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Problem-based learning as a facilitator of conceptual change

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ABSTRACT

We investigated whether problem-based learning (PBL) can foster conceptual change. Students were randomly assigned to a PBL, lecture-based, or self-study group, all receiving instruction about the topic of Newtonian laws. Conceptual change was measured from pre- to immediate post-test (directly after instruction) and from immediate post-test to delayed post-test after one week. Results showed that the PBL-group outperformed both the lecture and the self-study group on the immediate post-test. This result supported the hypothesis that PBL can increase the likelihood of conceptual change. The PBL group also outperformed both other groups at the delayed post-test after one week; the decline in conceptual change from immediate to delayed post-test was similar for all three groups. Findings are discussed in terms of cognitive engagement.

1. Introduction

Learning scientific concepts is a challenging and complex process that often involves restructuring students' previously held beliefs that conflict with the scientific viewpoint. Students hold misconceptions across a variety of science topics including photosynthesis (Mikkilä-Erdmann, Penttinen, Anto, & Olkinuora, 2008), Newton's laws of motion (Kendeou & van den Broek, 2005; 2007), seasonal change (Broughton, Sinatra, & Reynolds, 2010), climate change (Sinatra, Kardash, Taasoobshirazi, & Lombardi, 2012), and emergent systems (Chi, 2008).

Restructuring students' misconceptions, also referred to as conceptual change, can be fostered through instruction that is specifically designed to help students recognize the conflict between their existing knowledge and the scientific explanation (Diakidoy, Kendeou, & Ioannides, 2003; Duit, Treagust, & Widodo, 2008; Leach & Scott, 2008; Merenluoto & Lehtinen, 2002; Sinatra & Broughton, 2011). Instructional interventions intended to promote conceptual change are most useful when they provide opportunities for students to critically weigh the scientific evidence in contrast with their prior knowledge (Broughton, Sinatra, & Nussbaum, 2013; Lombardi, Sinatra, & Nussbaum, 2013). In other words, students need to be highly *engaged* in order to process the new information deeply (Dole & Sinatra, 1998). In addition, conceptual change is more likely when students view the scientific explanation as plausible and fruitful (Posner, Strike, Hewson, & Gertzog, 1982).

An example of an instructional approach that has these characteristics and was developed with the aim of facilitating conceptual change among learners is transformative learning (Heddy & Sinatra, 2013; Pugh, 2002; 2004; Pugh, Linnenbrink-Garcia, Koskey, Stewart, & Manzey, 2010). Transformative learning experiences are those activities in which the learner applies classroom learning to his or her everyday life experiences that expand and enrich their perception (Pugh, Linnenbrink-Garcia, Koskey, Stewart, & Manzey, 2009). Students think about the ideas they learned in school in relation to events and objects outside of school. For example, a biology student may think more deeply about the different shapes of bird's beaks when she sees a hummingbird in nature after learning about the variety and utility of bird's beaks in science class. This heightened engagement with concepts presented in science class and transferred to everyday world experiences has been associated with conceptual change (Pugh et al., 2009; 2010).

Broughton et al. (2013) used small group discussions while reading a text passage on Pluto's reclassification to a dwarf planet to promote conceptual change. The discussions provided students the opportunity to thoughtfully and critically weigh the scientific viewpoint in contrast to their own. Students who participated in

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the small group discussions were more likely to experience conceptual change about the rationale for the scientists' decision to reclassify Pluto than students who did not participate in the discussions. Additional instructional interventions for promoting conceptual change include self-explanation of key concepts in science texts (Chi, 2000), interviews (Hallden et al., 2002), refutational texts (Kendeou & van den Broek, 2005; Mason, Gava, & Boldrin, 2008; Mikkilä-Erdmann, 2002; Sinatra & Broughton, 2011), and computer simulations (Biemans & Simons, 2002; Nussbaum & Sinatra, 2003).

Each of these interventions has shown promise for increasing the likelihood of conceptual change. However, on the other hand, these interventions also pose some challenges in terms of their practicality. For example, some are not easy to implement in educational settings (e.g., transformative learning experiences), time consuming to design and implement (e.g., refutational texts), or they depend on initiative of others (e.g., interviews). Therefore, we investigated the potential of another instructional approach, namely Problem-based learning (PBL) in fostering conceptual change. PBL is an instructional approach that is intended to facilitate prior knowledge activation, critical analysis of arguments, and promoting deep understanding of the scientific perspective (Hmelo-Silver, 2004; Loyens, Kirschner, & Paas, 2012). Also the problems used in PBL, so-called complex problems (i.e., problems that can be solved in multiple ways) entail several features that can foster high levels of cognitive engagement. Advantages of PBL over the aforementioned interventions, is that it is an instructional method that integrates all of the cognitive processes that are considered conducive to conceptual change (e.g., discussion, critical analysis of arguments, prior knowledge activation, see paragraph 1.3), thereby making these processes part of an instructional routine rather than initiating them only within certain tasks. Moreover, PBL can be implemented for a wide range of topics and has already been successfully implemented in a wide variety of educational settings. In the next paragraphs, we will first describe the PBL process as well as conceptual change more in-depth. Next, we will argue why PBL has the potential to foster conceptual change.

1.1. Problem-based learning (PBL)

PBL is an instructional method that originated in medical education in the mid-sixties. Since its advent, it has been implemented worldwide in many disciplines and on many educational levels (Hung & Loyens, 2012; Schmidt, Van der Molen, Te Winkel, & Wijnen, 2009). In PBL, students work in small groups on complex problems before they have received any other curriculum input about the topic at hand (Barrows, 1986).

Working on problems is posited to be engaging and interesting for students since the problems present realistic phenomena (Loyens et al., 2012; Otting & Zwaal, 2006; Rotgans & Schmidt, 2011). In a first phase, students activate their prior knowledge while discussing the problem in the group, and propose possible explanations or solutions. Because their prior knowledge of the problem at hand is limited, they discover the gaps in their knowledge necessary to be able to fully understand the problem and satisfactorily explain or solve it. To that end, students formulate so-called learning issues (i.e., questions) that guide further self-study activities. All these activities in the first phase are referred to as the pre-discussion of the problem. Subsequently, in the second phase, students spend time selecting and studying literature relevant to the learning issues generated.

After this period of self-study, in the third phase, students share their findings with each other in the next tutorial meeting (i.e., reporting phase), which usually takes place two or three days after the pre-discussion of the problem, and come to an answer to the learning issues. The meetings are guided by a tutor - sometimes called facilitator or coach - whose role is to stimulate discussion, make sure that relevant content information is discussed (e.g., by asking questions), evaluate progress, and monitor the extent to which each group member contributes to the group's work (Loyens et al., 2012; Schmidt, Loyens, Van Gog, & Paas, 2007).

Previous studies have demonstrated that in terms of short-term knowledge acquisition, PBL students often learn the same amount of new information (though sometimes less) than students in lecture-based curricula. However, PBL generally has positive effects on long(er)-term knowledge retention, that is, PBL students retain significantly more of the learned information compared to students in a lecture-based curriculum (e.g., Capon & Kuhn, 2004; Dochy, Segers, Van den Bossche, & Gijbels, 2003; Strobel & Van Barneveld, 2009). This is ascribed to a deeper processing of new information, through processes such as elaboration and group discussions, which makes that new information becomes better structured and organized in memory (Schmidt, 1983; Van Blankenstein, Dolmans, Van der Vleuten, & Schmidt, 2011).

1.2. Conceptual change

It is well documented that students bring their previously formed conceptions with them to learning situations, including science conceptions (Broughton et al., 2013; Diakidoy et al., 2003; Mason, 2001; Mikkilä-Erdmann, 2002; Vosniadou & Skopeliti, 2005), and often, this prior knowledge contradicts the scientific explanation. For example, young children commonly hold the incorrect belief that the Earth is flat, based on their everyday experiences (Vosniadou & Brewer, 1992). In order for students to understand that the Earth has a spherical shape, they have to restructure their prior beliefs such that those will align with the scientific perspective. This restructuring of knowledge has been referred to as conceptual change (Chinn & Brewer, 1993; Duit, 1999; Posner et al., 1982; Vosniadou, 1999).

Multiple perspectives exist on how conceptual change occurs. Many of these perspectives use the Conceptual Change Model (CCM) proposed by Posner et al. (1982) and Strike and Posner (1992) as a framework. The CCM predicts that conceptual change is more likely to occur for the learner when four conditions are met. These conditions are *dissatisfaction* with one's existing conception, and finding the alternative explanation *intelligible*, *plausible*, and *fruitful*. Posner et al. (1982) explain that dissatisfaction occurs when learners lose confidence in their existing conceptual understanding and, therefore, become more receptive to replacing that prior knowledge with a more plausible explanation. The pre-discussion in PBL can trigger dissatisfaction with one's existing conceptions because students need to activate their prior knowledge and may experience this knowledge to be inadequate for understanding the underlying mechanisms of the problem at hand. Also, while selecting and studying literature, they may be confronted with frictions (i.e., cognitive conflict) between their prior knowledge and scientific views. This cognitive conflict can lead students to seek additional explanatory information in an attempt to resolve the conflict between their misconception(s) and the scientific explanations.

Activation of one's prior knowledge during pre-discussion and the subsequent critical analysis of information may also increase learners' cognitive engagement as they grapple to understand or resolve the problem. Cognitive engagement has been described as the quality of the individual's thinking in relation to cognitive strategies such as elaboration (i.e., deep-level learning strategies) as well as metacognitive strategy use and self-regulated learning (Linnenbrink, 2007; Pugh et al., 2009). Fredricks (2011) includes the