Support models for simulation-based inquiry learning of the photoelectric effect

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Abstract. This practitioner inquiry study evaluates two support models, Model Order Progression (MOP) and Concept Maps (CM), for inquiry-based learning of the photoelectric effect. The support models were evaluated on their impact on cognitive load, knowledge, retention, and scientific literacy. Results did not show a significant difference between the two models; however, the effect size showed a modest difference: MOP resulted in a smaller cognitive load, and CM showed better knowledge retention. In a follow-up study, the findings were used in combination with modeling instruction. This integrated approach offered a more effective way to support students in inquiry-based learning.

Introduction and background

One of the subjects in the physics curriculum of Dutch high schools is quantum physics. Quantum physics poses significant conceptual challenges for students, especially due to the mathematical complexity of quantum mechanics. To overcome this complexity, simulations can be used as they can visualise these complex concepts without the necessity for complex mathematics. A starting point for quantum physics can be the photoelectric effect [1], about which the University of Colorado made a great simulation that offers many possibilities for simulation-based inquiry learning [2].

Inquiry-based learning is used to achieve greater active engagement of students in the learning process. However, its effectiveness has been questionable, attributed to factors like lack of prior knowledge, inquiry skills, and cognitive load [3]. To overcome these factors, two different support models for inquiry learning were investigated in this practitioner inquiry (research conducted by teachers [4]).

Setup of study and results

This study evaluates Model Order Progression (MOP) in combination with the use of tables [5, 6] and Concept Maps [7] for teaching the photoelectric effect to 33 pre-university students in their final year (17 – 18 years old). MOP offers a structured method for exploring the relationships between variables with the aid of tables, while Concept Maps (CM) provides a holistic view of the domain structure. The impact on cognitive load, knowledge gain, retention, and scientific literacy was assessed through two post-tests with multiple choice- and essay questions. The questions in these tests were based on literature [8-11] but adjusted for the photoelectric effect.

This study's comparative analysis of the two support models revealed no significant differences between MOP and CM. Effect size calculations offered a more subtle view of their relative strengths. MOP support slightly reduced cognitive load and facilitated immediate knowledge acquisition, suggesting its utility in scaffolding the initial stages of inquiry by providing a clear, structured approach to exploring variable relationships. In contrast, CM support showed a slight advantage in promoting knowledge retention, potentially due to its holistic representation of domain structure, which may aid in the integration and long-term retention of complex concepts.

These findings underscore the complexity of designing effective instructional supports for inquiry-based learning in physics. The modest effect sizes indicate that neither model definitively outperforms the other across all measured outcomes, suggesting that the choice between MOP and CM may depend on specific instructional goals, such as whether the immediate reduction of cognitive load or the long-term retention of knowledge is prioritized.

One of the main problems with inquiry learning was the lack of inquiry skills among the students, which was revealed by the essay questions. In a follow-up of this study, the findings were used in combination with the modeling instruction approach [12]. In this approach, students received a research question about the relationship between two variables instead of just being given tables to fill as was done with MOP. Each group obtained its own, unique research question. All the findings were gathered, compared, and discussed with the students in a group discourse. During the discussion, the concept map of the photoelectric effect was constructed. The first results of this approach were promising.

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