech Republic, like many other countries, faces challenges related to declining interest in technical disciplines. Although 304,500 individuals were enrolled in tertiary education in 2022, only 58,699 students graduated—a 38% decrease compared to the 2012 peak (Czech Statistical Office, n.d.; OECD, 2023). Enrolment in technical fields has declined significantly, now falling behind traditionally less technical disciplines such as education and healthcare. Furthermore, only 26.67 % of Czech adults aged 25–64 hold a university degree, compared to the EU average of 37.67 % (OECD, 2023; Prague Monitor, 2023). These figures underscore the need to support early interest in STEM to ensure future innovation capacity and workforce readiness.

One promising approach to addressing this issue is the integration of STEM-related activities—especially simple chemistry experiments—into early childhood education. Such activities help develop children's scientific thinking, manual dexterity, and communication skills, while also encouraging curiosity and collaborative learning (Abdo & Carulla, 2020; Sundberg & Ottander, 2020). By offering engaging science experiences early on, educators can support a deeper and more lasting connection to STEM fields.

This study explores how preschool children interact with chemistry experiments and how these activities contribute to their manual skill development and understanding of basic STEM concepts. By observing children's behaviour and engagement during experimental activities, we aim to contribute to current knowledge on how early science education can help build long-term interest in technical fields.

EXPERIMENTS IN PRESCHOOL AGE

Chemistry experiments in preschool education are gaining attention as an effective tool for promoting curiosity, critical thinking, and collaboration among young learners. Preschool children have a natural tendency to explore and ask questions, and when guided appropriately, simple scientific activities can channel this curiosity into meaningful learning experiences (Fleer & Veresov, 2019; García-Rodeja, 2021).

One of the core pedagogical approaches in early science education is intersubjectivity—the creation of shared meaning between teacher and child. Fleer and Veresov (2019) emphasize that this shared understanding is essential for helping children grasp abstract scientific concepts by connecting them to everyday experiences. For instance, basic chemistry concepts like mixing substances or observing changes in matter become more accessible when children can relate them to familiar sensory experiences.

Play-based learning has been shown to be especially effective in developing chemical thinking. Activities designed to move from the macroscopic to the microscopic level—such as exploring the idea of ”smallness”—enable children to construct early models of scientific understanding (Abdo & Carulla, 2019, 2020; Sundberg & Ottander, 2020). The teacher's role is critical in scaffolding these activities, offering both support and challenge within the child's zone of proximal development.

Simple chemistry experiments—like mixing baking soda and vinegar, observing a burning candle, or growing salt crystals—encourage children to make predictions, observe outcomes, and reflect on cause and effect (Abdo & Carulla, 2020; Sesto & García-Rodeja, 2021). These experiences foster not only scientific thinking but also social interaction, as children collaborate, share observations, and solve problems together.

Emotional and social dimensions are deeply intertwined with learning outcomes. Research shows that children develop a positive attitude toward science when their curiosity is supported in a safe and engaging environment (Fleer & Veresov, 2019). Teachers' own perspectives on science and their ability to nurture scientific curiosity greatly influence the effectiveness of these early experiences (Spektor-Levy, Baruch, & Mevarech, 2013). Collaborative experimental activities further contribute to the development of communication skills and build a sense of community within the classroom.

These findings underscore the value of chemistry experiments as a foundation for later STEM learning. By integrating such activities into preschool settings, educators can provide children with not only knowledge, but also the confidence and enthusiasm needed to pursue scientific inquiry in the long term.

Research Objective and Questions

The primary aim of this exploratory study was to observe and describe the manual skills and engagement of preschool children during simple chemistry experiments. Specifically, the study focused on whether children could carry out basic operations such as mixing, dissolving, measuring liquids, and weighing. In addition, we explored their ability to follow the steps of an experiment, their reactions to the outcomes, and their capacity for self-assessment. The study also sought to understand the kinds of chemical phenomena that naturally capture their curiosity.

Based on this aim, we formulated the following research questions:

1. Are preschool children able to perform basic chemical operations such as mixing, dissolving, and measuring?

2. Can preschool children follow the steps of simple experiments, and how do they demonstrate engagement during these activities?

3. Which types of chemical phenomena attract the attention and curiosity of preschool children?

In line with the concept of engagement defined by Fredricks et al. (2004), we considered behavioral indicators such as sustained attention, active participation, and verbal or non-verbal expressions of interest during the experiments.

Findings from this study are intended to inform the development of future STEM-oriented programs in early childhood education, with a focus on supporting both cognitive and manual skill development through age-appropriate scientific exploration.

Sample Characteristics

The study was conducted in four kindergartens with a science-oriented curriculum. These institutions regularly integrate guided activities such as gardening, animal care, forestry education, and basic science experiments (e.g., water-based activities, weather observation). A total of 69 children participated in the study, of whom 62 % were girls and 38 % boys. In terms of age, 68 % of the children were six years old, 22 % were five, 7 % were seven, and two children were four years old.

Data Collection and Analysis

Data were collected through unstructured observation during science sessions. To ensure that each child had sufficient space and time for individual engagement, the class was divided into two smaller groups. This division was made purely for practical reasons—to create smaller, more manageable settings that allowed for closer observation of manual skills and engagement patterns. One group conducted the child-led experiments, while the other observed demonstration experiments. The groups then switched roles to ensure equal exposure.

Each session included three to four child-led experiments alongside one or two demonstration experiments facilitated by the educator. Observations focused on children's ability to handle materials, follow procedures, interact with peers, and respond to outcomes.

In addition to observations, we used a picture-based questionnaire to capture children's perspectives. Children were asked to draw their responses to a final open-ended question about what they found most interesting. Teachers assisted with labelling when necessary. These visual responses were analysed qualitatively to identify recurring themes in children's interests and questions

PREPARATION OF THE PROGRAMME

To test children's manual skills and engagement with chemical operations, we selected a series of simple, visually appealing experiments. The main criteria for selection included safety, familiarity of substances, and accessibility of the procedures. All experiments used materials commonly found at home, helping children relate the tasks to their everyday experiences. Alongside the children's hands-on activities, we included demonstration experiments conducted by the teacher (Tab 1). These were chosen for their strong visual impact and ability to spark interest and curiosity about chemical processes that would be too complex or unsafe for direct manipulation by children. Demonstration experiments served multiple purposes:

- They introduced scientific phenomena that complemented the child-led activities.
- They captured attention through visual or dramatic reactions (e.g., colour changes, gas formation, flame tests).
- They acted as motivational stimuli, encouraging children to ask questions and make predictions.
- They allowed for guided discussion and helped children form connections between observed effects and everyday materials.

Table 1: A selection of experiments for children and demonstration experiments

Experiments for Children	**Demonstration Experiments**
Lava lamp	Elephant toothpaste
Paper chromatography of coloured markers	Metal ion flame test
Non-Newtonian fluid	Burning gel
Crystals of salt	Blue bottle experiment
Sugar rainbow	Golden rain
Ghost glove	

Instructions for the children's experiments were carefully prepared to be clear, engaging, and visually intuitive. Each experiment was broken down into simple, illustrated steps with hand-drawn images to help children recognize tools and materials. This approach supported independent participation and reflected familiar elements from home. Examples of these instructions are shown in Figure 1.

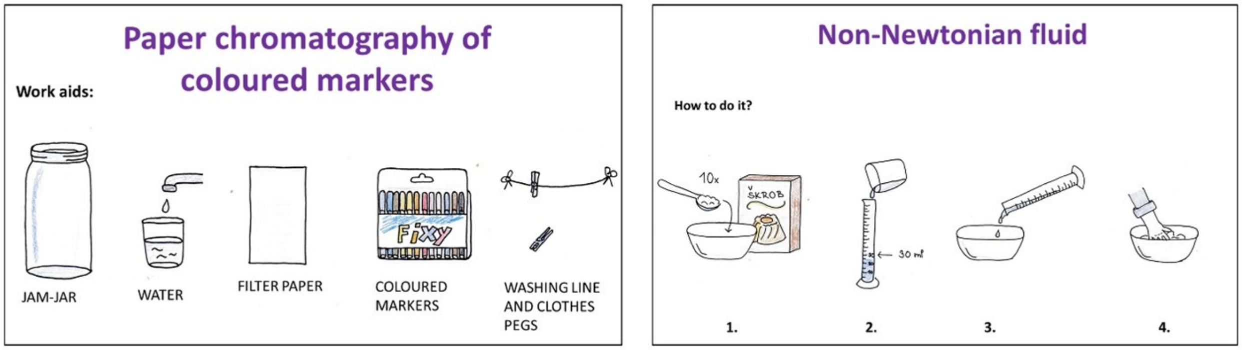

Figure 1: Example of processing instructions for an experiment: Paper chromatography of coloured markers (left) and non-Newtonian fluid (right).

To gather feedback, a picture questionnaire with clearly defined items was prepared for the children. The children were asked to draw their answer to the final question and, with the help of the teacher, add a label if necessary. A concrete example of the questionnaire is shown in Figure 2.

Figure 2: Questionnaire for children.

IMPLEMENTATION OF THE PROGRAMME

During implementation, we observed the manual dexterity of the children as they performed the selected experiments. These activities provided an excellent opportunity for developing fine motor skills such as pipetting, pouring, and stirring. Tasks like measuring vinegar, weighing salt, or gently mixing solutions required hand–eye coordination, attention to precision, and the ability to follow sequential steps (Figure 3).

Figure 3: Children measure the vinegar solution.

Dramatic demonstration experiments, such as "elephant toothpaste" or "golden rain", were conducted in between the children's own activities. These acted as stimuli for group discussion, allowing children to make predictions, share interpretations, and ask questions, thus deepening their cognitive engagement with the scientific content. Although the children did not perform these experiments themselves, their observational reactions and comments were included in the field notes.

At the end of the program, we reviewed all activities with the children, invited them to reflect on what they had experienced, and completed the questionnaire (Figure 4).

DISCUSSION

This study aimed to explore how preschool children engage with basic chemistry experiments, focusing on their manual skills, procedural engagement, and interest in scientific phenomena. Below we discuss our findings in relation to the research questions and relevant literature.

RQ1: Are preschool children able to perform basic chemical operations such as mixing, dissolving, and measuring?

Children in the study were generally able to carry out basic operations with a high level of independence. They mixed solutions, stirred substances, and handled small tools such as pipettes and measuring spoons. The most frequent difficulty was precision in measuring liquids, where several children exceeded the intended volume. This aligns with findings by Abdo & Carulla (2020) and Sundberg & Ottander (2020), who also noted that while preschool children can manipulate laboratory tools, they benefit from visual cues and scaffolding when precision is needed.

Fine motor skill development at this age is still in progress, yet our findings confirm that children are developmentally capable of engaging in simple chemistry tasks—especially when instructions are presented visually and the environment is well-structured. These observations are supported by Sesto & García-Rodeja

Figure 4: Example of a completed questionnaire.

(2021), who demonstrated that young children's conceptual engagement increases when they can physically interact with the phenomenon being studied.

RQ2: Can preschool children follow experimental procedures, and how do they demonstrate engagement during these activities?

Children were able to follow the experiment instructions step by step, with only occasional reminders from teachers. Their engagement was high at the beginning of the program and gradually declined after the third experiment. This drop in attention span suggests a natural limit to the number of sequential tasks suitable in one session, which is in line with Fredricks et al. (2004) who distinguish between behavioural, emotional, and cognitive engagement.

We observed:

- Behavioural engagement through attentive participation, turn-taking, and task completion.
- Emotional engagement via expressions of joy, excitement, or surprise during experiments.
- Cognitive engagement when children asked spontaneous questions or predicted outcomes (”Will it explode?”, ”Is it going to change colour?”).

Children reacted more actively during their own experiments compared to the demonstration ones, though demonstrations prompted reflective thinking and group discussion. For example, the “golden rain” and “elephant toothpaste” experiments triggered amazement and speculative questions (“Can we make this at home?”).

RQ3: Which types of chemical phenomena attract the attention and curiosity of preschool children?

Responses in the picture-based questionnaires revealed interest in both familiar and unfamiliar phenomena. The most frequently mentioned items were everyday substances like sugar and soap, but many children also drew or labelled ice cream, rainbows, robots, chewing gum, and fighter planes.

An overview of the children's spontaneous interests, as captured through the picture-based questionnaires, is presented in Table 2.

Table 2: How is it made...? and How does it work...?: Selected results of a pre-survey with children

How is it made...?	Count	How does it work...?	Count
Sugar	35	Battery	41
Soap	31	Robot	7
Bread	21	Fighter plane / Rocket	3
Ice-cream	7	Blender	3
Rainbow	6		
Chewing gum	4		
Sweets	4		

FUTURE RECOMMENDATIONS

This study confirmed that preschool children, when provided with visual guidance and appropriate support, can successfully engage in basic chemistry experiments. Most children demonstrated the ability to perform operations such as pouring, mixing, and dissolving. However, tasks requiring greater precision—such as pipetting small volumes or measuring exact amounts—proved more challenging for some participants.

These observations are consistent with Abdo and Carulla (2020), who noted that preschool children can conduct simple science tasks when procedures are adapted to their motor development level. Similarly, Sundberg and Ottander (2020) emphasized the need for task design that matches children's physical coordination, suggesting that scaffolded, repetitive practice enhances both skill and confidence. Our findings support these conclusions: fine motor skills in preschoolers are sufficient for experimental learning, but precise tasks require continued modelling and visual supports.

In terms of scientific curiosity, the children's responses revealed interest in how common items are made or how they function. This reflects the natural inclination of young children to explore real-world phenomena through observation and hands-on exploration (Fleer & Veresov, 2019). The link between early exposure to scientific inquiry and long-term interest in STEM subjects has been well-documented (Spektor-Levy et al., 2013; García-Rodeja, 2021). Based on our results, we propose the following recommendations for future research and practice:

1. Structured Observation Tools for Dexterity and Engagement

To systematically assess children's performance, future programs should incorporate structured observation sheets including:

- Fine motor indicators (e.g., stability of grip, accuracy of pouring),
- Attention markers (duration of focus, off-task behaviour),
- Verbal interaction (asking questions, explaining steps),
- Emotional responses (excitement, frustration, joy).

A useful framework can be adapted from Fredricks et al. (2004), who outline behavioural, emotional, and cognitive dimensions of engagement. Additionally, Fleer and Veresov (2019) advocate using ethnographic-style observations to capture intersubjective moments between teachers and children during science activities.

2. Expanding Experiment Topics Based on Children's Interests

Our data show that children are especially curious about food-related processes, colourful transformations, and technological objects. By aligning experiments with these themes, we increase personal relevance and cognitive investment. Examples of potential experiments include:

Food science:

- "How is chewing gum made?" → Making edible gels from gelatine and flavourings
- "How is ice cream made?" → Simple freezing experiments using salt and ice

Colour and light:

- "How is a rainbow formed?" → Light refraction through water droplets and prisms
- "How does colour change?" → Acid–base indicators with red cabbage juice

Basic mechanics and circuits:

- "How does a blender work?" → Building paper propellers or balloon-powered spinners
- "How do robots work?" → Simple LED circuits with batteries and copper tape

Choosing topics that reflect children's spontaneous interests helps establish intrinsic motivation and supports long-term knowledge retention (Spektor-Levy et al., 2013; Sundberg & Ottander, 2020).

3. Methodological Enhancements for Engagement Monitoring

- To gain deeper insight into how children engage with science activities, we suggest:
- Video documentation (with parental consent), allowing detailed coding of behaviours post-session,
- Teacher logbooks for real-time notation of verbalizations, questions, emotional shifts, and social interactions,
- Pictorial self-reflection tools, where children choose or draw images to express what they liked or learned,
- Mini interviews using puppets or toys to facilitate communication with shy or younger children.

These methods reflect current best practices in early childhood science research, as described by Sesto & García-Rodeja (2021) and Abdo & Carulla (2020), who emphasize the value of child-centred feedback and multimodal documentation.

CONCLUSION

This preliminary study highlights the importance of integrating chemical experiments into early childhood education to foster curiosity and develop manual skills. By engaging preschool children in basic chemical operations, we observed not only their ability to perform tasks like measuring, mixing, and weighing, but also their critical thinking and self-assessment skills. The results indicate that young children are naturally curious about the world around them, with particular interest in understanding everyday phenomena, such as how common objects are made or how they function. These findings underline the potential of hands-on, inquiry-based learning experiences in cultivating scientific literacy and sparking long-term interest in STEM fields.

The children's enthusiasm and ability to engage with the experiments suggest that incorporating such activities into early education programs could help address the growing skills gap in technical sectors. Moreover, by tapping into their natural curiosity, we can lay the foundation for future learning in science and technology, encouraging future generations to pursue careers in these fields. Moving forward, it is essential to continue designing STEM-focused programs that are not only educational but also aligned with children's interests, thereby ensuring that they remain engaged and motivated in their learning journey.

LITERATURE

Abdo, K., & Carulla, C. V. (2019). Designing play-based learning chemistry activities in the preschool environment. *Chemistry Education Research and Practice, 20*(3), 542–553. https://doi.org/10.1039/C8RP00306H

Abdo, K., & Carulla, C. V. (2020). Learning about science in preschool: Play-based activities to support children's understanding of chemistry concepts. *International Journal of Early Childhood, 52*(1), 17–35. https://doi.org/10.1007/s13158-020-00259-3

Czech Statistical Office. (n.d.). Od roku 2012 klesá počet absolventů vysokých škol. ČSÚ. https://csu.gov.cz/produkty/od-roku-2012-klesa-pocet-absolventu-vysokych-skol

Czech Statistical Office. (n.d.). Statistika volných pracovních míst. ČSÚ. https://csu.gov.cz/produkty/statistika-volnych-pracovnich-mist

Fridberg, M., Jonsson, A., Redfors, A., & Thulin, S. (2019). Teaching chemistry and physics in preschool: A matter of establishing intersubjectivity. *International Journal of Science Education, 41*(17), 2542–2556. https://doi.org/10.1080/09500693.2019.1689585

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research, 74*(1), 59–109. https://doi.org/10.3102/00346543074001059

OECD. (2023). *Education at a glance 2023: OECD indicators.* OECD Publishing. https://doi.org/10.1787/e13bef63-en

Sesto, V., & García-Rodeja, I. (2021). How do five- to six-year-old children interpret a burning candle? *Education Sciences, 11*(213). https://doi.org/10.3390/educsci11050213

Spektor-Levy, O., Baruch, Y. K., & Mevarech, Z. (2013). Science and scientific curiosity in preschool—The teacher's point of view. *Journal of Science Education, 35*, 2226–2253. https://doi.org/10.1080/09500693.2011.631608

Sundberg, B. (2020). *Children's emergent chemistry in the preschool* (Doctoral dissertation, Umeå University). DiVA portal. https://www.diva-portal.org/smash/get/diva2:1463364/FULLTEXT01.pdf

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Observational Skills Test: Construction and piloting of a scale aimed at the differentiation of organisms

Filip Hašpl, Karel Vojíř

Abstract

The development of scientific skills is an essential part of science literacy for all students. In biology, visual scientific observation is essential. It is used to study specific features as well as species identification. However, there is a lack of didactic tools targeting this skill. In the process of developing the Observational Skills Test, the intention was to create a set of tasks targeting the differentiation of organisms. A set of 36 tasks was developed. The tasks are designed to be easy to administer and evaluate and not time intensive. These tasks cover various groups, including fauna, flora and microcosms. The tasks have been content validated and piloted.

Keywords

Scientific skills; scientific observation; task development; lower secondary school; biology education

INTRODUCTION

Scientific observation is a cornerstone of scientific inquiry, forming a foundational step in data collection and engagement with the natural world (Klemm et al., 2020; Stoskopf, 2005). It underpins the scientific method as the basis for acquiring evidence-based information and fostering a systematic understanding of natural phenomena (Yurumezoglu & Oztas Cin, 2019). Beyond its applications in professional, scientific contexts, scientific observation plays a critical role in everyday life, enabling individuals to obtain, process, and evaluate information about their surroundings (Eberbach & Crowley, 2009). While everyday observation tends to be informal and focuses on superficial details, scientific observation is characterised by precision, structure, and a focus on specific, relevant phenomena (Remmen & Frøyland, 2019). This distinction underscores the complexity of scientific observation, which demands selectivity, the ability to concentrate on critical details, and the formulation of questions that deepen understanding and enhance the value of observations (see Eberbach & Crowley, 2009; Remmen & Frøyland, 2019).

In the field of biology, the scientific observation is particularly important. For example, species identification relies on the ability to visually differentiate morphologically specific individuals, observe them closely and view their specific traits accurately. This skill is indispensable for professional biologists and students alike, as it facilitates a deeper understanding of the living world (Gaskins & Paradise, 2010). Species identification challenges students to engage critically with biological characteristics, moving beyond superficial recognition to achieve true species identification. Without these observational skills, students may notice biological phenomena but fail to derive substantive understanding from them (Klemm et al., 2020).

Tasks on differentiation of various biological objects can provide a unique opportunity to nurture the precision, curiosity, and critical thinking that are integral to scientific observation. These skills, which are fundamental to biology and other scientific disciplines, contribute to the holistic development of scientific literacy (see AAAS, 1993). By cultivating these competencies, educators can promote a deeper engagement with the natural world and foster the intellectual rigour necessary for scientific inquiry (Eberbach & Crowley, 2009; Chalmers, 2013; Yurumezoglu & Oztas Cin, 2019). Despite its pivotal role in biology education, the systematic development of scientific observation skills is often neglected in teaching practice (Agustiani et al., 2020). To effectively address this shortfall, it is essential to evaluate students' current proficiency levels in this skill. There is also a need to be able to evaluate the effect of biology teaching, including science observation, e.g. in the context of outdoor learning (e.g. Čiháková, 2021) or lab activities (e.g. Nejedlý & Vojíř, 2024). However, there is currently a problem with the availability of tools designed to assess students' ability to observe biological objects in a structured, systematic, and meaningful way.

For the reasons mentioned, the Observational Skills Test focused on observing morphological features in organisms from the realms of fauna, flora, and the microscopic world is being developed (see Hašpl & Vojíř, 2024). In biology, morphological features serve as distinguishing characteristics that define different species. We follow a systematic approach based on individual morphological traits in practical applications, such as when working with identification keys. In the simulation of this process, the first part of the test was developed to recognise specific described organism traits such as colour, shape, or pattern based on observation. However, other phases of observation are also essential in the identification of species of organisms and their study. These include the differentiation of morphologically distinct species without targeting one assigned trait. Therefore, for a broader understanding of students' scientific observation skills in biology, it seems necessary to extend the test with additional scales.

The research aims and questions

The Observational Skills Test so far includes only tasks aimed at identifying the described morphological traits (see Hašpl & Vojíř, 2024). However, species identification also requires more advanced skills that involve not only recognising and analysing specific morphological traits but also the ability to differentiate multiple organisms based on an unspecified complex set of characters. This highlights the need for progression of test to address these more complex cognitive tasks, bridging the gap between isolated morphological observations and holistic species identification.

For this reason, we aimed to extend the Observational Skills Test by including a scale focused on differentiating morphologically distinct organisms and validate and pilot test the newly created part. This effort was guided by the following research questions:

1. How do students solve the organism differentiation part of the Observational Skills Test in a real lower secondary school setting?

2. What is the reliability of the organism differentiation part of the Observational Skills Test?

METHODOLOGY

To achieve the stated aims, a set of tasks for Observational Skills Test focused on the differentiation of various biological organisms via observation was developed and validated by experts in didactics and biology. Subsequently, the tasks underwent pilot testing. The data obtained from the pilot test were qualitatively analysed to address the research questions.

Tasks development and validation

The tasks were designed to evaluate students' ability to differentiate various organisms via observation. However, it was not relevant for students to know what species it was, only to recognize its distinctiveness based on external morphological traits. The primary focus of the test was on scientific observational skills, with deliberate efforts made to minimise the influence of extraneous cognitive factors, such as prior knowledge of particular species or specialised terminology. The steps of developing a task set are summarised in Figure 1.

In the first step, the structure of the tasks and the framework of their content were designed. The set consists of 36 tasks, all following a consistent structure. Students are required to select the number of organisms differing in external traits visible in a given set of photographs. Each task is accompanied by six photographs of organisms. The number of species presented in the photos is 1 to 6. Morphologically close but clearly distinguishable species were selected. Species from the same taxonomic order but different genera were chosen. This ensured that the organisms appeared visually similar yet differentiable due to differences in a complex of many different traits. To ensure the variability of the species observed, an even distribution of tasks with macroscopic animals (6 invertebrates, 6 vertebrates), macroscopic plants (6 gymnosperms, 6 angiosperms) and microscopic organisms (6 unicellular, 6 multicellular) was set. After the structure of the task set was designed, it underwent an evaluation and refinement process to ensure its validity, usability, and effectiveness. The initial test structure was presented to six experts specialising in biology and science education, including two international experts. Their comments, for example about clarity of task instruction, layout of the tasks and selected organisms were implemented into the structure of the tasks and the test.

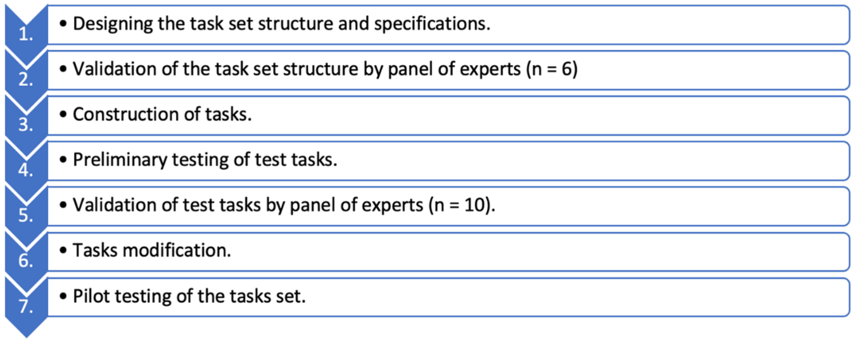

Figure 1: Process of Tasks Development.

The tasks were constructed consequently. To ensure fairness, accuracy, and the representativeness of the tasks, the following principles guided the selection of organisms in the photographs:

- Exclusion of familiar species: Species native to the Czech Republic and species included in secondary school biology textbooks were excluded, as these may have been familiar to students through personal experiences or schooling.
- Inclusion of European species: To minimise reliance on prior knowledge while maintaining ecological relevance, species occurring in Europe were chosen. These species resemble local organisms but are less likely to be known by students.
- Variability of species presented: In each task, different species are presented in order to cover a wide range of different traits for observation.
- Use of natural habitat photographs: Only photographs of living organisms in their natural habitats were included to simulate realistic observational scenarios. Images of herbarium specimens or taxidermy were avoided to ensure authenticity and align with real-world observation techniques, such as direct observation, binoculars, or microscopy.
- High-Quality Visuals: Only photographs of sufficient quality, with accurate colour representation and precise morphological details, were included to limit any technical bias stemming from poor image quality.

The tasks underwent preliminary testing to evaluate its initial effectiveness and identify areas for improvement. Ambiguous or poorly performing items were reworded or replaced with clearer and more effective alternatives.

Following, the created tasks were content validated by a panel of experts (N = 10). Experts with PhDs in science education, zoology, botany and microbiology were represented, as well as biology teachers from practice. Two foreign experts were also represented to enable wider applicability of the test. The experts reviewed key aspects of the test tasks: 1) The selection of taxonomic orders and species of organisms. 2) The relevance and clarity of the morphological traits. 3) Representativeness of photographs. 4) The appropriateness of the test's design for secondary school students in terms of complexity, cognitive demand, time consumption and alignment with educational standards. Based on expert feedback, the tasks were modified i.e. some tasks were reworked with different more suitable organisms or photos were changed for more appropriate morphological traits observability.

Piloting a task set

The task set was pilot tested. The research involved a sample of 95 Czech lower secondary school students aged up to 15 years drawn from five different classes taught by two separate teachers. The sample was selected to align with the target group for the tasks explicitly designed for lower secondary education. All students attended a public school and followed the standard curriculum. Prior to participation, students were informed about the purpose of the study and provided their consent. Anonymity was ensured throughout the research, and all data were handled with strict confidentiality.

Students solved a task set individually in an electronic environment via Microsoft forms using desktop computers. Before solving, the students were informed about how to solve the test. Time was not limited in any way. The solving took place in a classroom familiar to the students without unusual distractions. After completion, group interviews were conducted with the students. It was determined whether they understood the assignment and whether they encountered any problems with the test while solving it.

Data gathered from interviews with students, alongside records of time spent on tasks and student test responses, were analysed descriptively and summarised. The analysis also included an evaluation of students' test performance. Analysing score distributions assessed performance variability.

To assess the reliability, Cronbach's alpha was computed to evaluate the overall consistency of the tasks. This value was compared to established benchmarks in the academic literature to determine whether the test and its subscales demonstrated acceptable levels of reliability. The Kruskal-Wallis test was employed to explore variations in student performance across different tasks. Then, for effect size, the epsilon square was computed.

RESULTS OF PILOT TESTING AND DISCUSSION

The pilot testing of the tasks set demonstrated its usability in school settings. Feedback from post-test interviews indicated that students found the tasks comprehensible and the photographic materials readable. However, some students reported challenges, such as difficulties in accurately counting similar organisms and experiencing a high cognitive load during task completion. These issues highlight potential areas for refinement, particularly in the cognitive demand and design of specific tasks. Teachers administering the test did not encounter any technical difficulties with its computer-based implementation, affirming its logistical feasibility. On average, students completed the test within 13 minutes and 4 seconds. This duration is short enough to be easily integrated into a typical lesson while aligning with recommended limits for maintaining student focus and engagement during individual tasks (cf. Bradbury, 2016). These findings suggest that the test is well-suited for classroom use without disrupting the standard curriculum. The average success rate of the students was 50 % (SD = .171), with individual performance ranging from 14 % to 78 % (see Figure 2). The wide variation in scores indicates that the test effectively measures a broad spectrum of observational skill levels.

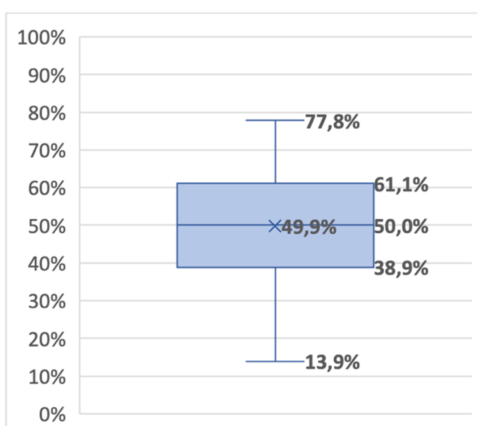

Figure 2: Students' success in solving the tasks.

The internal consistency of the test was found to be good, with a Cronbach's alpha coefficient of $\alpha = .757$

(comp. Taber, 2018). It suggests that the test is reliable for assessing general observational skills connected with organism differentiation. However, the Kruskal-Wallis test revealed a statistically significant difference with a small effect on students' performance based on the type of observed organisms ($H = 10.527$, $p = 0.005$, $\varepsilon^2 = 0.003$)—botanical, zoological, or microbiological. Based on the post hoc analysis, it was found that students performed significantly better when observing zoological objects compared to botanical ($p = 0.038$) and microbiological ($p = 0.001$). This difference is in the case of plants with a small effect size ($\varepsilon^2 = 0.001$) and in the case of microorganisms with a moderate effect size ($\varepsilon^2 = 0.051$). This trend may be attributed to several factors. Children and adolescents often exhibit a natural curiosity toward animals, likely due to their visibility and perceived relatability to humans (Prokop & Tunnicliffe, 2010). Additionally, recognising animal species may be easier for students due to the distinctive morphological features of many animals, which are often more noticeable than the features of plants or microorganisms. In contrast, plant species may require closer observation of more subtle morphological details (Bebbington, 2005). Conversely, microorganisms require specialised equipment like microscopes for observation. This limitation inherently reduces students' exposure to microbiological organisms in everyday life and classroom settings. Furthermore, students may also develop stronger emotional connections to animals, as they often relate to them through anthropomorphism, pet ownership, or conservation narratives, fostering interest and familiarity (Myers Jr et al., 2004). Lastly, cognitive and perceptual factors could also play a role. Humans are evolutionarily predisposed to quickly recognise and differentiate between animals, as this ability likely offered survival advantages to early humans in identifying predators, prey, or other significant species in prehistoric times (New et al., 2007).

We also have to mention that the effectiveness of the observational skills test is inherently constrained by the selection of organisms and their associated groups. The specific items included in the test influence the scope of morphological features that can be observed and compared. While the test allows for the evaluation of student's progress within its defined framework, it cannot comprehensively cover all possible morphological traits across the immense diversity of biological groups and organisms. Selecting a representative subset of organisms for a test introduces trade-offs between breadth and feasibility. Furthermore, the inclusion of certain groups and the exclusion of others shapes the focus of the test and the development of students' skills. Another key limitation lies in the apparent non-uniformity of observational skills across different organism groups. This suggests that the cognitive and perceptual demands of observation vary significantly between groups, making direct comparisons of students' skills across taxa as well as between species of the same taxon differing in other traits challenging. Therefore, it seems desirable to extend the research also in the direction of investigating specific procedures for differentiating various groups of organisms and identifying strategies for tracking particular types of morphological traits.

CONCLUSION

Observational Skills Test was extended with a task set that is suitable for administration in school settings. This newly expanded set of organism differentiation tasks allows us to follow another of the essential steps in observing organisms, investigating them and identifying them. The tasks were content validated, and the results of pilot testing indicate good reliability. Thus, it can be used for following research that could serve to provide a deeper understanding of the development of observational skills in biology education. The validated task construction methodology can also be used for the construction of other tasks. Thus, the test can be modularly modified to monitor students' observational skills in selected groups of organisms.

Partial results also suggest intrinsic differences in observational skills in conjunction with different biological objects and traits. This reveals other knowledge gaps that could be addressed.

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LITERATURE

AAAS. (1993). *Benchmarks for scientific literacy.* New York: Oxford University Press.

Agustiani, E. D., Rustaman, N., & Wulan, A. R. (2020). Elementary School Teachers' Scientific Competence and Their Teaching Experiences. *Jurnal Basicedu, 4*(2), 306-313. https://doi.org/10.31004/basicedu.v4i2.328

Bebbington, A. (2005). The ability of A-level students to name plants. *Journal of Biological Education, 39*(2), 63-67. https://doi.org/10.1080/00219266.2005.9655963

Bradbury, N. A. (2016). Attention span during lectures: 8 seconds, 10 minutes, or more? *Advances in Physiology Education, 40*(4), 509-513. https://doi.org/10.1152/advan.00109.2016

Čiháková, K. (2021). IBSE and Outdoor Education Activates Both Children and Teachers. In M. Rusek, M. Tóthová, & K. Vojíř (Eds.), *Project-based Education and other activating Strategies in Science Education XVIII* (pp. 26-35), Charles University. https://pages.pedf.cuni.cz/pbe/files/2021/05/ProceedingsPBE2020_final.pdf

Eberbach, C., & Crowley, K. (2009). From Everyday to Scientific Observation: How Children Learn to Observe the Biologist's World. *Review of Educational Research, 79*(1), 39-68. https://doi.org/10.3102/0034654308325899

Gaskins, S., & Paradise, R. (2010). Learning through observation in daily life. *The Anthropology of Learning in Childhood, 85*, 85-110. https://doi.org/10.5040/9798881809201.ch-5

Hašpl, F., & Vojíř, K. (2024). Construction and Piloting of Observational Skills Test. *ICERI2024 Proceedings*, 2113-2119. https://doi.org/10.21125/iceri.2024.0589

Chalmers, A. (2013). *What is this thing called science?* McGraw-Hill Education (UK).

Klemm, J., Flores, P., Sodian, B., & Neuhaus, B. J. (2020). Scientific Reasoning in Biology - the Impact of Domain-General and Domain-Specific Concepts on Children's Observation Competency. *Frontiers in Psychology, 11*, Article 1050. https://doi.org/10.3389/fpsyg.2020.01050

Myers Jr, O. E., Saunders, C. D., & Birjulin, A. A. (2004). Emotional dimensions of watching zoo animals: An experience sampling study building on insights from psychology. *Curator: The Museum Journal, 47*(3), 299-321. https://doi.org/10.1111/j.2151-6952.2004.tb00127.x

Nejedlý, A., & Vojíř, K. (2024). How to construct inquiry tasks: A methodological framework and task piloting. *Project-based Education and other activating Strategies in Science Education XXI*, Prague, 125-135. https://pages.pedf.cuni.cz/pbe/files/2024/09/PBE2023_final.pdf

New, J., Cosmides, L., & Tooby, J. (2007). Category-specific attention for animals reflects ancestral priorities, not expertise. *Proceedings of the National Academy of Sciences, 104*(42), 16598-16603. https://doi.org/10.1073/pnas.0703913104

Prokop, P., & Tunnicliffe, S. D. (2010). Effects of having pets at home on children's attitudes toward popular and unpopular animals. *Anthrozoös, 23*(1), 21-35. https://doi.org/10.2752/175303710X12627079939107

Remmen, K. B., & Frøyland, M. (2019). Students' use of observation in geology: towards 'scientific observation' in rock classification. *International Journal of Science Education, 42*(1), 113-132. https://doi.org/10.1080/09500693.2019.1704914

Stoskopf, M. K. (2005). Observation and cogitation: How serendipity provides the building blocks of scientific discovery. *Ilar Journal, 46*(4), 332-337. https://doi.org/10.1093/ilar.46.4.332

Taber, K. S. (2018). The use of Cronbach's alpha when developing and reporting research instruments in science education. *Research in Science Education, 48*, 1273-1296. https://doi.org/10.1007/s11165-016-9602-2

Yurumezoglu, K., & Oztas Cin, M. (2019). Developing children's observation skills using a fractal pattern from nature. *Science Activities, 56*(2), 63-73. https://doi.org/10.1080/00368121.2019.1696734

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Formation of Metal Dendrites During Electrolysis: An Inquiry-Based Project for Secondary Schools

Milan Šmídl, Zuzana Maňásková

Abstract

This study investigates the formation dendrites of metals during the electrolysis of aqueous solutions as an inquiry-based activity in secondary education. The research analysed the dependency of dendrite formation on various factors. The findings demonstrated that metals such as iron, cadmium, cobalt, and zinc could form dendrites under specific conditions. These outcomes provide a valuable framework for incorporating inquiry-based activities into chemistry education, not only at secondary but also primary levels. The study offers a fresh perspective on experimental teaching in chemistry and serves as an inspiration for further inquiry-based projects on electrolysis and metallurgy.

Keywords

Metal dendrites; electrolysis; inquiry-based learning; secondary education; experimental chemistry

INTRODUCTION

Electrolysis has long been a well-established and widely used process in primary and secondary school education. It is typically employed as a demonstration experiment for students and, when appropriate equipment is available, as a laboratory activity. The most common applications include the electrolysis of water, sodium chloride solutions, or copper(II) sulphate solutions. Electrolysis belongs to the category of redox processes, which have consistently been challenging and abstract topics for students, particularly at the secondary school level. Numerous studies have examined the underlying reasons for these difficulties and proposed potential solutions (Ali et al., 2022; Henychová et al., 2023; Saricayir, 2010; Tsaparlis, 2019; Turner et al., 2024). One effective way to make this topic more accessible is to incorporate student-centred experimental activities, ideally combined with active learning methods.

During the electrolysis of aqueous metal salt solutions, metallic crystals resembling tree-like structures, known as dendrites, are deposited as the electric current passes through the solution. Dendrites of tin, lead, silver, and copper are relatively easy to prepare and have been well-documented (Šmídl et al., 2022). These structures vary in shape and size, form rapidly (within minutes), and are visually striking. Additionally, their preparation requires minimal equipment and is not overly demanding.

This paper introduces the concept of a student project based on inquiry-based learning principles, in which students acquire fundamental scientific skills right from the beginning. These skills include the study of relevant sources, critical evaluation, processing and organisation of collected data. Based on this information, students generate research questions and hypotheses, which they then confirm or refute through experimentation. The final step involves formulating conclusions, which may lead to new problem situations, questions, or hypotheses, much like in real scientific research.

The student project presents an opportunity for meaningful and effective implementation of inquiry-based learning in secondary school chemistry classes. The research topic of the lesson focuses on investigating the formation of dendrites for metals beyond the commonly explored examples of copper, silver, lead, and tin, and on verifying various factors that influence the formation of dendrites. These factors include the type of compound used, its concentration in the solution, applied voltage, and the material from which the electrode is composed of.

THERORETICAL BACKROUND

Electrolysis and the Formation of Dendrites

When a direct current source is connected, an electric current passes through the electrolyte solution during electrolysis, initiating oxidation and reduction reactions at the electrodes. At the positively charged anode, oxidation occurs, involving the loss of valence electrons from atoms as they are transferred to the electrode. At the negatively charged cathode, reduction takes place, increasing the number of valence electrons in atoms as they accept electrons from the circuit. Due to electrostatic attraction, negatively charged anions in the solution migrate toward the positively charged anode, while positively charged cations move toward the negatively charged cathode.

At the electron-rich (negatively charged) cathode, atoms with lower electronegativity and lower standard reduction potentials are deposited; in this study, these are metals (including hydrogen). At the electron-poor (positively charged) anode, the species formed depend on the composition of the solution, generally comprising particles with higher electronegativity and higher standard reduction potentials. These often include gaseous products (primarily oxygen and/or halogens) or solid metal oxides that form insoluble precipitates.

Electrolysis of molten or aqueous metal salts is a vital process for extracting pure metals from minerals and ores. Examples include the production of aluminium from molten alumina and cryolite, as well as the recovery of alkali or noble metals from halide minerals. Although the principles of electrolysis and metal extraction have been known for a long time (Beneš et al., 1974; Housecroft et al., 2014).

The growth of crystals is a highly complex process, and its details are not yet fully understood (Kratochvíl, 2007). Similarly, the formation of metal dendrites during electrolysis is influenced by numerous, often poorly understood factors, making it a burgeoning area of research (Liu et al., 2019; Popov et al., 2016). Experiments have shown that exceeding a certain current threshold accelerates the growth of dendritic micro-crystals and can lead to delamination (defoliation) of graphite electrode layers (Parvez et al., 2013). As previously noted, the formation of dendrites in metals such as copper, silver, lead, and tin has been methodologically well-documented and is used in educational experiments at both primary and secondary school levels. Similar formations have been known since the time of alchemy, and some retain historical names—for instance, lead dendrites are called the "Tree of Saturn," silver dendrites the "Tree of Diana," and amalgams of silver are referred to as the "Philosophers' Tree" (Carmody, 1967). Dendritic growth of other metals, such as tin in the absence of a liquid solvent, can also be observed in electronic components, where metallic whiskers form micro-crystals that cause short circuits in electronic circuits (Xu, 2005). Dendrites hold significant potential for applications in electronic sensing and data storage, nanostructure fabrication, 3D integrated circuits, and batteries (Kim, 2010). Another possible application includes desalination of seawater and energy storage. In some cases, however, preventing dendrite formation is crucial, as in lithium-based batteries, where dendrites cause loss of capacity and short circuits during recharging (Han, 2014).

METHODOLOGY

The lesson plan and overall project structure were consistently co-designed by the teacher and the student, considering the student's individual interests and thematic preferences. Throughout the course of the activity, the projects underwent several iterative modifications, particularly in the formulation of research questions and hypotheses, selection and validation of appropriate materials, chemicals, and methods, as well as in the interpretation of results. In some instances, it was necessary to substantially revise the original topic or select a completely new one.

The general structure of student research tasks followed this framework:

1. Motivation and formulation of the central question

2. Development of hypotheses and research questions relevant to the topic

3. Independent experimentation, validation, and critical assessment of results

4. Final interpretation of findings, preparation of the written report, and presentation of results

The implementation took place in the school's laboratory using commonly available equipment and chemicals. A key principle of the activity was to maximize opportunities for student autonomy and encourage individual initiative.

The effectiveness of the inquiry-based approach was assessed qualitatively throughout the project using three primary methods:

1. **Observation.** The teacher, in the role of mentor, systematically monitored the progress of the work and recorded observations regarding the student's level of autonomy, ability to formulate questions, and capacity to interpret experimental results. The ability to independently design an experiment, respond to unsuccessful trials (re-evaluating the procedure, seeking alternative solutions), operate laboratory equipment, and actively utilize appropriate tools for data recording and analysis.

2. **Student Interview.** Upon completion of the project, a structured interview was conducted, during which the student reflected on the development of their own skills (e.g., hypothesis formulation, experimental design), their understanding of chemical phenomena, and their motivation to continue with inquiry-based work.

3. **Feedback from the Professional Community.** The project outcomes were presented at the final examination defences and at several student scientific conferences (e.g., secondary school research competitions). Subsequent discussions with experts and members of the educational community confirmed not only the academic rigor of the results but also the suitability of the topic for inquiry-based learning (IBL). Following the project presentation at student or professional conferences, feedback and comments from the expert panel or participants were collected, including audience questions and the student's responses, along with the student's own reflection on their participation.

To enhance the validity of the evaluation, these methods were applied in various combinations, and their outcomes were cross compared.

Lesson plan

The specific proposed instructional project was implemented at a vocational secondary school in Litvínov, within the framework of an independent research project conducted by a final-year student. The project was carried out from March 2022 to March 2023 as a long-term, individually mentored activity, which forms a mandatory component of the final examination at the school. Students choose their project topic based on their personal interests and academic orientation. The content of the research task was built upon previously established experiments summarized by Šmídl et al. (2022, pp. 41–46).

At the beginning of the year-long project, the student familiarized herself with topics related to the electrolysis of solutions, the properties and structures of metals, and metallic crystals, followed by an in-depth exploration of the formation of metal dendrites from solutions. Printed, electronic, and online resources were made available for study. Throughout the project, the teacher acted solely as a coordinator and mentor, assisting only when difficulties arose. The initial experiments were conducted using dendrites of copper, lead, silver, and tin, which are well-documented and straightforward to prepare. Next, research questions for the project were formulated to investigate the factors influencing the growth, shape, and size of the crystals:

- What are the effects of electrode material, solution concentration, applied voltage, type of chemical substance, and solvent on the shape and size of the crystals?

- Is crystal growth specific to metal compounds and solvents used?

Based on these research questions and preliminary experiments, the following fundamental hypotheses were proposed:

1. Crystals will be larger and more robust at higher applied voltages.

2. Crystals will be larger and more robust at higher solution concentrations.

3. Metal dendrites grow from solutions of their corresponding metal compounds, depending on the compound used.

4. Dendrites form exclusively in aqueous solutions.

5. The electrode material is a limiting factor for crystal formation and growth.

Subsequently, systematic verification of dendrite formation and growth was undertaken, considering the identified factors and different types of compounds dissolved in polar solvents—water, ethanol, methanol, acetone, and diethyl ether (Figure 1).

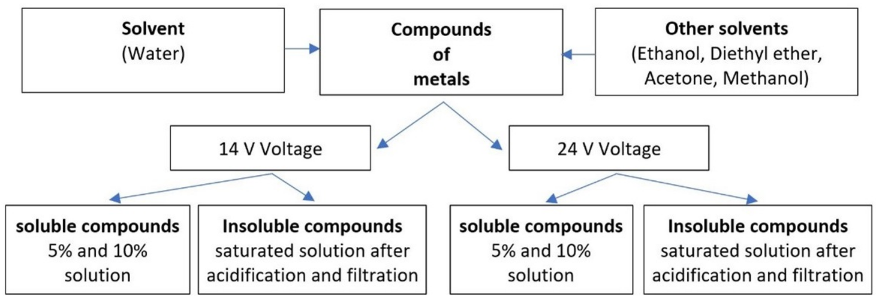

Figure 1: Scheme of factors influencing dendrite formation.

After assembling the electrolytic apparatus (Figure 2), which consisted of a DC power supply (ranging from 0 V to 30 V), a 10 cm diameter Petri dish, insulated wires, and graphite electrodes. Solutions of all available compounds (Table 1) were prepared at specified concentrations (5 % and 10 % for soluble compounds; for sparingly soluble or insoluble compounds, the suspensions were acidified and filtered to yield saturated solutions).

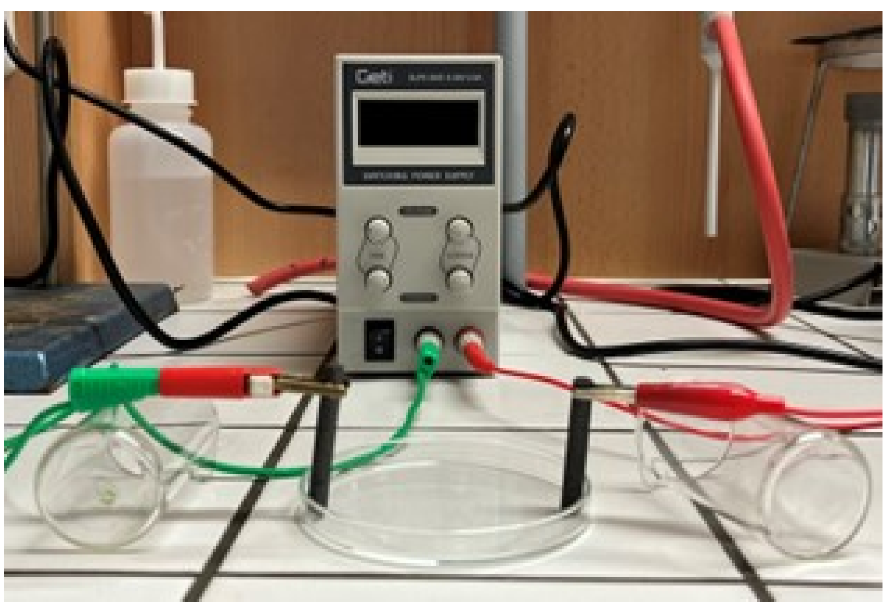

Figure 2: Picture of electrolysis apparatus.

Upon completion of the experimental work, the results were analysed and evaluated. Based on these findings, the formulated hypotheses and conclusions were either verified or refuted, including additional questions that emerged during the experiments.

Table 1: Types of metal compounds used. Compounds that formed dendrites are highlighted in **bold**.

Metal's name	**Type of substances**
Lithium (Li)	LiOH, LiCl, $LiNO_3$
Magnesium (Mg)	MgO, $MgCO_3$, $Mg(NO_3)_2$, $MgSO_4$
Manganese (Mn)	$MnSO_4$, MnO_2, $KMnO_4$
Titanium (Ti)	TiO_2
Aluminum (Al)	$Al_2(SO_4)_3$, Al_2O_3, $Al(NO_3)_3$
Zinc (Zn)	**ZnO**, **$ZnSO_4$**, **$(CH_3COO)_2Zn$**, **$ZnCl_2$**, $Zn(NO_3)_2$, $ZnCO_3$
Chromium (Cr)	Cr_2O_3, $Cr_2(SO_4)_3$, $Cr(NO_3)_3$
Iron (Fe)	**$FeSO_4$**, Fe_2O_3, $Fe_2(SO_4)_3$, $Fe(NO_3)_3$, $FeCl_3$
Cadmium (Cd)	**$CdSO_4$**, **$Cd(NO_3)_2$**, **$CdCl_2$**, **$(CH_3COO)_2Cd$**
Nickel (Ni)	$NiSO_4$, $Ni(NO_3)_2$
Cobalt (Co)	**$CoSO_4$**, **$CoCl_2$**, $Co(NO_3)_2$
Bismuth (Bi)	$Bi(NO_3)_3$

RESULTS AND DISCUSSION

Dendrite growth

Experimentally, it was confirmed that, among the studied metals and their compounds, dendrites were reliably formed only by the following metals and their respective compounds:

- $FeSO_4$
- $CdSO_4$, $Cd(NO_3)_2$, $CdCl_2$, $(CH_3COO)_2Cd$
- ZnO, $ZnSO_4$, $(CH_3COO)_2Zn$, $ZnCl_2$
- $CoSO_4$, $CoCl_2$

Other metals and compounds did not form dendrites or produced only a coating on the electrode, lacking dendritic structures. Due to the equipment limitations of a secondary school laboratory, it was not possible to precisely determine the composition of the metal dendrites, or the products formed on the electrodes. However, it can be inferred that the dendrites on the negative cathode consist of pure metals.

An intriguing area of exploration could involve the products formed on the positive anode. For example, during electrolysis of silver nitrate with graphite electrodes, dendritic formations also appear on the graphite anode. These may involve silver compounds, such as silver oxide, or potentially interesting carbon modifications (Šmídl et al., 2022). Additionally, various gases may be generated during the process, which could be identified through gas chromatography.

In this study, dendrite formation was not observed for magnesium and lithium, although other research has reported their occurrence under different conditions (Liu et al., 2021). The formation of bimetallic dendrites, such as silver and gold (Ji et al., 2014), manganese (Xie et al., 2022), cadmium (Popov et al., 2016), and zinc (Ostanina et al., 2015), has also been documented.

Factors influencing dendrite formation

During the preparation of solutions, it became evident that some solutions needed to be acidified with an acid corresponding to the compound's anion (hydrochloric, acetic, nitric, or sulphuric acid) to prevent turbidity and formation of a suspension, or the insoluble portion had to be filtered out. As dendrites did not form in solutions of compounds dissolved in non-aqueous solvents but exclusively in aqueous solutions, the hypothesis was confirmed.

Among the factors influencing crystal growth, it was observed that higher solution concentrations (10 %) and higher applied voltages (24 V) resulted in shorter, less branched, more robust, and often darker crystals. Conversely, at lower concentrations (5 %) and lower applied voltages (14 V), dendrites were longer, finer, lighter, and more branched. Both hypotheses regarding these conditions were thus validated. Several types of electrodes were tested (electrodes made of the same metal as in the solution, copper electrodes, and graphite electrodes). However, no significant effect of electrode material on dendrite formation was observed. Consequently, inexpensive graphite electrodes, which can be reused after cleaning, proved to be the most suitable. The hypothesis that electrode material influences crystal growth was therefore not verified. The type of compound used was confirmed to be critical for dendrite formation and growth. It appears that dendrite formation is influenced not only by the specific metal but also by the anion of the compound in which the metal is bound. It was not possible to establish a consistent relationship where certain types of compounds always led to dendrite formation while others did not. The types of compounds and their ability to produce dendrites exhibited no discernible patterns. Additional factors potentially influencing crystal growth were identified during the experiments. The distance between electrodes, for instance, affected dendrite morphology: the closer the electrodes, the denser, shorter, and more robust the dendrites. Another possible factor distinguishing metals and compounds was the speed of crystal growth, which ranged from seconds (e.g., for cadmium) to tens of minutes (e.g., for zinc and cobalt). However, the size of the electric current passing through the system, as determined by the aforementioned factors, appears to be the key determinant of crystal growth. The student independently identified most of these questions during her work.

The topic of electrolysis and its application in the extraction of metallic materials is highly relevant today due to the growing demand for battery storage systems. Moreover, this topic is profoundly interdisciplinary, intersecting with fields such as chemistry, physics, technology, engineering, crystallography, geology, ecology, and numerous others. This comprehensive approach facilitates the integration of acquired knowledge and skills. All these aspects align with the concept of inquiry-based learning, whose benefits are well-supported by numerous studies (e.g., Acar et al., 2013; Supasorn, 2014; Kondratiev et al., 2024).

The importance of inquiry-based teaching

The model presented in this article allows for varying degrees of student autonomy. However, due to its extended time requirements, it is particularly suitable for working with gifted students at an advanced level, fostering their independence and initiative. For novice and less proficient students, such as those in standard classroom instruction, it is advisable to provide step-by-step guidance and a higher level of support (Orosz, 2023). A similar experimental study confirmed the benefits of inquiry-based teaching. For instance, Wheeler et al. (2012) investigated the impact of inquiry-based activities on students' ability to ask questions and formulate hypotheses. The effectiveness of inquiry-based instruction in improving student outcomes has been well-documented for many years (Khan et al., 2011). Although this method cannot be applied universally or continuously throughout instruction, its role in engaging students and enhancing their understanding of the subject matter is indisputable.

However, a systematic review of studies on this topic has demonstrated that the research has predominantly emphasized conceptual and affective domains, while fewer studies have focused on the epistemic dimension. Finally, regarding methodology, the reviewed articles included numerous quantitative studies, often with small sample sizes and varying quality. Therefore, there is a need for further research with larger participant groups, longer study durations, more purposeful sampling, and a stronger focus on epistemic and social dimensions (Jegstad, 2024).

Student assessment of lesson plan

The aim of this study was not only to experimentally verify the formation of dendrites in various metals during electrolysis but also to evaluate the benefits of inquiry-based learning in secondary school chemistry education. The study demonstrated students' initiative and active engagement in the project, deeper understanding of electrochemical processes, and the acquisition of independent work skills and analytical thinking within the framework of inquiry-based instruction. During the experiments, students actively sought answers to their own questions, which led to greater engagement and motivation for further investigation. They observed relationships between experimental conditions and the formation of dendritic structures, learned to draw conclusions based on observations, and discussed potential causes of differing results. This process contributed to their ability to critically evaluate scientific information and develop essential skills for scientific work.

One of the key benefits was the improvement of students' ability to formulate hypotheses and design experiments to test them in the context of a real chemical process, the progression of which they controlled themselves. Students realized that the scientific process is dynamic and often generates new questions rather than providing definitive answers. This strengthened their ability to work systematically, adapt to new challenges, and perceive chemistry not merely as a collection of facts but as an interactive and continuously evolving field.

The author has extensive experience with this type of student-led inquiry-based activity, having supervised at least two or three such projects annually with final-year secondary school students for the past 15 years. Therefore, the observed outcomes may be considered generalizable to broader educational contexts. Overall, the benefits of this and similar activities are supported by the experiences of more than 40 students.

The observation and interview were conducted by the supervising teacher (mentor) and the project opponent from the same school. However, additional evaluation of the activity took place during the final examination defences and at three independent academic conferences by members of the respective committees (by at least three evaluators on the committee). A comparison of all evaluations yielded identical or highly consistent results, which substantiate the conclusions presented in this paper.

CONCLUSION

Within the framework of the student inquiry-based project, the growth of metal dendrites from solutions of their compounds was confirmed for zinc, cadmium, iron, and cobalt. Factors influencing this growth were verified. Lower applied voltages and lower solution concentrations resulted in finer, more branched, longer, and lighter dendrites, while higher voltages and higher concentrations produced shorter, more robust, less branched, and darker dendrites. The electrode material was found to have no significant effect on crystal growth (we used the cooper, iron and graphite electrodes), with rod-shaped graphite electrodes proving to be the most suitable due to their low cost and reusability after cleaning. Among the polar solvents used for solution preparation, only water led to the formation of dendrites. The application of electrolysis in combination with the deposition of metals from solutions proved to be an exceptionally appealing topic. This was due not only to its visual impact and relevance to multiple scientific domains but also to its incorporation of numerous aspects of authentic scientific work. At the same time, the process was simple to perform and required minimal equipment, making it an ideal subject for inclusion in secondary school curricula.

Although a more detailed and extensive dataset would be required to unequivocally confirm and generalize the claim that repeated implementation of similar instructional approaches leads to improved student understanding of complex chemical processes—processes that are often difficult to grasp through purely theoretical instruction—the study nonetheless supports this assertion. Overall, the findings corroborate those of numerous prior studies, indicating that inquiry-based learning not only enhances students' comprehension of chemical phenomena but also fosters the development of key scientific competencies, such as analytical thinking, problem-solving, and the ability to cope with uncertainty. This instructional model thus proves to be an effective and inspiring tool for engaging students in active chemical investigation, thereby contributing to deeper learning and future success in scientific and technical disciplines.

The project was originally designed as a long-term inquiry-based activity spanning one academic year. However, its content and structure are sufficiently flexible, and its minimal material requirements allow for a shortened version suitable for standard chemistry instruction, depending on the selected level of complexity and the available laboratory resources. Within the framework of upper secondary education, the project directly aligns with curricular topics such as redox reactions, electrolysis, chemical processes in aqueous solutions, and the properties of metals, as defined in school educational programs and national curriculum guidelines. A simplified version of the project can also be adapted for lower secondary education, for instance, as a project day or laboratory exercise focusing on the electrolytic preparation of metals and observable changes in solutions under the influence of electric current. Successful implementation of the project in broader school practice requires certain teacher competencies. Primarily, it necessitates foundational experience with inquiry-based science education (IBSE), the ability to work with open-ended questions, and a willingness to accept that experimental outcomes may not always be predictable. It is also advantageous if the teacher can integrate knowledge from multiple scientific disciplines (chemistry, physics, and technology). From a methodological perspective, it is beneficial to provide teachers with specific worksheets and methodologically developed lesson plans, enabling them to implement the project effectively even without extensive prior preparation.

LITERATURE

Acar Sesen, B., & Tarhan, L. (2013). Inquiry-based laboratory activities in electrochemistry: High school students' achievements and attitudes. *Research in Science Education, 43*, 413-435. https://doi.org/10.1007/s11165-011-9275-9

Ali, M. T., Woldu, A. R., & Yohannes, A. G. (2022). High school students' learning difficulties in electrochemistry: A mini review. *African Journal of Chemical Education, 12*(2), 202-237. https://www.ajol.info/index.php/ajce/article/view/229361

Beneš, A., Drastík, F., Hostinský, Z., Koutský, J., & Němec, J. (1974). *Nauka o kovech.* SNTL – Nakladatelství technické literatury.

Carmody, W. R., & Wiersma, J. (1967). A study of the silver tree experiment. *Journal of Chemical Education, 44*(7), 417-419. https://doi.org/10.1021/ed044p417

Han, J. H., Khoo, E., Bai, P., & Bazant, M. Z. (2014). Over-limiting current and control of dendritic growth by surface conduction in nanopores. *Scientific Reports, 4*(1), 7056. https://doi.org/10.1038/srep07056

Henychová, H., & Machková, V. (2023). Počítačové animace a simulace elektrolýzy a galvanického článku jako prostředek podpory názornosti ve výuce chemie na střední škole. *Biologie-Chemie-Zeměpis, 32*(2), 2-11. http://dx.doi.org/10.14712/25337556.2023.2.1

Housecroft, C. E., & Sharpe, A. G. (2014). *Anorganická chemie.* Vysoká škola chemicko-technologická v Praze.

Jegstad, K. M. (2024). Inquiry-based chemistry education: A systematic review. *Studies in Science Education, 60*(2), 251-313. https://doi.org/10.1080/03057267.2023.2248436

Khan, M. S., Hussain, S., Ali, R., Majoka, M. I., & Ramzan, M. (2011). Effect of inquiry method on achievement of students in chemistry at secondary level. *International Journal of Academic Research, 3*(1), 955-959. https://kubanni-backend.abu.edu.ng/server/api/core/bitstreams/a1e6ed6c-f862-431f-a8dc-d5250ffd3b17/content

Kim, S. J., Ko, S. H., Kang, K. H., & Han, J. (2010). Direct seawater desalination by ion concentration polarization. *Nature Nanotechnology, 5*(4), 297–301.
https://doi.org/10.1038/nnano.2010.34

Kondratiev, V. V., & Tolstopyatova, E. G. (2024). Theoretical courses and laboratory practice as the key to successful education in electrochemistry. *Journal of Solid State Electrochemistry, 28*(3), 1199-1204.
https://doi.org/10.1007/s10008-023-05588-6

Kratochvíl, B. (2007). Crystallization of Pharmaceutical Substances. *Chemické Listy, 101*(1), 3-12.

Liu, H., Cheng, X. B., Jin, Z., Zhang, R., Wang, G., Chen, L. Q., & Zhang, Q. (2019). Recent advances in understanding dendrite growth on alkali metal anodes. *EnergyChem, 1*(1), 100003.
https://doi.org/10.1016/j.enchem.2019.100003

Orosz, G., Németh, V., Kovács, L., Somogyi, Z., & Korom, E. (2023). Guided inquiry-based learning in secondary-school chemistry classes: a case study. *Chemistry Education Research and Practice, 24*(1), 50-70.
https://doi.org/10.1039/D2RP00110A

Parvez, K., Li, R., Puniredd, S. R., Hernandez, Y., Hinkel, F., Wang, S., XinLiang, F., & Mullen, K. (2013). Electrochemically exfoliated graphene as solution-processable, highly conductive electrodes for organic electronics. *ACS Nano, 7*(4), 3598–3606.
https://doi.org/10.1021/nn400576v

Popov, K. I., Živković, P. M., & Nikolić, N. D. (2016). Electrochemical aspects of formation of dendrites. *Zastita Materijala, 57*(1), 55-62.
https://doi.org/10.5937/ZasMat1601055P

Saricayir, H. (2010). Teaching electrolysis of water through drama. *Journal of Baltic Science Education, 9*(3), 179-186.
https://doi.org/10.4236/ce.2019.101007

Supasorn, S., Khattiyavong, P., Jarujamrus, P., & Promarak, V. (2014). Small-scale inquiry-based experiments to enhance high school students' conceptual understanding of electrochemistry. In F. Tao (Ed.), *Education, Research and Innovation* (81st ed., pp. 85-91). IACSIT Press.
https://doi.org/10.7763/IPEDR.2014.V81.14

Šmídl, M., Špitálská, T., & Šícha, V. (2022). Vznik dendritických krystalů kovů ve vodných roztocích účinkem stejnosměrného elektrického proudu. *Biology-Chemistry-Geography/Biologie-Chemie-Zeměpis, 31*(1), 41-46.
http://dx.doi.org/10.14712/25337556.2022.1.3

Tsaparlis, G. (2019). Teaching and learning electrochemistry. *Israel Journal of Chemistry, 59*(6-7), 478-492.
https://doi.org/10.1002/ijch.201800071

Turner, K. L., He, S., Marchegiani, B., Read, S., Blackburn, J., Miah, N., & Leketas, M. (2024). Around the world in electrochemistry: a review of the electrochemistry curriculum in high schools. *Journal of Solid State Electrochemistry, 28*(3), 1361-1374.
https://doi.org/10.1007/s10008-023-05548-0

Wheeler, L. B., & Bell, R. (2012). Open-ended inquiry: Practical ways of implementing inquiry in the chemistry classroom. *The Science Teacher, 79*(6), 32-39.
https://1url.cz/ZJf84

Xu, C., Zhang, Y., Fan, C., & Abys, J. A. (2005). Driving force for the formation of Sn whiskers: compressive stress-pathways for its generation and remedies for its elimination and minimization. *IEEE Transactions on Electronics Packaging Manufacturing, 28*(1), 31–35.
https://doi.org/10.1109/TEPM.2005.846461

Yu, P., Lowe, S. E., Simon, G. P., & Zhong, Y. L. (2015). Electrochemical exfoliation of graphite and production of functional graphene. *Current Opinion in Colloid & Interface Science, 20*(5–6), 329-338. https://doi.org/10.1016/j.cocis.2015.10.007

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What does water hide?

Jan Hrdlička, Alena Šrámová, Lenka Sedláková

Abstract

Supplementing traditional 'indoor' education with outdoor education can help increase student's motivation and create space for all-round student education. The purpose of outdoor education is to connect the teaching text as much as possible with the real environment and what students can actually observe around them. The out-of-school learning "What does water hide?" was one of the choices for the inter-subject thematic days for the second year of secondary school. In the field of chemistry, the teaching focused on the measurement of selected properties of water in the natural environment. The little pond Brdatka were selected for the measurements. This place is easily available from Beroun The content of some ions is relatively easy to determine, such as some other properties – temperature, pH, conductivity or oxidative-reduction potential, which can be easily determined with a Vernier probes. Students completed simple pre- and post-measurement tests as a part of the topic day. As part of their participation in the topic day, they made a short presentation. This presentation was intended to convey the knowledge and experience gained to the other students in the year-class. These presentations were given in a moderated 'conference'.

Keywords

Outdoor education; STEM; chemistry education

INTRODUCTION

Outdoor education is a pedagogical approach aimed at the all-round development of students in a natural environment outside the traditional school classroom. The aim of outdoor education is to connect the teaching text as much as possible to the real environment and to what students can actually observe around them. Another aim of outdoor education is to develop students' key competences and skills. Key competences include a wide range of skills that help students to develop collaboration, problem-solving skills, critical thinking and scientific methodology to promote environmentally responsible behaviour.

Hofmann (2011, pp. 310-311) defines outdoor education as "a comprehensive form of learning involving a variety of teaching methods, including observation, experiment, design method, cooperative methods, and experiential pedagogy. In terms of its organisational form, outdoor education uses field exercises, nature walks, excursions, thematic trips and expeditions, the importance of such teaching being primarily based on students' work in the field, outside the school".

KEY ELEMENTS OF OUTDOOR EDUCATION

Due to outdoor education, students are more closely connected to their surroundings and the surrounding nature. The emphasis is on experiential learning in the natural environment. This allows students to experience direct contact with nature and contributes to a deeper understanding of its laws. Such experiences not only strengthen the emotional relationship with nature but also lead to the development of environmental awareness and personal responsibility for environmental protection. Being in nature and having direct experience of natural processes, such as plant growth, animal life or the water cycle, helps students to better understand the ecological context, promotes sensitivity to environmental issues and motivates them to behave sustainably in their daily lives (Chawla, 2006; Wells & Lekies, 2006).

In learning through their own experiences and hands-on activities in nature, students engage all their senses, and this teaches them to explore the world through personal experience. Practical tasks such as measuring temperature, pH or other chemical and physical parameters promote deeper retention and understanding of the material. Outdoor learning gives students the opportunity to combine theory with practice, which greatly increases their motivation and interest in learning. Outdoor education improves learning outcomes – improved knowledge test scores, better student attitudes towards school, enhancement of school behaviour, raising of attendance and overall superior student outcomes have been observed. Thus, outdoor education contributes to increased teaching effectiveness (American Institutes for Research, 2005; Blair, 2009; Dyment, 2005; Lieberman & Hoody, 1998). German research has also shown significant improvements in literacy, writing skills, and mathematics for children attending ”forest kindergarten” (Gorges, 2011). Outdoor education also has a positive impact on the development of critical thinking skills understood as a process of deliberate self-regulated evaluation and decision making, i.e., problem-solving skills involve students’ ability to interpret, analyse, evaluate, reason, explain, and self-regulate (Ernest & Monroe, 2004). Another benefit is the development of personal and social skills. One of the key competences that are also developed is the ability to cooperate and communicate. Outdoor activities are often designed to encourage cooperation between students. Solving tasks and overcoming challenges together helps to develop teamwork skills, effective communication, respect for others’ opinions and the ability to resolve conflicts and thus take responsibility for work done together.

Outdoor education also benefits problem-solving and challenge-taking skills. It offers unpredictable situations that motivate students to find creative solutions. For example, when exploring unfamiliar terrain, adapting to changes in the weather or navigating in nature, students learn independence, develop self-confidence and improve their decision-making skills. This promotes students’ emotional, behavioural and intellectual development (Chawla, 2006; Kellert, 2005; Lester & Maudsley, 2006).

Regular exercise in nature improves physical fitness, promotes healthy muscle and bone development and reduces the risk of civilisation diseases. Being outdoors also has a beneficial effect on students’ mental well-being, reduces stress and helps improve concentration and mood, not only for students but also for teachers (Bell & Dyment, 2006; BTCV, 2009; Dyment & Bell, 2008; Kuo & Faber Taylor, 2004; Muñoz, 2009; Wells & Evans, 2003). Research by Blair (2009) and Dyment (2005) has shown that students prefer this type of learning to traditional classroom learning. Outdoor education thus represents a comprehensive approach to developing not only academic knowledge, but also key skills and values that help students develop a harmonious relationship with themselves, other people and the environment.

RESEARCH AIM AND HYPOTHESES

PISA (Programme for International Student Assessment) science education performance is tested within each testing cycle. The last PISA testing focused on science literacy was in 2015 and the next one will be in 2025 (Česká školní inspekce, n.d.). PISA science education testing focuses on students’ ability to apply knowledge and skills in science, such as biology, physics, chemistry and geography, to real-world problems. (Eivers, Shiel & Pybus, 2008) The test includes questions that require critical thinking, data analysis and reasoning about scientific phenomena. Science test results provide a picture not only of students’ level of knowledge, but also of their ability to apply scientific practices and understanding of natural phenomena. The PISA testing in 2022 showed that students from the Czech Republic ranked slightly above the OECD average in science education, which was a better result than in 2018 (Boudová et al., 2023, pp. 29-33). The study suggest that the challenge for the Czech education system is to innovate in science education and improve conditions for the development of critical thinking in students.

PISA results also point to various factors that influence the level of science education, including: educational policy, socio-economic factors, teaching methods (interactive and hands-on science teaching has a positive impact on student achievement), and teachers and the school environment themselves (Boudová et al., 2023, pp. 29-33).

The PISA results also show that promoting critical thinking and the ability to apply scientific principles to real-world problems is essential for improving student performance in science (OECD, 2024). The challenge for the Czech Republic is to innovate teaching methods, promote scientific thinking and develop science teaching qualifications. Therefore, it is very important to focus on the undergraduate preparation of future teachers and to introduce them to a rich variety of activating teaching methods during their studies. The authors of the article believe that one of the possible ways to improve students’ relationship with science and to support the development of key areas of science literacy is to include outdoor education among the commonly used teaching methods in school practice.

The key areas of scientific literacy defined by the PISA tests are scientific explanation of phenomena, planning and evaluating scientific investigations, and interpretation of measured data (OECD, 2023).

The aim of the research is to demonstrate the role of outdoor education in the development of key competences in science education as defined by the PISA tests.

Research hypotheses:

1. Hypothesis: Students who participate in outdoor learning show a higher degree of integration of knowledge from different subjects. There is a seamless and non-violent integration of the individual teaching subjects in the implementation of outdoor learning. Students connect knowledge from different learning areas and put it into new contexts when completing tasks. Questions are asked in the pre-test and post-test, that are not "typical" of one subject but put knowledge from several subjects into context.

2. Hypothesis: Outdoor education promotes problem-solving competence. Students devise procedures for solving problems or tasks and put them into practice. In the project, these include sample recruitment, the procedure for determining the properties of a sample, and/or recording the evaluation and interpretation of the measurements.

3. Hypothesis: Outdoor education improves cooperation and communication between students.In a working group of students brainstorming takes place, students discuss ways of solving a problem, the facts found and also prepare an output presentation. The evaluation of the presentation was carried out by the teachers according to predefined criteria.

THE RESEARCH PROCESS

The participants of the research were 2nd year students 15 – 16-year-old of the Joachim Barrand Gymnasium in Beroun. Within the framework of the "project days", which are organized every year, the students could choose among the offered "projects". 90 students were divided according to their interest into historical, science and language activities. The distribution of students was not equal. 22 % of them chose the science area, which is 20 students. 33 % opted for the historical area, and the remaining 45 % of students chose language activities. The group of students who chose science oriented activities consisted of 19 students from a four-year grammar school and one student from an eight-year grammar school. The theme of the science day was "What does water hide?". The students were divided into 6 working groups according to their preference. There were 6 stations prepared for the students, where the groups took rotation.

First, the students had to invent and build a device to take water samples from different depths using pre-prepared utilities. These utilities were hose, rod, rope, paint attachment, rubber bands, beakers. The students then worked with the collected samples at the different stations. At the first station, they determined the temperature of the water depending on the depth of the sample. At the second station, they measured the pH and saw if it changed with the depth of the sample. The third station was devoted to the oxidation-reduction potential (ORP). At the fourth station they determined the cations and anions in the water samples by indicating stripe. Dissolved oxygen probe was at the fifth station and conductivity probe was at the sixth station.

The students were introduced to Vernier probes and their handling at school. After completing the pre-test, they packed their outdoor measurement kits (school lab-kit), which were transported to the selected site. The site chosen by the teachers was a small reservoir called Brdatka near Beroun. The students moved to the site on foot. The teachers chose the site according to predefined criteria: time availability, access to water, safety during teaching, hygienic safety of the resource. The teachers checked in advance what outcomes could be expected.

The knowledge tests were designed to include questions that have cross-curricular overlap and are not taught in either science subject. Thus, students had to draw on knowledge from multiple subjects and reflect on their answers. The pre-test and post-test were validated by consulting five teachers of chemistry, biology and physics who teach at the high school. The analysis of the prepared pre-test and post-test showed that at least some of the questions given in the post-test should be modified to make it different from the pre-test. The questions were modified by reversing the meaning of the question from the pre-test otherwise by negating the question. Subsequently, the teachers agreed that the test as designed was appropriate for the students. The pre-test and post-test were administered to check the comprehensibility and difficulty to the students of the 2nd year of the bachelor's degree in chemistry teaching at FPE WBU in Pilsen.

The questions asked in the pre-test and post-test including the correct answers are given in Table 1. Questions marked with an asterisk are those that were given in the post-test by negation.

Table 1: Test questions and their correct answers

Question	**Correct answer**
Q1: The hardness of water	Depends on the amount of dissolved cations.
Q2: The unit for the water conductivity is *	mS
Q3: Calcium ions dissolved in spring water come from *	Limestone
Q4: The greening of water in reservoirs during the summer, technically eutrophication, is caused by	Too high nutrient levels, mainly nitrates and phosphates.
Q5: Estimate the optimal pH for most organisms living in water	6–8

RESULTS

Already the fact that only 20 % of the students chose a science project already suggest a dislike of science subjects. After interviewing the students who chose science activities, it was found that 20 % of them (4 students) chose the subject because of their classmate and 25 % (5 students) chose the activity because of their teacher.

Hypothesis 1: Students who participate in outdoor learning show a higher degree of integration of knowledge from different subjects.

The results of the pre-test and post-test are shown in the following figures (Figure 1 and Figure 2). For the post-test responses for the negated questions, the inverted value of the response was shown in the graph. No analysis of the questions was conducted with the students after the pre-test. Three weeks elapsed between the pre-test and post-test. 80 % of the students participated in the pre-test (i.e. 16 students), 60 % of the students participated in the post-test (i.e. 12 students).

Correct answers to the Question 1 (d) in the post-test are 91.7 %, a clear increase from the pre-test (62.5 %) (Figure 1). Thus, the correct answer to this question is better conveyed by completing the outdoor class and consolidated in memory due to personal experience with measurement. The proportion of correct answers to the Question 2 (b) in the post-test is 41.7 %, a clear increase compared to the pre-test (18.8 %) (Figure 2). Although this question focusing on a simple fact is clearly difficult, memorisation of the unit of conductivity, although it should be known from physics, is not even at the level of half of the students.

The correct answers to Question 3 (b) in the post-test are 83.3 %, a decrease from the pre-test (93.8 %) (Figure 2). 7 students answered the question correctly each time. The percentage decrease in the success rate may be due to the fact that the same students answered the question correctly. And it points to the fact that the students did not associate the information about the source of calcium ions in the water near Beroun with the location and the geological substrate. The percentage of correct answers to the Question 4 (b) in the post-test is 75 %, a slight increase from the pre-test (68.8 %) (Figure 2). Another important factor is that there has been a decrease in incorrect answers. The Question 5 showed the most obvious improvement (91.7 % vs. 75 %) (Figure 2), with a significant decrease in incorrect answers, thus clarifying the major influence of pH on aquatic life.

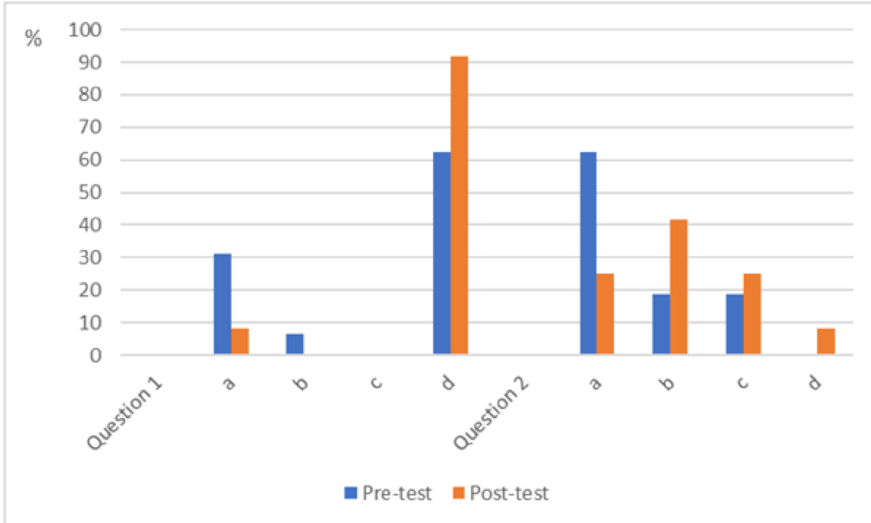

Figure 1: Percentages of answers to questions 1 and 2.

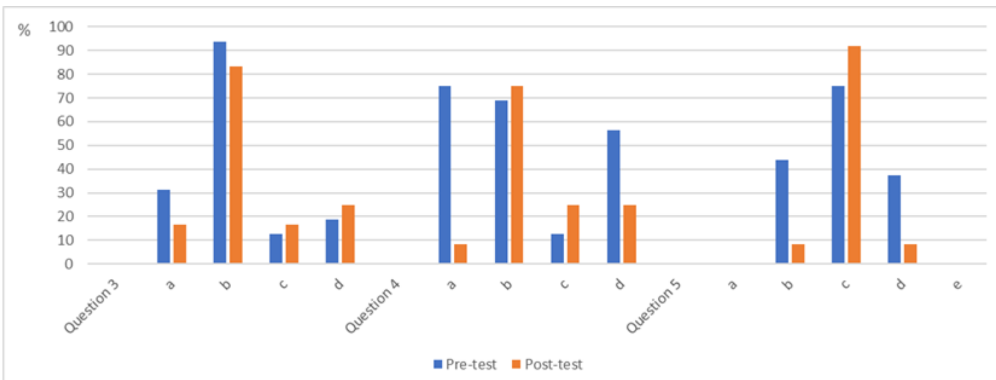

Figure 2: Percentages of answers to questions 3, 4 and 5.

The percentages of correct answers obtained in the pre-test and post-test were statistically verified. After evaluating the Shapiro-Wilk test, it was found that the obtained results did not have a normal distribution. Therefore, McNemar's pair test was used to compare the pre-test and post-test results, which ultimately did not show the above improvement at a statistically significant level and therefore did not support the hypothesis that completing the above-described outdoor activity has an effect on knowledge improvement.

Hypothesis 2: Outdoor education promotes problem-solving competence.

In the field, students had to figure out how to determine the depth of the reservoir and how to sample from each depth. Students could ask the teacher for different tools, which were transported to the site by car. At first, the groups worked independently, but gradually all the groups joined together and invented a sampling device together.

The students prepared an improvised sampling device from a hose and a pole to sample water from different depths. They then split back into working groups and started working at each station with the measuring devices. The students made tables for the measurements, evaluated them and compared them with the other groups.

While working on the individual stations, the students had to solve the problem situations that arose. All groups except one, which measured the water temperature first, had to re-sampling the water just before the measurement, otherwise the results were biased. The group that measured the water temperature as their third task measured the same temperatures in all of them. After consulting each other in the group and slight assistance from the teacher, the students discovered that the water had been warmed by the surrounding air.

Another problem that the students had to solve was technical. Some groups had incorrectly checked the battery status of their school laptops and ran out of battery during the measurement. To complete the work successfully, they installed an app on their phone and used the wireless sensors to connect directly to their personal phone.

There were several problematic situations that arose during data collection and processing, and the students had to deal with all of them. If a normal school lesson had taken place, the students would most likely not have been exposed to the experiments or would not have been exposed to having to deal with so many problem situations at the same time.

Hypothesis 3: Outdoor education improves cooperation and communication between students.

The students brainstormed in working groups, discussed ways of solving the problem, the facts found and also prepared an output presentation. The work groups were monitored by the teachers. Each teacher observed two groups and noted the interactions between the students. In each work group, all students were involved. Within each group, there was a division of roles into two timekeepers and one recorder.

The students developed a presentation which they presented at the final student conference to their classmates and first year students. The students had three weeks to develop their joint presentation. The actual presentation was divided into individual measurements and its procedures, and the results were then presented by one student from each working group.

The evaluation of the presentation was carried out by the teachers according to predefined criteria. The first evaluation criterion was how the students prepared the PowerPoint presentation – design, clarity, typography, etc. The second criterion was facts accuracy – how they interpreted the measured data, how they explained the trends in the individual graphs and how they generalized the measured data. The third criterion was the evaluation of the presentation – compliance of time frame, rhetoric, language, use of technical terms, as well as the response to questions from the audience.

Different groups showed different quality of outcomes. Some students made factual errors or inconsistencies in their presentations. Some groups found it difficult to deduce a general conclusion from the measured values. Presentation delivery was of varying levels, but each group developed and presented their contribution. In addition to first- and second year students, teachers of various subjects were present at the student conference and this teachers evaluated the presentation of the groups' outputs very positively.

Students took additional video throughout the day. The students themselves came up with the idea. The activity is very positively evaluated by the authors of the paper from a social point of view. It documents very well the collaborative work, the cooperation between students and groups, the ability to question others, and the experience gained in the final processing of the video.

CONCLUSIONS

The authors of the paper are aware that the research sample is small and due this fact is a bias in the results. In the subjective assessment, there was a visible improvement in the students' knowledge, which had deepened, and there was also, according to the subjective assessment, a better connection between the subjects taught. But the objective statistical evaluation did not show the above improvement at a statistically significant level and therefore did not support the hypothesis that completing the outdoor activity described above influences knowledge improvement.

However, we consider other hypotheses about the benefits of outdoor education to be confirmed. Thus, this approach contributed significantly to improving students' skills in several key areas – improvisation, problem solving implementation, and effective communication and collaboration in problem solving. The practical focus of outdoor education has provided students with valuable experiences that allow them to better understand theory in a real-world context. Regardless of their level of initial skills, all participants were able to process their newly acquired knowledge with varying levels of depth and creativity. Based on this processing, they then created presentations that provided them with the opportunity to not only share their experiences and knowledge with others, but also to develop skills in public speaking and visual communication. Overall, this form of learning proved to be particularly beneficial in terms of developing a range of soft skills that are important to students' future professional and personal lives.

LITERATURE

American Institutes for Research. (2005). Effects of outdoor education programs for children in California. Palo Alto, CA.

Bell, A. C., & Dyment, J. E. (2006). Grounds for action: Promoting physical activity through school ground greening in Canada. Evergreen.

Blair, D. (2009). The child in the garden: An evaluative review of the benefits of school gardening. *Journal of Environmental Education, 40*(2), 15-38. `https://doi.org/10.3200/JOEE.40.2.15-38`

Boudová, S., Tomášek, V., & Halbová, B. (2023). Národní zpráva PISA 2022. ČŠI. `https://www.csicr.cz/CSICR/media/Prilohy/2023_p%c5%99%c3%adlohy/Mezin%c3%a1rodn%c3%ad%20%c5%a1et%c5%99en%c3%ad/PISA_2022_e-verze-9.pdf`

BTCV. (2009). Evaluation findings: Health and social outcomes. BTCV.

Česká školní inspekce. (n.d.). O šetření PISA. `https://www.csicr.cz/cz/Mezinarodni-setreni/PISA/O-setreni-PISA`

Chawla, L. (2006). Learning to love the natural world enough to protect it. *Barn, 2*, 57-78. `https://doi.org/10.5324/barn.v24i2.4401`

Chroustová, K., Bílek, M., & Šorgo, A. (2015). Development of the research tool to identify factors affecting the use of chemistry educational software. *Problems of Education in the 21st Century, 68*(1), 6-21. `https://doi.org/10.33225/pec/15.68.06`

Dyment, J. (2005). Gaining ground: The power and potential of school ground greening in the Toronto District School Board. Evergreen.

Dyment, J. E., & Bell, A. C. (2008). Grounds for movement: Green school grounds as sites for promoting physical activity. *Health Education Research, 23*(6), 952-962. `https://doi.org/10.1093/her/cym059`

Eivers, E., Shiel, G., & Pybus, E. (2008). A Teacher's Guide to PISA Science. Educational Research Centre, Dublin.

Ernst, J., & Monroe, M. (2004). The effects of environment-based education on students' critical thinking skills and disposition toward critical thinking. *Environmental Education Research, 10*(4), 507-522. `https://doi.org/10.1080/1350462042000291038`

Gorges, R. (2013, January 24). Waldkindergartenkinder im ersten Schuljahr. YUMPU. `https://www.yumpu.com/de/document/view/8576558/waldkindergartenkinder-im-ersten-schuljahr`

Hofmann, E., Trávníček, M., & Soják, P. (2011). Integrovaná terénní výuka jako systém. In T. Janík, P. Knecht, & S. Šebestová (Eds.), *Smíšený design v pedagogickém výzkumu: Sborník příspěvků z 19. výroční*

konference České asociace pedagogického výzkumu (pp. 301-315). Pedagogická fakulta, Masarykova univerzita.
https://doi.org/10.5817/PdF.P210-CAPV-2012-11

Kellert, S. R. (2005). *Building for Life: Designing and Understanding the Human-Nature Connection.* Island Press.

Kuo, F. E., & Faber Taylor, A. (2004). A potential natural treatment for attention deficit / hyperactivity disorder: Evidence from a national study. *American Journal of Public Health, 94*(9), 1580-1586.
https://doi.org/10.2105/ajph.94.9.1580

Lieberman, G. A., & Hoody, L. L. (1998). *Closing the achievement gap: Using the environment as an integrating context for learning.* SEER: Poway.

Lester, S., & Maudsley, M. (2007). *Play, naturally: A review of children's natural play.* National Children's Bureau.

Muñoz, S. A. (2009). Children in the outdoors: A literature review. Sustainable Development Research Centre.

OECD. (2023). *PISA 2025 Science Framework.*
https://pisa-framework.oecd.org/science-2025/assets/docs/PISA_2025_Science_Framework.pdf

OECD. (2024). *PISA 2022 results (Vol. III).*
https://www.oecd.org/content/dam/oecd/en/publications/reports/2024/06/pisa-2022-results-volume-iii_1933a4a1/765ee8c2-en.pdf

Rosdiana, A. F., Busono, R. R. T., & Yosita, L. (2020). Student learning motivation on Actionbound application implementation in construction and building utilities subject. *IOP Conf. Series: Materials Science and Engineering, 830*(4), 042085.
https://doi.org/10.1088/1757-899X/830/4/042085

Wells, N. M., & Evans, G. W. (2003). Nearby nature: A buffer of life stress among rural children. *Environment and Behavior, 35*(3), 311-330.
https://doi.org/10.1177/0013916503035003001

Wells, N. M., & Lekies, K. S. (2006). Nature and the life course: Pathways from childhood nature experiences to adult environmentalism. *Children, Youth and Environments, 16*(1), 1-24.
https://doi.org/10.1353/cye.2006.0031

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Birdwatching in the Non-Breeding Season: A Long-Term Project for Years 7-9 in Secondary School

Miia Aine Tissari, Janice Kay Forry, Dagmar Říhová

Abstract

This study deals with a guided, cross-curricular birdwatching project carried out during the non-breeding season. Over seven years, 181 pupils in Years 7-9 from two schools in the Central Bohemian region participated in the 5-month project focused on observing and identifying 33 local bird species. A paired-samples t-test of all pupils confirmed that the pre- to post-test improvement was statistically significant ($t(180) = -44.71, p = 0.001$), with a large effect size (Cohen's d = 1.36). On average, pupils' accuracy in bird species identification improved from 16 % to 47 %. Follow-up data revealed that 51 % of pupils continued birdwatching two years after the project. These findings show that long-term, natural science-based projects can enhance environmental knowledge, increase interest in local biodiversity and support the development of environmental stewardship.

Keywords

Ornithology; environmental education; guided project-based learning

INTRODUCTION

Studying animals, especially birds and mammals, is an attractive topic in natural science courses in secondary schools. Pupils show particular interest in learning about animal behaviour and ecology. The average weekly time allocation for science lessons usually enables the inclusion of only a summary of animal biology, and information on animal behaviour and complex interspecies relationships within the ecosystem is often completely missing. Children need to be enabled to observe and learn about their surroundings through enquiry and exploration, thereby developing a responsible relationship with nature and the environment, understanding that nature needs to be protected in the here and now and for future generations (Bogner, 1998, p. 27). When choosing topics for projects, pupils often focus their attention on topics that are serious and relevant, but distant, e.g., plastic waste in the oceans, the ever-expanding palm oil plantations, or the fate of the Amazon rainforests (Ballouard et al., 2011, p. 1). The importance of these topics cannot be disputed, but pupils often fail to realize that protecting nature must start in their own backyard (Ballouard et al., 2011, p. 1).

To get pupils more interested in taking care of the local environment and improve their research skills, we decided that a guided 5-month birdwatching project could enable pupils to

- engage in practical, hands-on activities,
- develop observational skills,
- learn to work systematically,
- enhance the ability to process obtained information and data.

Bird-focused activities can help counteract the growing disconnect between children and nature (Louv, 2005, p. 17; Soga & Gaston, 2016, p. 94), by providing direct, local experiences of biodiversity in everyday environments. Incorporating birdwatching into the school curriculum aligns with UNESCO's educational goals for sustainable development, which emphasize systems thinking, ecological literacy and engagement with local ecosystems (UNESCO, 2017, p. 7; Sterling, 2010, p. 511). Fostering affective connections to nature is also increasingly recognized as essential for promoting long-term pro-environmental behaviour (Chawla, 1998, p. 372; Schultz, 2002, p. 68). There are several similar projects to ours, but most differ in scope or duration, and deal with younger pupils. For instance, Gache and Zbughin (2016) focused on ornithology and bird identification as an after-school activity for those pupils who wanted to be involved. Hirschenhauser et al. (2012) had a 20-week project focusing only on the Northern bald ibis (Geronticus eremita). Their project worked with expert ornithologists who taught pupils aged 8–10. White et al. (2018) completed a 6-week project for 7–10-year-olds to enhance awareness, knowledge and attitudes towards local wildlife. They found a positive correlation between the project length and improved ability to identify bird species. Another project, the Bird School Project, based in Santa Cruz, California, aims to inspire middle school pupils and teachers to connect with and care for their local environment through hands-on birdwatching and natural history education (The Bird School Project, n.d.). Over 7,000 pupils have participated in the project but no formal data on its effectiveness in improving bird identification have been published to date.

Our 5-month cross-curricular project aimed to support pupils in achieving the following goals:

1. Develop the ability to identify and count birds on/around bird feeders.

2. Observe bird behaviour at/around bird feeders.

3. Build/improve knowledge of and relationship to one's surroundings and the environment.

METHODOLOGY

We chose to tackle bird identification because birds are everywhere, in cities, towns, woods, fields and on the water. They attract attention with their appearance, song and behaviour (Gache & Zbughin, 2016, p. 46). They are often visible and fairly easy to identify. In the winter (the non-breeding season), birds are even more visible because most trees are bare, and most birds have already moulted into their adult version and have formed flocks (Wahl, 1944, p. 24; Singer, 2013, p. 6).

Ten groups of 7th–9th graders from two Central Bohemian schools (Pyšely school – 92 pupils from 2014–2018; Strančice school – 89 pupils from 2019–2021) participated. The project started with Year 7 pupils because the biology of birds is part of their curriculum. Due to the teacher's interest as an avid amateur ornithologist, pupils from Years 8 and 9 were also included. In most of the classes from both schools, there was at least one pupil who had participated in Scouts or hunting groups and had previous knowledge on bird species. The ten groups are described in more detail in Table 1.

Table 1: Composition of the ten groups of pupils from two schools that participated in the birdwatching project

Group	School Year	School	Class	Number of Pupils
S1	2014/2015	Pyšely	7	23
S2	2016/2017	Pyšely	7	21
S3	2016/2017	Pyšely	8	17
S4	2017/2018	Pyšely	8	8
S5	2017/2018	Pyšely	9	23
S6	2019/2020	Strančice	9	16
S7	2019/2020	Strančice	9	15
S8	2019/2020	Strančice	8	16
S9	2020/2021	Strančice	8	23
S10	2020/2021	Strančice	7	19

The Pyšely school is in the northern part of the Lower Sázava region in a rural town surrounded by hills, fields, meadows, and mixed forests. Gardens around the houses are generally large, with old trees and numerous shrubs. Newly built neighbourhoods, however, lack extensive vegetation and resemble a "green desert". The Strančice school is in a town close to the D1 motorway, not far from Prague. Over the past 15 years, the village has undergone significant changes in character where typical rural gardens are gradually disappearing, giving way to extensive residential development. The landscape is gently undulating, dominated by fields with a few mixed forests. From the teacher's communication with pupils, the Pyšely pupils tended to have more interaction with nature than the Strančice pupils (personal communication with Miia Aine Tissari).

The five-month project covered most of the non-breeding season (October to March), and because bird species migrate back to the region at different times (see, e.g., Svensson et al., 2016, p. 8; Khil, 2022, p. 14), more species could be observed. The extended project gave pupils more space and time to decide on key factors, e.g., type of bird feeders, feed, placement, means of reporting on bird numbers, and journaling. Having a longer project also meant improved understanding of the subject, ensured better absorption of information, and incorporation of the topic into cross-curricular subjects such as art, geography, languages, and mathematics.

Because the educational goal was to improve attitudes toward the local environment, the bird species chosen for our project were the most common, local and easily identifiable species that pupils could see in their backyards. Accessibility was key. The number of bird species included was also dependent on the pupils' age, abilities, and the amount of time available. Table 2 shows the final list comprising 33 species.

Table 2: Bird species observed, grouped by order and family

PASSERIFORMES			
Paridae & Aegithalidae	**Fringillidae**	**Turdidae & Passeridae**	**Others**
Great tit *(Parus major)*	European greenfinch *(Chloris chloris)*	Common blackbird *(Turdus merula)*	Eurasian jay *(Garrulus glandarius)*
Eurasian blue tit *(Cyanistes caeruleus)*	Eurasian bullfinch *(Pyrrhula pyrrhula)*	Mistle thrush / Song thrush *(Turdus viscivorus / Turdus philomelos)*	Eurasian nuthatch *(Sitta europaea)*
Marsh tit / Willow tit *(Parus palustris / Parus montanus)*	European goldfinch *(Carduelis carduelis)*	Fieldfare *(Turdus pilaris)*	European robin *(Erithacus rubecula)*
Coal tit *(Periparus ater)*	Eurasian siskin *(Spinus spinus)*	House sparrow *(Passer domesticus)*	Dunnock *(Prunella modularis)*
Crested tit *(Lophophanes cristatus)*	Hawfinch *(Coccothraustes coccothraustes)*	Eurasian tree sparrow *(Passer montanus)*	Yellowhammer *(Emberiza citrinella)*
Long-tailed tit *(Aegithalos caudatus)*	Eurasian chaffinch *(Fringilla coelebs)*	Eurasian wren *(Troglodytes troglodytes)*	Eurasian magpie *(Pica pica)*
	Brambling *(Fringilla montifringilla)*		

OTHER ORDERS			
Piciformes	**Columbiformes**	**Accipitriformes**	**Galliformes**
Great spotted woodpecker *(Dendrocopos major)*	Eurasian collared dove *(Streptopelia decaocto)*	Eurasian sparrowhawk *(Accipiter nisus)*	Common pheasant *(Phasianus colchicus)*
Middle spotted woodpecker *(Dendrocopos medius)*	Common wood pigeon *(Columba palumbus)*	Common kestrel *(Falco tinnunculus)*	
European green woodpecker *(Picus viridis)*			

Stage 1: Introduction to the project – An open discussion addressed how we can help birds when winter is coming. Pupils are tested on their knowledge using photos of the 33 common local bird species chosen. Pupils evaluated their results. A correct answer for one point included both the genus and species, a half-correct answer for half a point included only the genus or, in some cases, the species if the name is commonly used. A

completely incorrect answer received no points. Pupils then suggested ways to improve their knowledge. The teacher guided pupils toward a birdwatching project. Pupils researched various types of bird feeder stations and details on placement to decide what is best for their locations and then set up their bird feeder stations at their homes.

Stage 2: Birdwatching – Pupils observed birds that came to their feeders from the end of October to the middle of March. First, pupils were given key guidelines to become observers, meaning to behave in a way so that no harm should come to the birds (Khil, 2022, p. 39). Pupils researched information on suitable clothing (warm, inconspicuous – not bright colours), tools, and equipment for birdwatching and identification. Pupils recorded their observations and experiences in "bird journals" (in their chosen form, e.g., hand-written, on the computer). Throughout this period, they could consult their teacher with any problems or uncertainties. They also learned to use binoculars, bird atlases, and identification keys (e.g., Svensson et al., 2016; Schmid, 2020).

Stage 3: Oral presentations – In the middle of each March, each pupil prepared a 5-minute presentation on what they considered the most interesting bird species that visited their bird feeder. Because the project was cross-curricular, pupils often added drawings, paintings, and photos from their art or geography classes to their presentations.

Stage 4: Post-test – At the end of March, pupils were tested again on the same 33 bird species using the same photos and evaluation format as at the beginning of the project. Pupils then calculated the difference between their points in the first and final tests and assessed their own progress.

Stage 5: Conclusion – Feedback on the project was obtained through a teacher-mediated discussion in which pupils reflected on their experiences, test results, changes in attitude toward the environment and possible ways to improve the project. Each pupil was asked to describe their most memorable experience from birdwatching. Pupils calculated class results from birdwatching (which species showed up the most and which was never seen). They also used maps to plot bird species occurrences to see if certain species appeared more in one location than another (see Figure 1). Pupils used their bird journals, drawings, photos and maps to create an exhibit open to parents for one afternoon and accessible to schoolmates and teachers for a week.

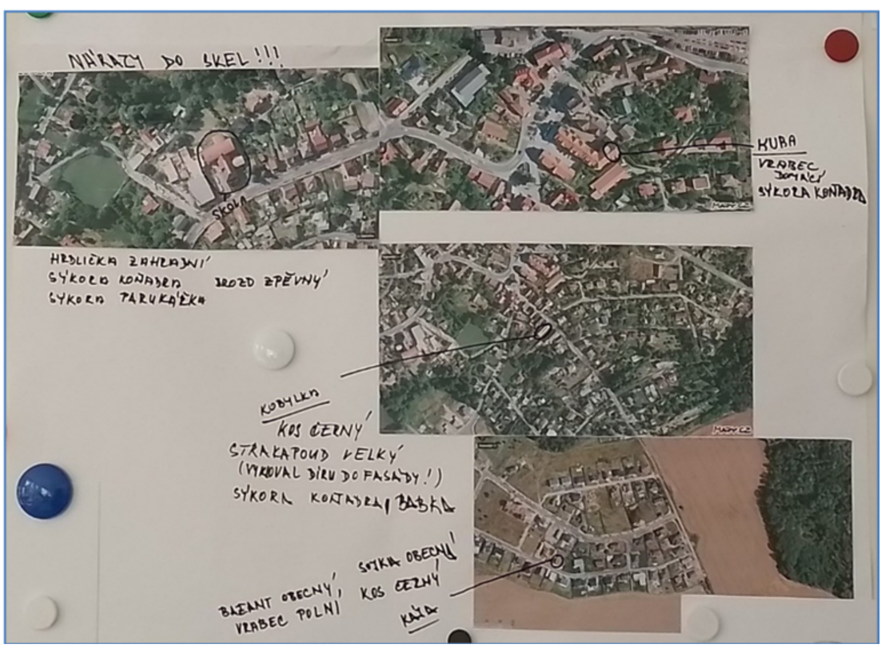

Figure 1: In groups, pupils marked maps to show the location of their bird feeding stations and listed the most frequently seen species at their locations. Photo: Miia Aine Tissari.

Although the birdwatching project was not originally designed for in-depth statistical analysis, the pupils' results provided sufficient data for basic analysis. Data from the pre- and post- tests were processed by the teacher using Microsoft Excel (v16.86) for standard deviation of the population (STDEV.P – used because group sizes varied) and Cohen's d to determine how much of an effect the project had (see Figure 2). The proportion of fully correct answers from Pre-test and Post-test was calculated by dividing the number of fully correct responses by the total number of responses. Other statistical analyses were conducted using Python (v3.10) with the scipy.stats library. A paired-samples t-test was used to compare pre-test and post-test scores within the same participants (ttest_rel), and an independent-samples t-test was conducted using Welch's correction for unequal variances and sample sizes (Pyšely: $n = 92$; Strančice: $n = 89$) to compare post-test scores between the two schools. The results in Figure 3 were obtained from an e-mail survey of previous participants.

RESULTS

Between 2014 and 2021, ten groups of 7th–9th graders from two Central Bohemian schools (Strančice and Pyšely) completed the guided project focused on birdwatching and identification. In total, 181 pupils aged 13–15 from classes, ranging in size from 8–23 pupils, participated. A paired-samples t-test of all pupils that participated in the 5-month birdwatching project confirmed that the pre- to post-test improvement was statistically significant ($t(180) = -44.71$, p .001), while an independent-samples t-test with unequal variances found no significant difference in post-test scores between schools ($t(87.5) = 1.20$, $p = .231$). Figure 1 shows mean pre- to post-test bird identification score improvements across the ten classes at both schools. Cohen's d values also indicate positive effect sizes (moderate to large) for every class. However, the magnitude of improvement varied across classes, with the highest effect sizes in S7-S10 (Strančice) and S1 (Pyšely), suggesting more pronounced learning gains in those groups. Conversely, classes such as S2 showed improvement, but comparatively smaller, reflecting differences in group dynamics and prior knowledge. Error bars in Figure 2 represent 1 standard deviation, calculated using STDEV.P, to reflect variability at the class level. In some classes (e.g., S1, S3, and S4), post-test scores were more tightly grouped, which may suggest pupils had become more consistent in their understanding. In others (e.g., S2 and S9), the range of scores widened, which may point to differences in how pupils responded to the project. Interestingly, low pre-test variability may simply reflect limited prior knowledge rather than genuine consistency. Despite these differences, the overall gain – from 16% to 47% accuracy of complete responses – highlights the project's potential as a broadly effective model for nature-focused learning.

Before and after the project, the most known species remained mainly the same but changed in order from most to least known. In the pre-test, the best known was the great tit (*Parus major*), followed by the blue tit (*Cyanistes caeruleus*), the European blue jay (*Garrulus glandarius*), and the blackbird (*Turdus merula*). In the post-test, the best known was the blue tit and the great tit, followed by the blackbird and then the crested tit (*Lophophanes cristatus*). Some species were difficult to identify before and after the project as well, either because these species (e.g., *Prunella modularis*, *Fringilla montifringilla*, *Turdus pilaris*) were less colorful or because they did not show up at the bird feeders. Therefore, pupils were less familiar with them.

The most surprising incorrect answers occurred when pupils confused the great spotted woodpecker (*Dendrocopos major*) with a black woodpecker (*Dryocopus martius*), known as a "datel" in Czech. Later, we realized that some educational posters used in classrooms mistakenly had a picture of a great spotted woodpecker under the letter D for "datel".

Several factors could have directly influenced post-test gains in this study. These include individual differences in pupils' prior knowledge of birds and general science ability. Some pupils demonstrated high identification skills from the outset, leaving little room for measurable improvement. Environmental conditions, such as local bird diversity, habitat quality, and bird feeder visibility, likely varied between school sites and individual pupils' homes. In particular, the placement of bird feeders was constrained by the pupils' living situations (e.g., flats vs. houses), which may have affected their exposure to bird species during the project. These factors highlight opportunities for further research using more controlled or context-sensitive designs.

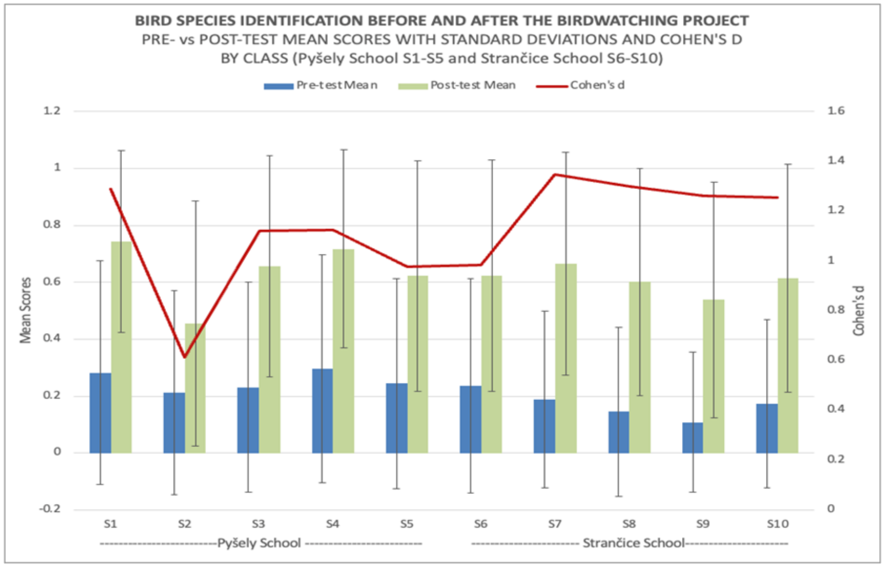

Figure 2: Mean pre-test and post-test scores for bird species identification across ten classes in two Central Bohemian schools (Pyšely and Strančice) participating in the guided project. Blue bars indicate mean scores from the pre-test administered prior to the project; green bars show means from the post-test given after the birdwatching project was completed. Error bars represent ± 1 standard deviation, calculated using STDEV.P, based on full class-level data. The red line denotes Cohen's d, illustrating the standardized effect size of the project for each class, where values of 0.2, 0.5, and 0.8 typically represent small, medium, and large effects, respectively (Cohen, 1988).

Families also got involved with the project. Pupils often reported back that their family members had started birdwatching as well. The amount of involvement can be seen in Figure 3: active involvement (in blue) meant that family members helped feed and observe the birds. Passive involvement (in orange) meant that they bought bird feed but did not feed or observe. No involvement (in grey) meant that pupils bought bird feed and cared for the feeders themselves.

An e-mail survey found that 51 % of pupils (two years after they finished the project) were still feeding or observing birds, thus supporting our project goal of improving environmental stewardship.

As mentioned in the Introduction, most projects do not match our project in scope or duration. Other examples of projects address a different age group, e.g., the Nord University's European Bird ID Program, which ran from 2010-2018, involved 798 adult students from nine European countries who underwent an online bird identification test before the study, followed by field tests and subsequent online exams. Their results indicated significant improvements in both visual and auditory bird identification skills (Husby et al., 2024, p. 20) and may support adding online identification programs to our project in the future. Our results, however, are most comparable with those from the project of White et al. (2018, p. 6). Their 220 pupils aged 7–10 from 8 schools showed a 42.6% increase in their ability to identify 12 bird species after participating in a 6-week project. Our pupils showed a 47% increase in accuracy after our five-month project. Both projects found a positive correlation between the length of the project and the improved ability to identify bird species.

CONCLUSION

By watching birds, pupils learned to identify the species that come to their feeders, observe and register different bird behaviours, and discover how to care for birds properly. In most pupils, a more profound interest in studying these animals and a higher desire to protect birds and their environment was piqued. Based on the final discussions with pupils in Stage 5 of the project, the project had helped pupils to become more aware of their local surroundings, with pupils seeing that certain birds prefer certain areas of the

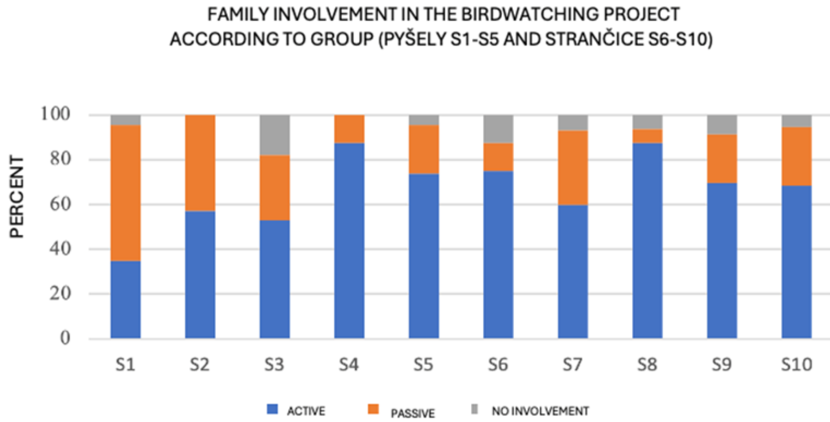

Figure 3: Family involvement in the birdwatching project for groups S1–S5 (Pyšely school) and S6–S10 (Strančice school). Blue indicates active family involvement, orange indicates passive involvement; grey indicates no family involvement (for details, see text).

municipality (from maps they had prepared), types of trees, and bushes. The pupils' feeling of environmental stewardship has also changed; they started caring more about whether the birds have enough food or clean water sources available. Our results show that science-based projects can positively impact education, help build environmental awareness, and form and strengthen pupils' feelings of stewardship toward nature.

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LITERATURE

Ballouard, J.-M., Brischoux, F., & Bonnet, X. (2011). Children prioritize virtual exotic biodiversity over local biodiversity. *PLOS ONE, 6*(8), e23152.
`https://doi.org/10.1371/journal.pone.0023152`

Bogner, F. X. (1998). The influence of short-term outdoor ecology education on long-term variables of environmental perspective. *The Journal of Environmental Education, 29*(4), 17-29.
`https://doi.org/10.1080/00958969809599124`

Chawla, L. (1998). Significant life experiences revisited: A review of research on sources of environmental sensitivity. *Environmental Education Research, 4*(4), 369-382.
`https://doi.org/10.1080/1350462980040402`

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.

Gache, C., & Zbughin, G. (2016). Environmental education through ornithology like optional classes. In M. Shelley, S. Alan, & I. Celik (Eds.), *Proceedings of the International Conference on Education in Mathematics, Science and Technology (ICEMST)* (pp. 46-50). ISRES Publishing.
`https://www.epess.net/index.php/epess/article/view/150/150`

Hirschenhauser, K., Frigerio, D., Leithinger, V., Schenkenfelder, I., & Neubock-Hubinger, B. (2019). Primary pupils, science and a model bird species: Evidence for the efficacy of extracurricular science education. *PLOS ONE, 14*(7), e0220635.

https://doi.org/10.1371/journal.pone.0220635

Husby, M., Fiskum, T. A., Belchev, B., Bino, T., Hristov, I., Keišs, O., Kuzyo, H., Samotskaya, V., Šćiban, M., & Šoštarić, I. (2024). Effective learning and testing of bird identification skills. *Journal of Biological Education.* https://doi.org/10.1080/00219266.2024.2386256

Khil, L. (2022). *Příručka k pozorování ptáků.* Kazda.

Louv, R. (2005). *Last child in the woods: Saving our children from nature-deficit disorder.* Algonquin Books.

Schmid, U. (2020). *Poznáte ptáky našich zahrad?* Kazda.

Schultz, P. W. (2002). Inclusion with nature: The psychology of human-relations. In P. Schmuck & P. W. Schultz (Eds.), *Psychology of sustainable development* (pp. 61-78). Springer. https://doi.org/10.1007/978-1-4615-0995-0_4

Singer, D. (2013). *Krmení ptáků v zimě – Pozorujeme, určujeme a správně krmíme.* Grada.

Soga, M., & Gaston, K. J. (2016). Extinction of experience: The loss of human-nature interactions. *Frontiers in Ecology and the Environment, 14*(2), 94-101. https://doi.org/10.1002/fee.1225

Sterling, S. (2010). Learning for resilience, or the resilient learner? Towards a necessary reconciliation in a paradigm of sustainable education. *Environmental Education Research, 16*(5-6), 511-528. https://doi.org/10.1080/13504622.2010.505427

Svensson, L., Mullarney, K., & Zetterström, D. (2016). *Ptáci Evropy, severní Afriky, a Blízkého východu.* Ševčík.

The Bird School Project. (n.d.). About the Bird School Project. Retrieved May 9, 2025, from https://www.birdschoolproject.org/

UNESCO. (2017). *Education for Sustainable Development Goals: Learning objectives.* United Nations Educational, Scientific and Cultural Organization. https://unescodoc.unesco.org/ark:/48223/pf0000247444

Wahl, V. (1944). *Pražské ptactvo – Ptáci velkoměsta a jeho okolí.* Česká grafická unie a.s.

White, R. L., Eberstein, K., & Scott, D. M. (2018). Birds in the playground: Evaluating the effectiveness of an urban environmental education project in enhancing school children's awareness, knowledge and attitudes towards local wildlife. *PLOS ONE, 13*(3), e0193993. https://doi.org/10.1371/journal.pone.0193993

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