

UNDERSTANDING HOW STUDENTS LEARN TO APPLY SCIENCE IDEAS – MANY MODELS THINKING AS A UNIFYING APPROACH?

Modern science standards and policy documents stress the importance of students being able to apply science ideas to make sense of the natural and engineered world. Therefore, this ability and its diagnosis and promotion has been described from numerous theoretical models and perspectives, e.g., within models of competency, theories of domain expertise, or knowledge-in-use. While these different theoretical models provide a similar vision of their goals for science education, there is a lot of variation in how exactly they conceptualize science learning and what aspects of science learning are emphasized over others. For example, the knowledge-in-use model heavily emphasizes how exactly students should be able to apply their knowledge but the description of underlying dispositions remains less detailed. In contrast, there are theoretical models of competency that describe the underlying dispositions very detailed. However, these models rarely describe how exactly students are expected to use their knowledge. Theoretical perspectives derived from research on domain expertise stress how the knowledge, skills, and abilities needed to make sense of the world by drawing on science are shaped by the social norms and specialized ways of knowing in communities of practice. Although each of these theoretical models provides valuable implications for science education, it is challenging to balance all of them. To be able to balance these different theoretical models that provide similar visions and goals, many models thinking, which has been used with great success in other domains, seems to be a promising approach. This approach considers variations in theoretical models as a resource to draw upon. The premise of many models thinking is to use ensembles of different theoretical models to make sense of complex phenomena – and science learning certainly is a complex phenomenon.

This symposium aims at starting a conversation about how many models thinking can successfully be applied in science education research that focuses on models of student learning. The first presentation will delineate what many models thinking encompasses and consider Blömeke et al's continuum model as a common frame of reference against which different theoretical lenses can be compared and contrasted. The second presentations will present the knowledge-in-use perspective, focusing on the performance side of Blömeke et al's model. The third presentation will present a competency perspective that emphasizes the dispositional aspects of the Blömeke model. The fourth presentation will point out a perspective rooted in expertise research that emphasizes the situation-specific skills and social dimension of Blömeke et al's model. Finally, James Pellegrino will introduce and guide the discussion about how ensembles of theoretical models around competency, expertise, and knowledge-in-use can be framed by many models thinking and whether such a unification can help to promote our understanding of how students learn to apply their science knowledge.

Keywords: Scientific Literacy, Science Education, Learning Theory

MANY MODELS THINKING AND ITS POTENTIAL FOR THEORY DEVELOPMENT

Being able to apply science ideas to make sense of the natural and engineered world around us is undoubtedly a central ability in our modern society. Therefore, this ability and its diagnosis and promotion has been described within numerous theoretical models, e.g., within models of competence. In most cases, these theoretical models provide a similar vision of their goals for science education, however, there is a lot of variation in how exactly they shape science learning. Although each of these theoretical models provides valuable implications, it is challenging to balance all of them within science education. To be able to balance these different theoretical models and combine their best aspects to optimize science education, many models thinking, which has been used with great success in other domains, seems to be a promising approach. This approach argues for complementing a multitude of theoretical models to make sense of complex phenomena – and science learning certainly is a complex phenomenon. For this reason, we aim at starting a conversation about how many models thinking can successfully be applied in science education. In this symposium contribution we will give deeper insights in the approach of many models thinking and further present Blömeke et al.'s continuum model as a common frame of reference against which different theoretical lenses can be compared and contrasted.

Keywords: Scientific Literacy, Science Education, Learning Theory

A MULTITUDE OF MODELS

Depending on where one looks, one can find different labels for the ability to make sense of the natural and engineered world by drawing on science. Within the context of the US Framework for K-12 Science Education the term *knowledge-in-use* (Harris et al., 2016) has gained traction, and in the European context *competency* is an often encountered label, e.g., in the German science standards (Sekretariat der ständigen Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland, 2020). While one might be tempted to downplay these differences as mere issues of terminology, a closer look shows that there are indeed profound differences in the underlying theoretical models associated with these labels, i.e., they represent distinct theoretical lenses on the same phenomenon. Yet another theoretical lens on this phenomenon comes from research on expertise and communities of practice (Airey & Linder, 2017).

These lenses emphasize different aspects in how they model the ability to make sense of the natural and engineered world by drawing on science. The underlying models differ in their components and relationships between the components they consider and how they emphasize these components. One key distinction is whether the models primarily describe students' abilities in terms of actual performances or rather focus on the dispositions that presumably underly these performances. In the theoretical model of *knowledge-in-use* (National Research Council, 2012; NGSS Lead States, 2013) the way in which students should be able to integrate scientific practices, disciplinary core ideas, and cross cutting concepts is precisely described in terms of numerous performance expectations. However, descriptions of the underlying dispositions and their development, e.g., the development of an integrated knowledge about energy, remain relatively vague. In contrast, theoretical models of *competency*, focus much more on the dispositions underlying the desired student performances in terms of solving various problems including motivational, volitional and social aspects in learning (Weinert, 2001). Differences like these outlined here have important implications for science education research, as they lead to different conceptual and methodological consequences for science education research (see e.g., Blömeke et al. (2015)).

THE CASE FOR MANY MODELS THINKING

Given a situation where we face different theoretical lenses and underlying models, it would be naïve to try and find out what *the* proper model is and how it can be applied correctly (Page, 2018). This is caused by two reasons: first, “*all models are wrong, but some are useful*” (Box et al., 2005), what is the proper model critically depends on its intended use. Second, it at least implies an epistemological position indicating that there is such a thing as a *true* model – a position which does not only run counter the previous point but also defies modern positions in the philosophy of science and metascience (Feyerabend, 2016; Reichenbach, 1977; Smaldino, 2020). In the following, we utilize many models thinking to frame different theoretical models for the idea of combining their implications to make sense of how students develop the ability to apply their scientific knowledge in the natural and engineered world.

The core tenet of many models thinking is “*the age-old ideas that we achieve wisdom through a multiplicity of lenses.*” (Page, 2018 p. 5). In consequence, many models thinking argues for applying a multitude of models that aim at describing the same phenomenon. Using models that emphasize different aspects of a phenomenon (e.g., dispositions vs. performances) or use different ways to describe the same aspects (e.g., different statistical models) provides a fuller picture of the phenomenon at hand as such theoretical models complement each other and allow for better predictions as prediction errors cancel out so that the average of many models typically outperforms the best individual model (Page, 2011; Patel et al., 2011). However, one cannot just use any number and kind of models together to arrive at these benefits. In short, the models need to be sufficiently diverse but also fitting descriptions of the same phenomenon. Thus, the complexity, which makes it hard to capture science learning in a single model, becomes an asset in a many models thinking approach. With the models of *domain expertise*, *competency*, or *knowledge-in-use*, science education researchers already have numerous theoretical models at hand that have different theoretical underpinnings and thus emphasize different aspects of how students develop the ability to make sense of the world by drawing on. What remains to be done, is to delineate these differences so that complementary models can be purposefully selected to complement each other.

This approach is different from traditional science discourses about concurring models that focus at differences between models to invite a discussion about which model is more adequate. In contrast, a many models thinking approach would acknowledge the differences as resources that allow to fruitfully combine these perspectives in an ensemble model. In the context of science education research, a challenge in this endeavor is that most models are verbal models. Thus it is often not easy to say to what extent two models just use different terminology for the same concept or actually refer to different underlying concepts – the potential for theoretical ambiguity arising from verbal models is not singular to science education research and has recently been voiced by a number of scholars from the social sciences (diSessa, 2014; Fiedler, 2017; Fried, 2020; Smaldino, 2020). However, this challenge is a not natural phenomenon but can be addressed by starting a discussion about multiple models and thus identifying commonalities and differences that can serve as a starting point for an ensemble model.

TOWARDS A MANY MODELS THINKING APPROACH

We propose to start this discussion based on a common frame of reference that allows situating the different models relative to each other. Such a common frame of reference is the continuum model of competence (Figure 1) proposed by Blömeke et al. (2015). It describes how performances arise from dispositions which include cognitive, affective and motivational components which are effectively mediated by situation specific skills. Framing theoretical perspectives such as competency or knowledge-in-use in light of this model allows us to see the similarities and differences between these perspectives, the first step in successful many models thinking. To guide our comparison we deduced the following questions from the continuum model: 1) What

are the dispositions students should acquire?, 2) How do the different dispositions interact with each other and what do students need to coordinate them?, 3) What are typical situations in science classes and everyday-life in which these skills should be applied? and 4) What performances are expected?

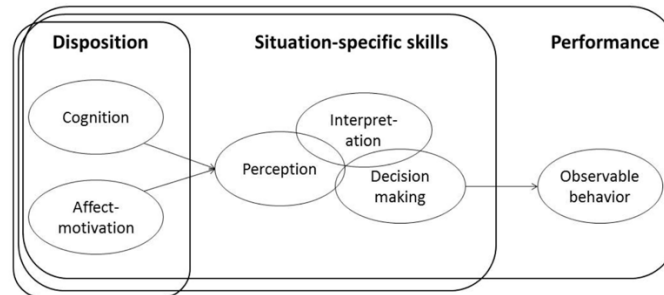


Figure 1. Competence as a continuum. Reproduced from Blömeke et al. (2015).

The answers to these questions will help us to understand where and how these theoretical perspectives can complement each other in productive ways. How exactly a resulting ensemble of models would look like is certainly beyond the scope of this text and the symposium. However, we think that even starting the conversation about how to employ many models thinking in the realm of science education will be valuable as it will lead to deliberate and careful theorizing leading to better developed, clearer theories with less ambiguity (diSessa, 2014; Page, 2018; Smaldino, 2020).

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KNOWLEDGE-IN-USE IN SCIENCE AND IMPLICATIONS FOR THE DESIGN OF LEARNING ENVIRONMENTS

A knowledge-in-use perspective, when applied to science, creates a model for science learning built on the coordinated and intertwined use of disciplinary knowledge via disciplinary practices to achieve goals around understanding phenomena or solving problems that individuals and communities face. Such a model posits that students use multiple “dimensions” of science to authentically make sense of phenomena and solve problems, and defines these dimensions. This model of science learning has profound implications for the design of learning environments, especially in terms of how to design instruction and assessment to support multi-dimensional science learning, and how to scaffold students’ developing expertise to enable them to engage in complex performances while they are developing their constituent knowledge, skills, and abilities.

Keywords: Knowledge-in-use, science practices, scientific literacy

KNOWLEDGE-IN-USE

Many current educational systems aim to promote deeper learning and foster students’ 21st century skills and capabilities (Pellegrino & Hilton, 2012). For students to succeed in tomorrow’s world, they will continue to need deeper learning, i.e., the type of learning that allow them to take what they learned and apply it flexibly and productively to new situations. Flexibility is the key in realizing this transfer, and one requirement for engendering such flexibility is that students develop a durable and interconnected conceptual knowledge base. Students must also be able to use disciplinary tools and methods in a flexible way, modified as needed to suit the particulars of the problem while being guided by their interconnected conceptual knowledge base. Knowledge-in-use emphasizes this union of using disciplinary knowledge productively through engaging in discipline-specific methods to achieve an intended outcome. Knowledge-in-use builds in the goal of transfer and assumes that transfer can only occur if students’ deeper learning has been fostered.

Science and Science Learning

As shown in Figure 1, knowledge-in-use has a particular flavor when manifest within science, which has been reified with the publication of *A Framework for K-12 Science Education* (NRC, 2012). In particular, the knowledge-in-use perspective, and the NRC framework, emphasize that students should be using science to make sense of observed phenomena and solve a variety of problems¹. To do so, they must bring to bear not only their disciplinary knowledge, but also the use of science and engineering practices (Harris et al., 2019).

The “use” in scientific knowledge-in-use: Science and engineering practices

The science and engineering practices described in the NRC Framework (2012) provide a collection of activities that form a core approach to engaging in sensemaking and applied problem-solving (see Table 1). The NRC Framework elevates the role of practices to the same level as the more traditional “science content knowledge”. Fundamentally, the NRC framework adopts a multi-dimensional perspective in order to capture the integrated and coordinated use of knowledge, skills, and abilities that scientists use to engage in sensemaking and problem solving across multiple disciplines. These practices describe the means by which students (and scientists) can *use* their disciplinary knowledge. Critically, each practice requires a unique mixture of knowledge, skills, and ability to engage in effectively. Thus, students have to learn to use the practices and practice their use repeatedly, in a variety of contexts.

¹ *Problems* in this context refers to complex STEM problems (e.g., “How could electromagnetic waves be used to transmit information?”), not traditional “plug-and-chug” problems (e.g., “Use Ohms law to determine the voltage drop that would occur if two additional 20 Ω resistors were added to the circuit shown below.”).

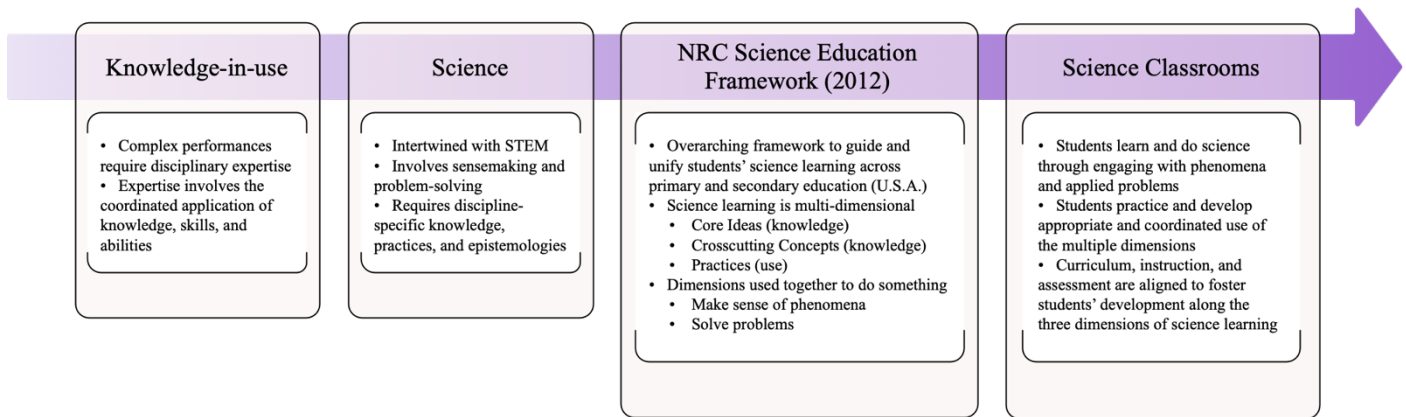


Figure 1. Schematic illustrating how a knowledge-in-use perspective manifests in science, is operationalized via the NRC Framework, and provides a corresponding vision for formal science learning environments.

Table 1. One of the three NRC Framework dimensions, which represents the “use” component of scientific knowledge-in-use.

Science and Engineering Practices (NRC, 2012)	
• Asking Questions and Defining Problems • Planning and Carrying Out Investigations • Analyzing and Interpreting Data • Developing and Using Models	• Constructing Explanations and Designing Solutions • Engaging in Argument from Evidence • Using Mathematics and Computational Thinking • Obtaining, Evaluating, and Communicating Information

Reductionism with knowledge-in-use and multi-dimensional science learning

The knowledge-in-use perspective brings two prominent features when applied to science and science learning:

- A multi-dimensional foundation that acknowledges at least two dimensions: knowledge and use
- An objective to use knowledge productively, to do something (i.e., to engage in sensemaking or problem-solving).

Therefore, students in science classrooms should engage in tasks that are complex and in which they must use their knowledge in concert with relevant science and/or engineering practices to achieve specific objectives. In doing so, however, teachers and designers of formal learning environments cannot focus just on (b). The sensemaking and problem-solving tasks have to be designed from, and connect back to, the multi-dimensional foundation of knowledge-in-use (a). To do so, requires a reductionist approach, common in experimental psychology, of reducing complex performances into their constituent pieces. These pieces must be defined and identified and connected to the multi-dimensional framework (a). The departure from traditional reductionist approaches is that those pieces have to then be built back up into the complex performances that students engage in. Those complex performances are the work that students must engage in, and the resulting artifacts and products (along with process) can be evaluated against both (a) and (b) (Harris et al., 2019). Said another way, from a students’ perspective they should see the gestalt (b) – the whole – as the driving motivation and challenge. From a teachers’ and learning designers’ perspectives, they must ensure that (a) is sufficient to enable (b), and that (b) requires (a); students must have the foundational parts necessary to enact the complex whole. To support students in putting their knowledge to use, learning environments need to be designed with that dual focus on the pieces and the whole of performance.

IMPLICATIONS FOR INSTRUCTION AND ASSESSMENT

Given the goal that students should engage in similar work as scientists and engineers, students must learn to use their disciplinary knowledge, skills, and abilities as resources that can be applied to interesting and

challenging problems. Although the reductionist approach is useful in understanding the knowledge, skills, and abilities needed to perform the task, students should not practice only this reduction. Students need extensive and varied opportunities to practice using the dimensions *together* to solve problems. In formal learning environments, these problems need to be carefully selected or designed, so that they afford students opportunities to use the targeted knowledge, skills, and abilities (Author, 2018). Multi-dimensional learning is orders of magnitude more difficult to coordinate and assess; careful planning and alignment of curriculum, instruction, and assessment is critical.

For instruction, understanding the constituent science dimensions and their associated knowledge, skills, and abilities can help teachers target and promote their students' learning. However, it would be a mistake to focus students' learning on isolated dimensions without providing them the opportunities to practice using those dimensions together. Nevertheless, using them together is difficult especially when students are still learning them. One solution is the judicious use of well-placed scaffolding within instructional tasks. Doing so can allow students to engage in complex science tasks by easing the difficulty or complexity of certain aspects of the task. This scaffolding must be targeted – it should focus on specific knowledge, skills, or abilities that are required by the task but that might serve as barriers to students' success. The reductionist approach is critical here, as it allows one to consider all the pieces and decide which ones should be scaffolded given the needs of the learners.

For assessment, understanding the constituent science dimensions is also critical. Again, the emphasis has to be on both the whole and the parts; complex performances are one of the best assessments of students' learning (as opposed to disconnected, unidimensional measures of discrete or inert knowledge) if they are carefully designed (Author, 2020). Creating these complex assessment tasks requires planning and documentation at the level of the individual dimension and associated knowledge, skills, and abilities to ensure they're effectively elicited through engaging in a complex performance to respond to the assessment task. Students' performance on the task can then be evaluated by considering their responses and/or products holistically, and in relation to indicators of their proficiency with the individual dimensions used.

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THE ROLE OF KNOWLEDGE IN PROBLEM SOLVING AS PART OF STUDENTS' RESEARCH COMPETENCE

Scientific competence means to solve problems by applying science processes, theories, models, and heuristics. Science processes, theories, models, and heuristics are referred to as science knowledge. Understanding means to be able to identify, recall, adapt, and apply this knowledge. This also includes the highly demanding skill to use this knowledge as analogies to develop new descriptions of a situation or transferring symmetries and structural similarities. Research into the role of understanding for scientific competence demands to analyze the problem-solving process in depth. In this paper, we present two studies that use different approaches for this. In the first study, we try to support students in applying their physics knowledge to an unknown experimental problem-solving situation. In the second study, we investigate in how far established indicators for dynamic problem solving are suitable to different content and contexts in order to identify how knowledge interferes with common descriptions of problem solving. From the first study, we will discuss the design necessary for such in-depth-process-analysis, see that even with high-intense support eight-grade-students struggle to successfully apply their knowledge to experimental situations, and discuss some reasons for that. The second study shows us, that ten-grade-students use different strategies to solve dynamic problems, depending on the content-context-combination of the problem. We argue that this might support the idea, that understanding of science knowledge is essential for approaching problems in a specific way. Combining the findings from both studies, the role of understanding science for science competence could be described in a more elaborated and differentiated way.

Keywords: Conceptual Understanding, scientific competence, science processes

THEORETICAL BACKGROUND

Problem-solving is widely seen as an important part of students' science competence (c.f. Waddington, Nentwig, & Schanze, 2007). In science learning situations, problem-solving can be related to experimental work (Klahr & Dunbar, 1988). Problem-oriented experimental work reflects a typical scientific research process and offers the opportunity to apply a wide range of important scientific competencies, such as modelling, planning and conducting experiments, reasoning, and communicating science content (Arnold, et al., 2018). In a nutshell, we attempt to investigate how students apply science conceptual understanding in science processes while solving problems.

Problem solving

It is known that higher expertise leads to a different problem-solving strategy than lower expertise (c.f. Kozma, 2020), and higher pre-knowledge is highly predictive for successful problem-solving (c.f. Truscucu, Spanday, & de Vries, 2020). In science education, the problem-solving process is often described in several steps (Löffler, Pozas, & Kauertz, 2018). First, students have to recognize and understand the problem, e.g. by formulating the problems as text or verbally. Second, they need to suggest and try out possible attempts for the solution, until they find and formulate the solution (3rd step). Sometimes the solution is explicitly reflected or evaluated afterwards.

While problem solving often is initiated by a static problem description that contains all relevant information about the system in which the problem is stated, recent research shifts more to the question, what is necessary to solve a problem within a dynamic situation with a certain complexity regarding the interaction of input- and output-variables. This kind of complex, dynamic problems are closer to real-life problems like the climate crises, pandemics, etc. and therefore of high relevance for educating (Funke, Fischer, & Hold, 2018). Greiff et al. (2012) describe this problem-solving in three phases: Exploration, modelling, and the actual problem-

solving as intentionally set the input-variables in a way, that the intended pattern of outcome-variables is reached.

Science knowledge

Knowledge is an important predictor for successful problem-solving. Knowledge is often understood as a network of linked concepts, that represents a certain area of a domain (Tang & Johnson, 2021). The knowledge how scientific research processes are conducted is also part of the science knowledge (Toth, Suther, & Lesgold, 2002) and might be important for describing problem-solving. On a meta-level, the knowledge about nature of science, which includes creativity (Schwartz, Lederman, & Crawford, 2004), requires certain schemata to approach problems. Those schemata are successful approaches to understand a system and they potentially connect the understanding of the problem to the established corpus of science models - so called heuristics (Graulich, Hopf, & Schreiner, 2010). Heuristics could be interpreted as hints, how to proceed when facing unknown phenomena (e.g., where does energy comes from, how is it transformed? What is the smallest portion possible in that system that can be transported?). In the light of common distinctions in national education standards it seems reasonable to assume three kinds of knowledge: Theoretical knowledge in science which means all concepts and models, procedural knowledge which means all processes that are related to science, and heuristics which means all scientific attempts to unknown systems.

RESEARCH QUESTIONS

For describing students' science competence, the application of science knowledge in problem-solving situations is essential. Although it is known that knowledge is in general important for successful problem-solving, the question remains, how science knowledge in detail interfere with the decisions and ideas during the problem-solving process and how this can be supported.

RESEARCH METHODS

The first study focuses on the question, how students make use of knowledge and if this use makes the solving process more successful. Therefore, students are supported by a prior training for conceptual understanding of three physics concepts (Newton's law of interaction, the Bernoulli effect, conservation of angular momentum) that are needed to understand the physics of dynamic lift on a wing, and two prompts given during the problem-solving. The first prompt is to apply the variable control strategy and the second how to use the theoretical knowledge in certain moments of the process. This intervention (N = 106) is compared to a group (N = 108), that does not get the second prompt. The problem-solving process is videotaped and will be analyzed according to a deductively developed category schema. The theoretical knowledge (pre-post), interest, self-efficacy, and strategical knowledge regarding the variable control strategy (pre-post) are also tested.

The second study searches for the distinction between general skills for dynamic problem solving and the physics-specific aspects. Therefore, students solve three pairs of items in a digital dynamic problem-solving system. Each pair of items bases on the same physics model, but the items have different context (e.g. rocker and scale). In the first item, the students (N = 460) have to explore the system to identify the physics model, in the second item they have to establish a certain situation (e.g. bring the scale in balance) by using their experience from the first item. The process is automatically recorded and rated along a set of indicators, that come from a study about general dynamic problem-solving (Greiff et al., 2012). A test for theoretical physics knowledge about the content used in the item-pairs and Greiff's instrument are administered to the students, too.

FINDINGS FROM BOTH STUDIES

In the first study, we found that all instruments show sufficient quality and both groups benefit from the prompts and the prior training. However, the groups do not differ significantly in their knowledge gain or in the strategical knowledge after controlling for the affective variables. The category schema shows sufficient interrater reliability. Preliminary findings from the video analysis show that the experiments present different

difficulties for the students depending on how familiar they were with the content. Analysis of response to prompting shows no significant difference between the two groups.

The second study reveals that the structure from Greiff's instrument cannot be completely reproduced, since the exploration scale shows insufficient reliability. Some indicators show different behavior in the item pairs: In two item pairs the students do not explore successfully but solve the problem in the second item, in the third item pair, it was inverted. The results, Greiff's instrument, and the theoretical knowledge test show unexpected correlations and only weak correlations overall.

DISCUSSION AND IMPLICATIONS

In the first study, the students have been supported in applying theoretical and procedural knowledge to the experimental problem-solving. From a first glance at the video analysis, we gain insight, that strengthen this knowledge for formulating hypotheses and finding interpretations of the data, is not sufficient. The impression remains, that students need a deeper understanding of that knowledge, maybe by an extended training, and better heuristics to succeed. In the second study, we see, that content leads to different exploration and problem-solving behavior, while modelling seems to be less related to the concrete content. The low and unexpected correlations with the theoretical knowledge test lead to the assumption, that students struggle with the abstract representations in physics and stay close to the context (Löffler & Kauertz, 2014), so they do not see the link between the two items in a pair. Hence, the fundamental idea of transferring physics knowledge from one context to the next, seems to need support. This again calls for stronger view on heuristics, how to approach physics problems, to make existing theoretical and procedural knowledge valuable for students in problem solving situations.

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A SOCIAL SEMIOTIC APPROACH TO DEVELOPING STUDENT REPRESENTATIONAL COMPETENCE

In this symposium paper we adopt a social semiotic lens. Following Airey & Linder (2017) we define social semiotics as the study of the development and reproduction of specialized systems of meaning making in particular sections of society. In our work we use social semiotics to understand teaching and learning in undergraduate physics. Using this lens, and building on earlier definitions, we offer a new definition of representational competence for a discipline such as physics. Our reason for doing this is in order to provide science teachers with a practical suggestion about how student learning might be organised. For our purposes we define representational competence in terms of the ability to appropriately interpret and produce a set of accepted, disciplinary-specific representations of real-world phenomena, and link these to scientific concepts. We developed this definition because many areas of science are based on using representations to create scientific explanations of real-world observations. Combining these three aspects (real world, representations and scientific concepts) into a representational competence triangle, we argue that tasks that start with one vertex of the triangle and generate the other two will necessarily practice the desired representational competence. We demonstrate the usefulness of this definition by first performing a social semiotic audit of what it entails to become representationally competent in one particular semiotic system (graphs) for one particular area of physics (1-D kinematics). Using this audit, and our definition of representational competence, we then generated three open-ended tasks that we expected would help students develop representational competence in this area. We then went on to empirically demonstrate the potential effectiveness of the three tasks by trying them out with students. We tentatively suggest that our approach may be useful in other semiotic systems than 1-D kinematics and indeed in other areas of science than undergraduate physics.

Keywords: Representations, Instructional design, Graphical representations.

INTRODUCTION

For our contribution to this ESERA symposium examining different models of competency in science education, we will discuss science learning from the perspective of social semiotics. Following Airey & Linder (2017, p95) we define social semiotics as “*the study of the development and reproduction of specialized systems of meaning making in particular sections of society*”. Within this perspective we are interested in understanding the accepted ways in which disciplinary-specific representations have come to be interpreted and used, and, naturally, how such representational competence can be taught to students.

REPRESENTATIONAL COMPETENCE

Lemke (1998) suggests that doing science requires the coordination of a wide range of semiotic resources such as graphs, diagrams, mathematics, specialist language, etc. Here, the notion of student representational competence has been suggested by a number of researchers as a way of capturing this skill of coordination (Kozma & Russell 2005; Nitz & Tippett 2012; De Cock 2012; Prain & Tytler, 2012; Linder et al. 2014; Padalkar & Hegarty 2015). Drawing on these sources, we have proposed a new definition of representational competence that we suggest is more easily operationalized by teachers in a science such as physics:

Representational competence (R) is the ability to appropriately interpret and produce a set of disciplinary-accepted representations of real-world phenomena and link these to formalised scientific concepts.

Volkwyn et al. (2020, p91)

We found it useful to represent this new definition in the form of a triangle (see Figure 1.). Next, following Lemke (1998), we note that representational competence will be made up of **a discrete set** of representational

competencies within a number of semiotic resource systems. Here, we conceptualize each system e.g. graphs (R_{GRAPH}), diagrams ($R_{DIAGRAM}$), mathematics (R_{MATH}), ... etc., as having its own version of the triangle in Figure 1. Note here that R is made up not only of the sum of these discrete representational competencies with respect to a particular concept, but also entails the ability to fluently move *between* each of these different representations of the concept to create what Airey and Linder (2009) term a critical constellation of resources with respect to the object of interest. This aspect is not the focus of this paper.

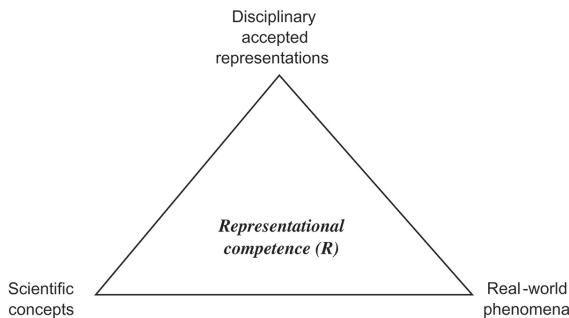


Figure 1. The representational competence triangle (Volkwyn et al. 2020, p92)

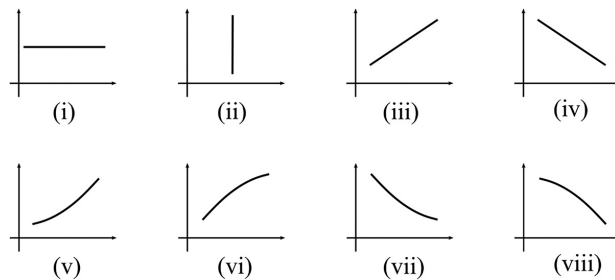


Figure 2. Semiotic audit of the generic affordances available for meaning making with graphs.

SEMIOTIC AUDIT

In order to demonstrate the usefulness of our definition we decided to apply it to one particular semiotic system (R_{GRAPH}) in one particular area of physics (1-D kinematics). To do this we first performed a semiotic audit (Airey & Eriksson, 2019) to determine the ways in which graphs were used in this area of physics and the typical types of graph. Figure 2. Shows the generic meaning making affordances of line graphs. Essentially, any graph can be composed by combining the eight different shapes. In 1-D kinematics the three graphs that are generally used are position-time, velocity-time and acceleration-time. Thus, we argue that for students to be representationally competent in graphs in 1-D kinematics, they need to be able to interpret the disciplinary meaning of the eight shapes across the three graphs and link these to real-world motion.

DEVELOPING REPRESENTATIONAL COMPETENCE

In order to operationalize our definition, encapsulated in the representational competence triangle (Figure 1.) we suggest that (R_{GRAPH}) in this area will be developed through *tasks that involve students linking the three vertices of the triangle*. We therefore designed three separate tasks. In each task, students would start at one of the vertices of the triangle and generate the other two. The tasks would also increase in complexity as the students became more familiar with the area. To help us in this project we had a laboratory tool, the iOLab (Selen, 2013) that when moved, displayed the three kinematics graphs on a computer screen in real time.

The three tasks

In task 1, the students started at the right-hand vertex of the representational competence triangle. They were asked to observe the motion of a toy car, from there, inspect the three graphs generated and finally explain the motion in terms of kinematics concepts. In task 2 the students started in the left-hand vertex of the triangle. They were instructed to create a situation in which the iOLab moved with constant acceleration. (Here, all the student pairs eventually released the iOLab on an inclined plane.) The students were then asked to predict what the three graphs would look like in terms of their shapes and directions. In task 3, students started with the upper apex of the triangle. The task required students to reproduce the same generic graph shape that they had been given across the three graphs by moving the iOLab. This proved particularly challenging and it was here that we saw definite signs of students starting to link the different shapes across the three graphs to the movement made and the kinematics concepts of position, velocity and acceleration.

DISCUSSION AND RECOMMENDATIONS

In this paper we believe that we have offered a new way of operationalizing representational competence (in the form of the triangle in Figure 1). Although the empirical work presented in this paper dealt with the application of our characterisation to the developing and practicing representational competence in one particular semiotic system for a very particular area of physics, we would argue that there are potentially wider lessons to be learned. Here we suggest that the notion of a disciplinary semiotic audit together with our description of how we constructed our three tasks from the representational competence triangle can potentially provide guidance for teachers on how to help students develop and practice representational competence in other semiotic systems for other areas of physics and indeed in science education in general.

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