

GAMIFICATION AND VISUAL MODELS AS TOOLS TO SUPPORT UNDERSTANDING OF ATOMIC STRUCTURE AMONG SECONDARY SCHOOLS STUDENTS

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Abstract

Atomic structure is one of the most abstract and challenging topics in chemistry education. Students often struggle to visualize submicroscopic structures and to grasp atomic models and the concept of orbitals. Traditional lecture-based methods frequently prove insufficient, leading to decreased motivation and the reinforcement of misconceptions. The aim of this project was to develop and evaluate the effectiveness of alternative teaching methods for atomic structure, based on gamification and analogical models. It is assumed that incorporating elements of play and narrative (e.g., the periodic table as a game board, orbitals as airplane flight paths) enhances students' understanding, engagement, and long-term retention of knowledge. The study involved a group of secondary school students divided into an experimental group (taught using games and analogies) and a control group (taught using traditional methods). The effectiveness of the methods was assessed through a knowledge test, a questionnaire on perceived difficulty, and observation of student activity during lessons. Additionally, interviews with students and teachers were conducted to evaluate the attractiveness and educational potential of the developed models. The findings indicate that the use of gamification and analogical thinking significantly improved students' comprehension of abstract concepts and increased their motivation to learn chemistry. The results may serve as a basis for developing a set of innovative teaching tools and lesson plans that foster scientific competencies through play, experience, and imagination.

Keywords: *Gamification, analogical models, analogical thinking, alternative teaching methods in chemistry.*

1. Introduction

The teaching of chemistry belongs to areas of science education in which students often encounter difficulties due to the high level of abstraction of presented concepts. One of the most demanding topics is atomic structure, as it requires operating at the submicroscopic level and integrating multiple representations of knowledge, such as graphical models, symbolic notation, and mathematical interpretations (Johnstone, 1991). Students must develop the ability to imagine invisible structures and understand theoretical models, which often leads to alternative conceptions and misconceptions (Taber, 2013).

The literature indicates that difficulties in learning chemistry arise not only from the nature of the content but also from the dominance of traditional lecture-based teaching methods. Transmission-oriented approaches limit students' opportunities to actively construct knowledge and develop deep conceptual understanding (Gilbert & Treagust, 2009). In response, constructivist-based strategies increasingly emphasize the active role of the learner.

One such approach involves the use of cognitive analogies, which help students map familiar experiences onto new scientific concepts, reducing cognitive load and supporting mental representation building (Orgill & Bodner, 2004). Gamification is also gaining importance as a strategy supporting intrinsic motivation and engagement through narrative, challenges, and immediate feedback (Hamari, Koivisto, & Sarsa, 2014; Kalogiannakis, Papadakis, & Zourmpakis, 2021).

Despite growing research on analogies and gamification, their integration as a coherent instructional environment influencing cognitive, emotional, and metacognitive processes remains underexplored. The present study aims to address this gap by analyzing the effects of an integrated instructional approach in teaching atomic structure.

2. Objectives

The main objective of the study was to evaluate the effectiveness of integrating instructional analogies and gamification elements in teaching atomic structure.

The specific objectives included: determining the impact of the applied methods on the level of conceptual understanding of chemical topics, analyzing students' emotional experiences during the learning process, assessing the development of metacognitive competencies, such as self-regulation of the learning process, investigating the potential for knowledge transfer and the ability to apply analogies in new contexts.

3. Methods

The study had a quasi-experimental design and involved 150 participants, mostly secondary school students (72.8%), with the remainder at the university level. The sample was predominantly female (73.9%) and mainly aged 15–19. The instructional approach was based on a constructivist learning model (Bransford, Brown, & Cocking, 2000). The experimental group participated in lessons integrating instructional analogies and gamification elements, including visual analogies linking atomic structure to familiar objects and narrative activities such as interpreting the periodic table as a game board. The aim was to support spatial imagination and promote active knowledge construction through familiar experiential schemas, while the control group followed traditional instructional methods.

Data collection used triangulation of methods, including Likert-scale quantitative surveys, qualitative analysis of open-ended responses, and observations of student activity during lessons.

4. Results

The analysis revealed significant differences between the experimental and control groups in both cognitive outcomes and emotional experiences. In the experimental group, most students reported improved understanding of atomic structure, easier memorization, and better visualization of submicroscopic concepts, indicating that analogies and gamification effectively reduced the abstract nature of the content.

In contrast, only about 30% of students in the control group reported understanding the material. Many experienced difficulties related to visualizing atomic structures and lacked effective learning strategies, often relying on rote memorization. Emotional analysis showed that around 80% of control group participants experienced high stress levels associated with cognitive challenges, leading to frustration and decreased motivation.

Positive educational emotions such as curiosity, engagement, and cognitive comfort predominated in the experimental group. Students emphasized that analogies helped them conceptualize invisible processes, while gamification promoted active participation and reduced fear of making mistakes. More than half of the experimental group also reported improved metacognitive skills, including self-regulation and the development of individual learning strategies.

5. Discussion

The findings indicate that integrating instructional analogies with gamification produced multidimensional effects across cognitive, emotional, and metacognitive domains. Analogies supported the construction of mental representations of submicroscopic structures, facilitating a shift from rote learning to deeper conceptual understanding. Gamification enhanced engagement, reduced stress, and created a psychologically safe environment that encouraged experimentation and problem-solving.

Students also demonstrated increased metacognitive awareness and benefited from social learning through collaboration and discussion. A conceptual model emerges in which analogies reduce cognitive abstraction, while gamification strengthens emotional engagement and psychological safety, together supporting deeper processing and improved knowledge transfer.

The contrast between groups highlights the relationship between cognitive understanding and emotional experience. Control group students often experienced stress linked to difficulties in visualizing abstract concepts, which led to reliance on memorization and decreased motivation. These findings align with previous research suggesting that analogies function as cognitive bridges and that gamification enhances engagement and learner agency.

6. Conclusions

The study suggests that integrating analogical models and gamification can effectively support the teaching of highly abstract topics such as atomic structure. The approach simultaneously influenced cognitive, emotional, and metacognitive dimensions, improving understanding and increasing learner autonomy.

Analogies facilitated mental representation and conceptual understanding, while gamification enhanced engagement and participation. Clear differences between experimental and control groups highlight the importance of instructional design that addresses both cognitive and emotional aspects of learning. Such approaches may transform traditional teaching into environments that foster scientific thinking, creativity, and metacognitive development.

However, the approach may increase cognitive intensity, indicating the need to adjust pacing and instructional design. Future research should examine long-term effects on knowledge retention and transfer skills.

References

- Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.
- Clark, R. C., Nguyen, F., & Sweller, J. (2006). *Efficiency in learning: Evidence-based guidelines to manage cognitive load*. San Francisco, CA: Pfeiffer.
- Gilbert, J. K., & Treagust, D. F. (Eds.). (2009). *Multiple representations in chemical education*. Dordrecht: Springer.
- Hamari, J., Koivisto, J., & Sarsa, H. (2014). Does gamification work? A literature review of empirical studies on gamification. *Computers in Human Behavior*, 54, 152–161.
- Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*, 7(2), 75–83.
- Kalogiannakis, M., Papadakis, S., & Zourmpakis, A. (2021). Gamification in science education: A systematic review of the literature. *Education Sciences*, 11(1), 22.
- Orgill, M., & Bodner, G. M. (2004). What research tells us about using analogies to teach chemistry. *Chemistry Education Research and Practice*, 5(1), 15–32.
- Ryan, R. M., & Deci, E. L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective. *Contemporary Educational Psychology*, 61, 101860.
- Taber, K. S. (2013). Revisiting the chemistry triplet: Drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemistry Education Research and Practice*, 14(2), 156–168.
- Treagust, D. F., Harrison, A. G., & Venville, G. J. (1998). Teaching science effectively with analogies: An approach for pre-service and in-service teacher education. *Journal of Science Teacher Education*, 9(2), 85–101.