Scientific Reasoning with Interactive Diagrams in Primary Education

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Abstract

The growing attention for natural sciences in primary education is typically aimed at the development of practical experimental skills. Natural scientific reasoning, in which thinking back and forth between phenomena and explanations forms the connecting factor, remains underexposed. The focus of our study is on how interactive diagrams and matching experiments can support scientific reasoning and thus scientific literacy. We start with three design studies, which successively investigate how (1) the complexity of diagrams can be tailored to the developmental level of students, (2) the interactivity of diagrams can be adapted to the developmental level, and (3) the dialogue that arises during collaboration influences diagram construction. Finally (4), an effect study is carried out to examine the effects of the interactive diagrams on scientific literacy in school practice. Results of a preliminary study show that the approach enables several types of scientific reasoning, in a more autonomous way than in traditional science classes. Therefore, it is intended that this approach leads to an innovative teaching method that better meets the cognitive needs in upper primary education.

Keywords

interactive concept diagrams, scientific reasoning, primary science education

1. Introduction

Thinking back and forth between the world of phenomena and the world of ideas is essential for the development of scientific literacy [1]. It is therefore important to pay attention to scientific insights in science and technology education in addition to research skills [2, 3]. Particularly when creating scientific explanations (minds-on) from practical experiments (hands-on), forms of cognitive processing are necessary such as ordering, schematizing and modeling [4].

Current Science and Technology teaching practice (S&T) in primary education is often limited to doing individual 'experiments', i.e. mainly hands-on activities [5, 6] while minds-on activities such as reasoning with arguments are important for the development of understanding [7]. However, this requires advanced teaching strategies and pedagogical content knowledge. As a result, science lessons in upper primary education tend to focus on hands-on elements, rather than on the understanding of the underlying concepts. Consequently, the way in which focusing on thinking skills and conceptual understanding could take place in upper level of primary education requires further investigation [8].

One way to promote the learning of higher thinking skills, such as scientific reasoning, is to use diagrams as external representations for creating knowledge [9]. This allows students to create and manipulate knowledge constructs on the computer screen [10]. By providing diagrams with automated interactivity, students can receive direct, formative feedback on their actions. An important question is how and in what form the automated feedback can be provided and adapted to the needs and development of students [9].

We have created lessons on various types of scientific reasoning which combine short, hands-on practical activities with minds-on learning through interactive diagrams. These lessons are made available as web-based applications [11].

The central question is how our approach can be used to promote scientific reasoning among students in upper primary education.

2. Problem outline

The aim of this PhD research is to gain new insights into how the use of interactive diagrams as a learning technology for science education can lead to an improvement in this type of reasoning, resulting in an increase in the effectiveness of science and technology education [12, 13].

The PhD research consists of four phases. The first three phases are design studies, which successively investigate:

1. how the complexity of diagrams can be tailored to the developmental level of students,

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Proceedings of the Doctoral Consortium of the 19th European Conference on Technology Enhanced Learning, 16th September 2024, Krems an der Donau, Austria.

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2. how the interactivity of diagrams can be adapted to the developmental level, and
3. how the dialogue that arises during collaboration influences diagram construction.

These three phases then culminate into an intervention (study 4), in which the effects of the interactive diagrams on scientific literacy are examined in school practice.

2.1. Research problems

In order to explore how interactive diagrams and matching experiments can support scientific reasoning and thus scientific literacy, the following problems need to be addressed:

1. What are adequate levels of complexity of interactive diagrams, taking into account individual differences in developmental level of students?

2. What are effective forms of adaptive feedback, when the learning needs of individual students are taken into account?

3. What is the effect of collaboration on the quality of the diagrams to be constructed?

4. What are the effects of working with interactive diagrams on the scientific reasoning skills and knowledge level of individual students?

In the next sections, these problems are discussed in more detail.

2.2. Problem domain

To represent a particular content, combinations of visual symbols and written language offer opportunities to scaffold students in the development of their scientific reasoning [14, 15].

Concept diagrams lend themself well to being digitized, as for instance done with the Cmap software [16, 17]. Adding a certain level of responsiveness can turn digital concept diagrams into interactive learning aids. These so-called interactive diagrams are applied in secondary scientific education [18, 19]. The application used in this study, however, is developed for use in primary education..

3. Methodology

3.1. Study 1: Complexity

Study 1 investigates how the complexity of diagrams can be defined and determined so that diagrams used in education can be tailored to the developmental level of the students.

In this research, complexity is operationalized on the basis of (a) the average level of familiarity with the vocabulary on which the reasoning and the associated diagram is based, and (b) the number of concepts and mutual relationships between these concepts.

To tailor the diagram complexity to the development level, the complexity levels of the diagrams are categorized. By measuring at different levels of diagram complexity, it can be determined how the quality of the diagrams to be constructed relates to the complexity of a certain type of diagram and adjustments can be made accordingly.

3.2. Study 2: Interactivity

Study 2 investigates how the interactivity of the diagrams can be adapted to the development level and learning needs of individual students.

Automated feedback takes place via automated evaluation of student-computer interactions, subsequently presented to the student via visual cues in the diagram. This software evaluation takes place (1) when the student selects, positions and/or connects diagram elements, and (2) during task performance and after task completion.

By varying the interactivity in the ways described above, the effectiveness of the different forms of automated feedback can be determined by measuring the quality of the diagrams that are constructed.

3.3. Study 3: Collaboration

Study 3 investigates how the dialogue that arises during collaboration among students influences the quality of the diagrams they construct.

Research shows that conversational activities stimulate the development of scientific reasoning [20]. Also, collaborative discussion, in which students respond to each other's ideas in a constructive way, offers opportunities to improve thinking and learning of science [21].

In general, working in heterogeneous groups offers a more challenging learning environment than working in homogeneous groups [22]. To investigate whether the composition of pairs based on developmental level has an effect on the quality of the diagrams that are constructed, students are clustered in homogeneous or heterogeneous pairs. By determining the diagram quality per student and analyzing the vocabulary and the quality of the reasoning of the dialogue, the effect of mutual cooperation is examined.

3.4. Study 4: Effect

Study 4 is an effect study on a larger scale in which the effects of working with the interactive diagrams on both the development of scientific reasoning skills and the subject-matter knowledge level of students are investigated.

Through the previous studies, insights have been gained about (1) complexity, (2) interactivity, and (3) collaboration. In study 4, these insights are combined into an experimental pretest/posttest design with a retention measurement.

3.5. Contributions

Potential contributions to solving the problem on technology enhanced learning are:

1. A validated measure for determining the complexity of diagrams.
2. Interactive diagrams that are tailored to the performance level of students in terms of complexity.
3. Insights into the effects of different forms of adaptive feedback.
4. Insight into the effect of collaboration on the quality of the diagrams constructed.
5. Insights into the effect of working with interactive diagrams on the individual development of scientific reasoning skills and professional knowledge.

4. Results

4.1. Preliminary ideas

By using representations of scientific thinking and working methods, also called crosscutting concepts [23, 24], we investigate different types of diagrams associated with (1) reasoning in patterns, (2) causal reasoning, and (3) reasoning in systems. To realize this, the predict-observe-explain routine of primary science education is translated into a web-based application called Minds-On [11, 12, 13].

4.2. Proposed approach

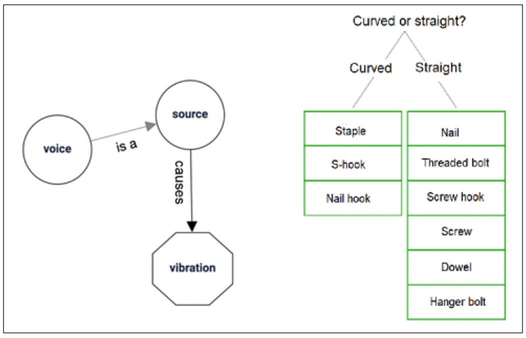

Figure 1: Examples of diagrams: causal reasoning (left) and classification (right) [12].

The Minds-On application shows a section of the diagram with its ingredients (Figure 1), consisting of nodes (individual concepts) and lines (relationships). The appearances of both the nodes and the lines depend on their type (e.g., circular nodes denote objects, thin arrows denote 'has/is' relationships and bold arrows denote causal relationships). Before filling in a diagram, students conduct an experiment relating to the concepts in the diagram (e.g. about the properties of 'sound'). As an initial scaffold, one or more concepts are already in place in the diagram. Next, students can drag and drop concepts into diagram nodes, during which automated feedback is presented in the form of evaluative statements. Until all concepts are placed correctly, students also receive automated feedback by means of a check function. After successfully completing a diagram step, students progress to the next experiment. Throughout this stepwise progression, the complexity of the diagram increases, until culminating in its final form.

4.3. Preliminary Results

A study was carried out with primary school students (9-12 years, n=490) in the Metropolitan Region of Amsterdam, Netherlands, showing that most students successfully complete the task within standard lesson time. The approach enables the effective application of several types of scientific reasoning, in a more autonomous way than in traditional science classes. Results indicate that successful task completion is associated with less dependency on the interactive functions. However, since a minor proportion of the students did not use the interactive functions as envisioned, we conclude that additional forms of interactivity, focusing on vocabulary and reasoning abilities, are necessary [12].

5. Concluding remarks

Diagrams for scientific reasoning have already been implemented successfully, although most studies concern middle-school students (or higher), who create diagrams from scratch [25]. The pre-formal developmental stages that characterize students in Primary Science Education (PSE) are less advanced, and ask for a more object-related, scaffolded approach. Therefore, a unique design element is the stepwise building up of the concept, by combining short hands-on experiments with the corresponding part of the interactive diagram. Interactive functions, such as the presentation of inference statement to the student during construction of the diagram, and a check-function after completing each diagram step are considered essential for the scaffolding of scientific reasoning at the primary level. The built in datalogger allows for detailed measurements of relevant user parameters.

Acknowledgements

The research presented here is co-funded by The Netherlands Organization for Scientific Research (NWO), PhD-grant for teachers, grant number 023.0I7.002 and the Dutch Regie-orgaan SIA, project Minds-On, grant number RAAK.PUB06.033.

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