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Constructivism and personal epistemology development in undergraduate chemistry students[☆]

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ABSTRACT

Students' beliefs about knowledge, or their personal epistemologies, are critical components of the learning process. Researchers and educators need to understand how portrayals of knowledge in the classroom shape personal epistemology development. Using a quasi-experimental design, an organic chemistry instructor taught a traditional, lecture-based course and a constructivist-based interactive-learning course. Students ($N = 270$) completed three surveys assessing personal epistemology and perceptions of constructivism in the classroom. Although the interactive-learning classroom did not seem to affect personal epistemology, evidence suggested that perceptions of a complex learning environment predicted changes in personal epistemology. Students' initial epistemic beliefs predicted how they perceived the classroom environment. Results also supported an epistemic alignment hypothesis: students performed better on the final exam when their beliefs matched the course structure. Findings support an interactive model between students' personal epistemologies and epistemic climate and highlight the challenges of changing beliefs through single-semester classroom interventions.

Knowledge construction is a central component of education. Through the process of building knowledge, each learner develops beliefs about what knowledge is and how it is justified, a system of cognitions known as *personal epistemology* (Hofer & Pintrich, 2002). Students' specific beliefs about knowledge, also referred to as epistemic beliefs, predict their self-regulation strategies (Bråten, Anmarkrud, Brandmo, & Strømsø, 2014; Muis, 2007; Muis & Franco, 2009) and are also closely interrelated with student motivation (Chen & Barger, 2016; Bråten & Strømsø, 2004). Students' personal epistemologies also predict achievement in various contexts (Bråten & Ferguson, 2014; Dai & Cromley, 2014; Muis, 2004; Trautwein & Lüdtke, 2007). College chemistry classrooms are one such context. For example, undergraduates who have chemistry-specific epistemic beliefs (e.g., "In chemistry truth is unchanging.") that closely match their preferred general epistemic beliefs (e.g., "I prefer to study subjects where truth is unchanging.") tend to receive higher grades in chemistry (Dai & Cromley, 2014).

Given the importance of students' epistemic beliefs to the learning process, it is essential to understand the situational factors that might influence changes in personal epistemology (e.g., Feucht, 2010; Muis & Duffy, 2013). Researchers and educators have debated the virtues of two types of college pedagogical practices: traditional, lecture-based classrooms and constructivist, active-learning-based classrooms (Freeman et al., 2014; Friesen, 2011). Many researchers and educators have taken a strong stance on which teaching approach is more appropriate in STEM fields based on students' learning and achievement, but few of these researchers have considered the role of students' epistemic beliefs in this debate. Assessing epistemic beliefs can complement existing research on the effectiveness of pedagogical techniques as an explanatory mechanism or describe how the classroom formats might affect underlying beliefs that students can carry beyond the course. The current study examines the complex relations between students' perceptions of constructivist pedagogical practices and personal epistemology development.

1. Theoretical background

1.1. Personal epistemology

Although there are many ways to conceptualize personal epistemology (Alexander, 2016; Chinn, Buckland, & Samarapungavan, 2011; Hofer & Pintrich, 1997), one prominent conceptualization examines

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independent beliefs about the nature of knowledge (its structure) and how knowledge is justified (its sources). Philosophers often define knowledge as justified, true beliefs (Greene, Azevedo, & Torney-Purta, 2008), but the focus in personal epistemology is on how *individuals* think about knowledge themselves. Students generally hold these beliefs implicitly; they may not think about these beliefs until they are explicitly asked to articulate them. Students' beliefs are both domain-general (e.g., “all knowledge is unchanging,”) and domain-specific (e.g., “chemistry knowledge is unchanging;” Muis, Bendixen, & Haerle, 2006). To some extent, these different levels of beliefs relate in a hierarchical manner, such that someone who has a domain-general belief is more likely to hold a similar domain-specific belief; however, individuals can, and often do, hold different beliefs across domains, such as chemistry and history (for a review, see Barger & Linnenbrink-Garcia, 2017; Muis et al., 2006).

Three beliefs particularly relevant to the debate between lecture-based and active-learning-based classrooms have also received considerable attention by researchers studying epistemic beliefs more broadly (see Greene et al., 2008; Hofer, 2000; Hofer & Pintrich, 1997): 1) simple/certain knowledge, 2) justification by authority, and 3) personal justification. *Simple/certain knowledge* involves the structure of knowledge, and indicates the belief that knowledge is composed of unchanging, unrelated facts, instead of complex, evolving information. The belief that chemistry knowledge involves a collection of unchanging facts that need to be memorized (e.g., equations and symbols that are learned through memorization) exemplifies simple/certain knowledge. On the other hand, the belief that scientists' understanding of molecular structures and energetic processes constantly evolves would not. Both justification by authority and personal justification involve sources of knowledge. A belief in *justification by authority* implies that knowledge is handed down by authority figures. A belief in *personal justification* means that individuals construct knowledge for themselves and therefore can hold different understandings of what is true. Students with strong justification by authority beliefs would view chemistry teachers and textbooks as the primary sources of knowledge, whereas students with strong personal justification beliefs think that people might come to different understandings by approaching problems from different perspectives.

Theoretically, different types of beliefs are considered adaptive or maladaptive for learning and achievement (e.g., Muis, 2004). The belief that knowledge is simple/certain, for example, has been described as less availing, as it has been linked to lower achievement and learning (Qian & Alvermann, 1995; Trautwein & Lüdtke, 2007). This connection has been attributed to students using shallower cognitive processing when they believe knowledge is simple/certain (Muis, 2004; Strømsø & Kammerer, 2016). The evidence regarding the relation between beliefs about sources and process of knowledge justification and achievement is less consistent across contexts (e.g., Bråten & Ferguson, 2014; Bråten, Ferguson, Strømsø, & Anmarkrud, 2013; Conley, Pintrich, Vekiri, & Harrison, 2004). In introductory science courses, it is especially important to understand that experts have agreed upon trustworthy, foundational principles and that not every opinion in science is valid (particularly if that opinion is not based on reliable scientific processes). However, over-reliance on teachers might prevent students from learning how to solve problems on their own or discover novel solutions, especially in more advanced scientific study. Furthermore, it is also important to understand that scientists' knowledge and understanding of scientific principles is constantly being developed, and therefore scientists might have conflicting ideas that deserve further inspection. Accordingly, the most sophisticated approach to the source of knowledge may be a balance between justification by authority and personal justification (Greene et al., 2008). To summarize, beliefs about justification are not simply adaptive or maladaptive in science, but depend on how they guide the student to useful or unuseful behaviors in different contexts.

The extent to which students match their epistemic beliefs to the demands of the course may explain the conflicting evidence (Dai & Cromley, 2014). Epistemic cognition has been described as “flexible” and dependent on contexts (e.g., Kienhues, Ferguson, & Stahl, 2016). However, researchers have not yet examined whether this flexibility can be adaptive if students come to hold beliefs that match the epistemic climate of the context. Following this line of thinking, we propose that students will learn more when their beliefs match the way that knowledge is portrayed in a particular class. Students beliefs about the source of knowledge may direct them to seek or construct knowledge using different strategies (e.g., memorizing what the instructor says or practicing problems on one's own), which would be differentially effective depending on how the course is designed. It is therefore possible that students with less constructivist beliefs (i.e., justification by authority beliefs) will perform better in more traditional, lecture-based college courses (i.e., courses that are more objectivist in nature because the teacher's lecture serves as the singular truth in the class), whereas students with more constructivist beliefs (i.e., personal justification beliefs) will perform better in a constructivist-based, interactive-learning context. Instead of describing certain beliefs as availing, we propose the “epistemic alignment” hypothesis, which suggests that beliefs are more adaptive in contexts that call for them. Successful students are not simply those that hold universally “adaptive” beliefs, but rather are the students whose beliefs align with the demands of the learning context.

1.2. Mechanisms of personal epistemology development

Researchers have long observed that students' personal epistemologies can change over time (e.g., Kitchener & King, 1981; Perry, 1970; Schommer, Calvert, Gariglietti, & Bajaj, 1997). Recent work suggests two possible mechanisms for change, one explicit and one implicit (Brownlee, Schraw, Walker, & Ryan, 2016; Lunn Brownlee, Ferguson, & Ryan, 2017). Explicit mechanisms derive from the conceptual change literature (e.g., Posner, Strike, Hewson, & Gertzog, 1982). When students' existing beliefs are directly confronted, this can trigger a dissatisfaction with current beliefs called “epistemic doubt” (Bendixen & Rule, 2004). Examples of triggers include learners reading conflicting texts (Ferguson, Bråten, & Strømsø, 2012) or instructors directly confronting students' epistemic assumptions during class meetings (Kienhues, Bromme, & Stahl, 2008). For example, a student may believe that experts have all the answers; but, if the student then reads conflicting papers about how scientists disagree on what the healthiest foods are, he or she learns to believe that experts are not omniscient. Alternatively, epistemic change might occur implicitly through students' experiences with the underlying epistemic assumptions of the classroom. In these cases, the conceptions about nature of knowledge are not directly presented; students' assumptions may subtly change in ways that they are not aware of until they are explicitly asked with a targeted interview or survey question. For example, a child who goes to a school that allows students to direct their own learning may not be explicitly told that knowledge can be personally constructed, or even hear about “knowledge” or “truth” at all. Nevertheless, such an environment implicitly suggests that knowledge can be personally constructed and is not just handed down by authority figures. Such a child could also develop the belief that experts are not omniscient.

A classroom's “epistemic climate” is the amalgam of students' personal epistemologies, the instructor's personal epistemology, the epistemic messages in classroom instruction, and the way course materials present knowledge (Feucht, 2010). Within this interactionist model, a classroom context that portrays knowledge as complex and originating from multiple sources should lead students to develop similar epistemic beliefs. Instructors' personal epistemology leads them to create tasks within the classroom that correspond to those portrayals of knowledge. Qualitative research has also found that even within the same subject, the portrayals of knowledge can differ significantly between classrooms (Hofer, 2004). The structure of a course in turn implicitly provides