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Do student perceptions of teaching predict the development of representational competence and biological knowledge?

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ABSTRACT

Dealing with representations is a crucial skill for students and such representational competence is essential for learning science. This study analysed the relationship between representational competence and content knowledge, student perceptions of teaching practices concerning the use of different representations, and their impact on students' outcome over a teaching unit. Participants were 931 students in 51 secondary school classes. Representational competence and content knowledge were interactively related. Representational aspects were only moderately included in teaching and students did not develop rich representational competence although content knowledge increased significantly. Multilevel regression showed that student perceptions of interpreting and constructing visual-graphical representations and active social construction of knowledge predicted students' outcome at class level, whereas the individually perceived amount of terms and use of symbolic representations influenced the students' achievement at individual level. Methodological and practical implications of these findings are discussed in relation to the development of representational competence in classrooms.

1. Introduction

One goal of science education is to enable students to participate in decision-making and public debate regarding scientific issues. To be scientifically literate, students need to be supported in reading, writing, and communicating in science (Krajcik & Sutherland, 2010; Norris & Phillips, 2003; Yore, Pimm, & Tuan, 2007). Reading, writing, and communicating in science do not only rely on verbal discourse and written text. Science is instead a multimodal discourse utilizing a variety of representations (e.g., graphs, diagrams, symbols, formulae) and so interpreting, constructing, transforming, and evaluating different scientific representations are crucial skills for students to build and communicate a conceptual understanding of science (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001; Lemke, 2004; Yore & Hand, 2010). These skills have been referred to as representational competence (*RC*, Kozma, Chin, Russell, & Marx, 2000; Kozma & Russell, 1997, 2005) and contribute to being scientific literate. Scientific literacy thus comprises of the interacting dimensions of fundamental literacy, including the abilities to construct and interpret scientific discourses (*inter alia* RC), and the derived understanding about the principles and foundations of science (Norris & Phillips, 2003; Yore et al., 2007).

There is a growing body of studies that explored how RC is influenced by design factors of representations or by the strategies students use to reason with representations (e.g., Canham & Hegarty, 2010; Kozma, 2003; Kozma & Russell, 1997; Stieff, 2011; Stieff, Hegarty, & Deslongchamps, 2011). However, no study we know of has empirically analysed the interactive relationship between RC and content knowledge (CK) and only a few studies have analysed how teaching practices in authentic classroom settings affect RC (e.g., Hubber, Tytler, & Hastam, 2010; Kohl & Finkelstein, 2006; Prain & Waldrip, 2006; Tytler, Prain, & Peterson, 2007). This is surprising as there is strong evidence that students'

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cognitive and affective outcomes are generally influenced by teaching practices and instructional quality (e.g., Fraser, 2003; Kunter, Baumert, & Köller, 2007; Lipowsky et al., 2009; Schroeder et al., 2011). Therefore, we argue that it is crucial to incorporate an explicit representational focus in teaching and learning science as a part of domain-specific instructional quality in order to develop students' RC. The purpose of this study was twofold: First, we examine the relationship between students' RC and CK for one specific topic in biology education. Second, we analyse how scientific representations were used in biology classes using student perceptions of the classroom and explore how this impacted upon students' RC and CK. In view of the hierarchical nature of school settings with students being nested in classes, we chose a multilevel approach to disentangle student and class effects.

1.1. *Representational competence (RC)*

There is consensus among researchers that teaching and learning science involves a variety of external scientific representations (Ainsworth, 2006; Kress et al., 2001; Lemke, 2004; Yore & Hand, 2010). To classify these different representations, various categories have been suggested but no consensus has been reached (Wu & Puntambekar, 2012). We refer to categories by Gilbert (2005) and Wu and Puntambekar (2012) that take the mode and code of representations into account. We focus on verbal-textual representations (spoken or written text, terms), visual-graphical representations with a distinction between realistic and logical pictures[3] (Schnotz, 2001), and symbolic representations in terms of chemical symbols and equations.[4]

The development of abilities for dealing and reasoning with these scientific representations is crucial for learning science. RC addresses disciplinary skills for interpreting, constructing, translating, and evaluating representations that students should acquire to become proficient and literate in the domain. It includes the abilities to (a) use representations for describing scientific concepts, (b) identify, describe, and analyze features of representations, (c) construct and/or select a representation and (d) explain its appropriateness for a specific purpose, (e) compare and contrast different representations and their information content, (f) connect across different representations, map features of one type of representation onto those of another, and explain the relationship between them, (g) realize that representations correspond to phenomena but are distinct from them, and (h) use representations in discourse to support claims, draw inferences, and make predictions (Kozma & Russell, 2005).

Studies indicate that students' RC is closely related to students' conceptual understanding of the domain (Kozma & Russell, 1997; Stieff, 2011). However, these studies did not seek to empirically distinguish between content knowledge in the domain (CK) and RC. Kozma and Russell (2005) proposed five levels of RC ranging from a novice surface-based depictive use of representations—via symbolic, syntactic, and semantic use of representations—to an expert reflective and rhetorical use of representations. However, this developmental trajectory is likely to be neither stage-like nor automatic or uniform, and depends on the use of representations and the context of that use in learning environments. Kozma & Russell pointed out that "over time and given appropriate sets of physical, symbolic, and social situations, a student will increasingly display more advanced representational skills, come to internalize these, and integrate these into regular practice" (2005, p. 134). This pedagogical insight places special emphasis on teaching practices in instructional settings as these must provide appropriate opportunities for developing RC. In line with this assumption, we are interested in students' skills using scientific representations (RC), their understanding of the domain (CK), and the impact of teaching practices in biology education.

1.2. *Representations and representational competence (RC) in science class*

To foster the development of RC and CK, science instruction should provide students with opportunities to engage actively in representational tasks that make the role and function of representations explicit (Greeno & Hall, 1997; Hubber et al., 2010; Prain & Waldrip, 2006; Stieff, 2011). However, only a few studies have explored how representations are used in science classrooms and how this is related to students' outcomes. Kohl and Finkelstein (2006) found that an increased use of representations in a large-lecture physics course led to increased representational skills. Qualitative analyses of physics teaching units provided evidence that explicit instruction and a representational focus in teaching with diverse opportunities for students to develop their RC can foster students' learning of scientific topics and deepen their conceptual understanding (Hubber et al., 2010; Prain & Waldrip, 2006; Tytler et al., 2007). However, these studies did not test specifically for RC or CK and focused on the description of the teaching practices rather than relating these to quantifiable learning outcomes. Hence, the relationship between existing teaching practices, students' RC, and CK needs to be further analysed.

1.3. *Assessing representational practices in science class through students' perceptions*

In research on instructional quality, there is much discussion concerning how to assess teaching practices. In general, students', teachers', and/or external observers' perceptions are used to this end. Empirical studies, however, found only low to moderate correlations between these different perspectives (e.g., Clausen, 2002; Kunter & Baumert, 2006). These authors pointed out that each perspective constitutes a *specific* perception of the classroom with *perspective-specific* validities depending on the research context and, thus, has a *specific* value for describing classroom-teaching practices (Clausen, 2002; Kunter & Baumert, 2006). Although it is desirable to use different perspectives for describing the complexity of the classroom environment and its impact on student learning (Seidel & Shavelson, 2007), many studies rely on students' perceptions and ratings (Fraser, 2003; Seidel & Shavelson, 2007). Students have encountered a variety of teachers and teaching practices and asking them to rate these is economically applicable in the classroom (Clausen, 2002; De Jong & Westerhof, 2001). It has been argued that aggregated student ratings constitute a shared (and more objective) perception of teaching practices rather than representing individual perceptions (Kunter et al., 2007; Lüdtke, Robitzsch, Trautwein, & Kunter, 2009; Lüdtke, Trautwein, Kunter, & Baumert, 2006). In terms of construct validity, Wagner, Göllner, Helmke, Trautwein, and Lüdtke (2013) showed that students are able to differentiate between theoretical criteria of instructional quality and describe their teachers' teaching practices in this respect. Other studies revealed the predictive validity of (aggregated) student ratings for cognitive and affective outcomes (c.f. Fraser, 2003) that is higher than the

[3] Realistic and logical pictures are visual-graphical representations. These are spatial configurations that represent a subject with structural similarities between the object and the representation. In realistic pictures, such as photographs and drawings, the similarity between the object and the representation is concrete. In logical pictures, such as diagrams and graphs, the similarity is abstract (Schnotz, 2001).

[4] These are the most prevalent modes in teaching and learning photosynthesis in German biology class, the context of our study (Nitz et al., 2012).