Motivation and beliefs about the nature of scientific knowledge within an immersive virtual ecosystems environment

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A B S T R A C T

We explored Grade 6 students’ (n = 202) self-efficacy, epistemic beliefs, and science interest over a 10-day virtual ecology curriculum. Pre- and post-surveys were administered, and analyses revealed that (1) students became more self-efficacious about inquiring scientifically after participating in the activity; (2) students on average evinced a shift toward more constructivist views about the role of authority in justifying scientific claims; (3) students who identified more strongly with being a science person evinced greater gains in self-efficacy, developed a less constructivist view about the role of authority in justifying claims, and became more interested in science overall; and (4) students who held an incremental theory of ability evinced greater gains in self-efficacy. We discuss the implications of these findings for science educators and instructional designers in the design and use of immersive virtual worlds for middle school science students.

1. Introduction

Much research has shown that science is often considered more confusing and more difficult than other academic subjects (Britner, 2007; Cleaves, 2005; Dweck, 2007; National Academies of Science, 2011). Furthermore, in the context of the current educational climate in which such a high premium is put on students’ performance on standardized tests, teachers have little time to allow their students to explore science concepts in interesting ways, thereby contributing to students’ perception of science as dull. This struggle to motivate students presents a significant challenge especially during the middle school and high school years, when there is a marked general decline in motivation (Eccles et al., 1983).

In addition to motivating students to do well in science, another major goal of science reform is to advance students’ beliefs about the nature of scientific knowledge and knowing (National Academy of Sciences, 2011; National Research Council, 2000; National Research Council, 2007). The more recent work on these beliefs, called epistemic beliefs, has examined relations between the construct and other facets of cognition like motivation and self-regulation (Buehl & Alexander, 2005; Muis, 2004; Tsai, Ho, Liang, & Lin, 2011). Less attention, however, has been directed toward how epistemic beliefs change over short periods of time, especially with instructional interventions designed to tap students’ epistemic beliefs.

Finally, innovative technologies have been receiving a considerable amount of attention as a way to motivate students, and to provide students with science inquiry experiences that both make learning interesting and provide life-like simulations of what real scientists do. However, despite the widely accepted notion that technology-based activities are inherently motivating, the evidence regarding their motivational effectiveness is mixed (Moos & Marroquin, 2010). For example, as Moos and Marroquin noted, some research has shown that computer-based instruction increased students’ interest in the material. But other research has shown that there are a number of variables, such as prior knowledge, that modify the relationship between participation in technology-based activities and students’ motivation.

Another reason for these mixed findings could be the way that many researchers exploring educational technologies have conceptualized motivation—as a broad unidimensional construct. However, motivation is multifaceted in that some students may find an activity to be very interesting and enjoyable (i.e., high interest value beliefs) but not consider themselves competent enough to do well (i.e., lack self-efficacy). In fact, even in a recent meta-analysis, Wouters et al. (2013) adopted a broad view of motivation, yet reported findings on the overall construct of motivation without discussing which aspects of motivation seemed to be
affected by participation in technology and which aspects did not. Thus, research regarding the motivational affordances of technology should be based firmly in well-studied theories of motivation that treat motivation as a multidimensional construct (Chen, Zap, & Dede, 2013; Moos & Marroquin, 2010).

Given the above, three main objectives guided the present study. First, because some have begun to question the truism that technology is inherently motivating, we explored the effect of participating in an inquiry-oriented virtual environment on students’ interest in science and their confidence in being able to conduct scientific inquiry to solve a complex problem (i.e., students’ self-efficacy for scientific inquiry). Second, because the virtual environment was also designed to tap students’ beliefs about the nature of scientific knowledge—their epistemic beliefs—we explored the effect of participating in the virtual environment on students’ epistemic beliefs. Third, because numerous variables modify the relationship between participation in technology-rich activities and motivational outcomes, we sought to examine psychological moderators of this relationship. In particular, some researchers have shown that certain core assumptions can foster a framework for how students engage with their environment. The first core assumption we investigated was students’ theory of ability as either static (fixed theory of ability) or as malleable with effort (incremental theory of ability; Dweck, Chiu, & Hong, 1995). The second core assumption we studied was students’ science identity—beliefs about the extent to which individuals identify with scientists and their work (Estrada, Woodcock, Hernandez, & Schultz, 2011; Hernandez, Schultz, Estrada, Woodcock, & Chance, in press; Pugh, Linnenbrink-Garcia, Koskey, Stewart, & Manzey, 2009). In the present investigation we explored whether students’ theory of ability and their science identity modified the effect of the intervention on students’ self-efficacy, interest, and epistemic beliefs in science.

2. Theoretical framework

2.1. Science self-efficacy

Bandura (1997) defined self-efficacy as beliefs in one’s capabilities to learn or perform a task at a specified level of competence. Self-efficacy has been shown to affect how productively individuals think, how well they motivate themselves, how long they persist in the face of failures, and ultimately what and how much they achieve (see Pajares & Urland, 2006 for a review). In the domain of science, self-efficacy is related to how interested adolescents are in science, the types of goals they set for themselves, their level of achievement, as well as their persistence in pursuing science-related college majors and careers (Andrew, 1998; Beghetto, 2007; Britner & Pajares, 2001, 2006; Chen & Pajares, 2010; Gwilliam & Betz, 2001; Lau & Roeser, 2002; Lent, Brown, & Larkin, 1984; Luzzo, Hasper, Albert, Bibby, & Martinelli, 1999).

Given the crucial role self-efficacy has been shown to play, researchers have recently become interested in the various ways that self-efficacy can be formed. Bandura (1997) hypothesized that self-efficacy is formed by how people interpret information from four sources. The primary source is how one interprets past performances, or mastery experiences. For example, in science, as students engage in science-related tasks and activities, they interpret how successful they are from these experiences and form conceptions about how capable they are in engaging in subsequent science-related tasks and activities.

Self-efficacy is also influenced by watching the successes and failures of similar others. These vicarious experiences can be especially powerful when the role models whom an individual observes are perceived as being very similar to oneself. Next, teachers, parents, and classmates often send individuals messages, either verbally or through other indirect ways of communicating, about whether they think an individual can succeed. These verbal and social persuasions can be especially influential when they come from sources that an individual trusts. Finally, anxiety, joy, fatigue and other physiological and affective states serve as the fourth and final source of self-efficacy. How students interpret information from this source can often signal to students how competent they are (Bandura, 1997).

Can immersive technologies target these sources to bolster students’ self-efficacy? Some researchers have shown that such an endeavor is possible (e.g., Hsieh, Cho, Liu, & Schallert, 2008; Ketelhut, 2007; Moos & Honkomp, 2011; Rosenberg-Kima, Baylor, Plant, & Doerr, 2008). For example, Rosenberg-Kima et al. (2008) used an on-screen avatar that appeared similar and approachable to students to converse with students about the value of engineering careers. This visibly similar avatar was found to be effective at increasing the self-efficacy, interest, and utility beliefs of students in science and engineering courses.

Ketelhut (2007) also showed that students’ pre-intervention self-efficacy for scientific inquiry was related to students’ initial behaviors within a virtual world. However, after a number of visits to the virtual world, pre-intervention self-efficacy did not appear to affect students’ behaviors. She hypothesized that one reason why exposure to the virtual world may have nullified the effects of initial self-efficacy is because students were able to take on the identity of a scientist (in the form of an avatar) and possibly benefit from the vicarious experiences of seeing oneself succeed in doing science. This hypothesis represents one promising aspect of immersive technologies—the ability to use virtual role models to convey important information for learners, thereby targeting their vicarious experiences.

2.2. Interest

In addition to beliefs about competence, students can hold beliefs about the value of science. According to Eccles et al. (1983), these beliefs about the value of an activity can have a substantial impact on students’ willingness to participate in that activity. Within Eccles et al.’s expectancy-value framework of motivation, we focus specifically on the interest value component because of its germaneness to technology-rich activities. Students’ interest value describes the enjoyment that one gains from doing a task. This particular dimension of the expectancy-value framework is relevant for participation in technology-rich activities because technology can spark students’ initial interests in participating in an activity (Blumenfeld, Kempler, & Krajcik, 2006). That is, these activities can serve as an initial “hook” for students to continue engaging in a learning task. Numerous studies have also found that interest value is an important factor as students make decisions about choosing careers in Science, Technology, Engineering, and Mathematics (STEM; Lent, Lopez, Lopez, & Sheu, 2008; Lent, Paixao, da Silva, & Leitao, 2010). Interest value also is related to students choosing to take classes related to STEM fields (Watt, Eccles, & Durik, 2006).

How might technology-rich activities help support students’ evolving interests in science? Some scholars have argued that technology-rich activities can be used to develop students’ interest in subject matter by making the learning goals relevant and meaningful (Gee, 2003; Squire, 2003). For example, users of a 3-D immersive virtual world called Quest Atlantis assume the role of someone consulting a fictional Council to rebuild an arch that was destroyed by rulers of a fictional world. When learning goals are put within such a context, the learning goals themselves become interesting. Barab, Dodge, Jackson, and Arici (2002) found that when students completed quests within the Quest Atlantis context they completed significantly more quests and rated them
as more interesting compared to those who completed the same exact quests on a worksheet stripped of the fictional story context provided by the virtual world.

In the context of a technology-rich environment, a distinction should be made about the construct interest. Scholars distinguish between situational interest, defined as a short-lived enjoyment in an activity, and individual interest, which describes a long-term investment in activity (Hidi & Renninger, 2006). For technology-rich contexts, situational interest can be enhanced by connecting learning goals to personally relevant issues, by varying the challenge of a task, or by providing novel contexts for students to explore.

Although technology can most easily target students’ situational interest (e.g., being interested in a virtual science inquiry environment) it is much more difficult to develop that into the more enduring individual interest (e.g., being interested in the field of science). For example, Hickey, Moore, and Pellegrino (2001) found that using the Adventures of Jasper Woodbury videodisc activity alone was not sufficient to promote students’ interests in mathematics. Rather, the technology combined with teachers’ constructivist instructional practices predicted students’ gains in individual interest.

2.3. Epistemic beliefs

Students also hold beliefs about the nature of scientific knowledge and knowing—epistemic beliefs. For example, some students may believe that scientific knowledge is unchanging, and that the best way to accumulate this knowledge is to obtain it from external authorities like teachers or textbooks. Other students might, however, believe that scientific knowledge is continuously in flux, and that anybody can generate this knowledge. Recent work in this area outlines a model that consists of multiple somewhat independently operating dimensions (Greene, Torney-Punta, & Azevedo, 2010; Qian & Alvermann, 1995; Schommer-Aikins, 2004). That is, individuals can possess highly constructivist beliefs in one dimension (e.g., knowledge is complex and ever-changing) but also possess non-constructivist beliefs in another dimension (scientific knowledge can only be attained from knowledgeable authorities).

Researchers have also shown that these beliefs about knowledge and knowing are related to students’ motivation, including their self-efficacy (e.g., Beghett & Baxter, 2012; Chen, 2012; Chen & Pajares, 2010; for a review see Hofer & Pintrich, 1997). For example, Mason, Boscolo, Tornatora, and Ronconi (2013) found that students’ beliefs about how scientific knowledge is developed and how it is justified are indirectly related to students’ self-efficacy, mediated mostly through the goals that students set for themselves. Chen and Pajares (2010) found that beliefs about the degree to which science is a collection of right or wrong answers were directly related to science self-efficacy. Also, beliefs about how scientific knowledge is appropriately justified were directly related to science self-efficacy.

In Taking Science to School, Duschl, Schweingruber, and Shouse (2007) argued that students should participate in science activities that encourage evidence-gathering, proposing explanations for data, forming conclusions by evaluating competing claims, and reconsidering conclusions made from data based on new evidence. Designers of digital science learning activities capable of challenging students’ epistemic beliefs need to encourage and support these science inquiry tasks Duschl et al. described. Although there are good theoretical and empirical reasons for why inquiry-based learning environments can facilitate the progression of students’ epistemic beliefs from less constructivist stances to more constructivist ones, additional research is needed to investigate which aspects of inquiry-oriented environments might be connected to this progression (Bendixen & Rule, 2004; Feucht & Bendixen, 2010; Kittleson, 2011; Schraw & Sinatra, 2004). Because researchers are able to control how aspects of inquiry are presented in technology-based learning environments, such environments may be able to focus on the aspects of inquiry environments that are related to changes in epistemic beliefs. For example, researchers have found that, when students wrestle with conflicting information within complex, open-ended, problem spaces, their epistemic beliefs may evince a development toward more constructivist stances (Barzilai & Zohar, 2012; Ferguson, Braten, & Strømsø, 2012).

What is less well-known, however, is how these beliefs interact within highly complex immersive virtual worlds, where students do wrestle with complex and open-ended problems, but where the conflicting texts that confront students are less obvious. In the studies presented by those exploring text reading in online contexts, these conflicting elements are presented side-by-side. However, in complex immersive virtual worlds designed to simulate real-life problem spaces, such as exploring the causes and effects of a dynamic ecosystem, the conflicting elements are far more subtle. Although inquiry environments that are not technology-rich develop students’ inquiry skills and beliefs about the nature of scientific knowledge (cf. Conley, Pintrich, Vekiri, & Harrison, 2004), technology-enriched environments may further aid in this endeavor by making aspects of scientific phenomena that are difficult to see more obvious.

For example, researchers investigating student understanding of ecosystem dynamics found that students showed promising shifts toward explanations focused on patterns, processes, and change over time after using EcoMUVE, a virtual world that supports thinking about change over time and understanding connections between ecosystem factors (Grotzer, Kamarainen, Tutwiler, Metcalf, & Dede, 2013). In another study, Metcalf, Kamarainen, Grotzer, and Dede (2013) showed that teachers believed EcoMUVE to be more effective than their own traditional science curricula in engaging students and promoting learning of inquiry. Design features of the software that supported students’ inquiry activities included the opportunities for student-directed learning, exploration and discovery in the virtual world, ease of collecting and graphing data that showed change over time, and the role-based jigsaw pedagogy. Therefore, immersive virtual worlds that encourage students to collect and view data so that students can more easily understand complex causality potentially have the power to target and develop specific aspects of students’ epistemic beliefs. We describe specific aspects of EcoMUVE and how these aspects relate to the constructs we are investigating below.

2.4. Implicit theories of ability

Dweck (2002) argued that “much of society is stubbornly wedded to the idea that accomplishment, especially outstanding accomplishment, is about endowment. We ignore the fact that Mozart, Darwin, Michael Jordan, and Tiger Woods practiced feverishly and single-mindedly for years, and instead believe that they were simply born with one-in-a-million ability” (p. 39). This particular belief—that ability is something that people either have or do not have—may be especially prevalent in the context of science classrooms, where students often perceive the subject to be considerably more difficult than their other subjects (National Academies Press, 2011).

According to Dweck (1999), students tend to espouse one of two theories of ability. Some students believe that, with appropriate effort and strategies, they can improve their abilities. Students who hold this incremental theory of ability are more likely to view effort in a positive light, persist through difficulties, and ultimately achieve at higher levels than their peers who believe that their
abilities cannot be augmented. Students with this latter view—those who hold a fixed theory of ability—are likely to view effort as something that is required to make up for deficits in ability, are more likely to give up in the face of difficulty, and ultimately achieve at lower levels than their incremental theory peers.

Implicit theories of ability can also be domain specific. That is, some students may believe that their science abilities are a relatively stable entity while simultaneously believing that their social studies abilities are increasable (Stipek & Gralinski, 1996). As Bandura (1997) observed, “conceptions of ability should not be viewed as monolithic traits that govern the whole of life. The same person may view ability differently in different domains of functioning” (p. 119). Dweck and Leggett (1988) initially showed that implicit theories may apply to areas beyond the intellectual domain, such as in the social domain (i.e., social/personality traits like popularity) and even the moral domain (i.e., moral characteristics such as goodness or badness). Stipek and Gralinski (1996) explored whether implicit theories of ability were domain-specific, and contrary to their original hypothesis, students in Grades 3–6 did not espouse subject-specific beliefs about ability in math and social studies. However, as the researchers posited, “it is possible that, as children enter adolescence and begin to engage in higher level mathematics, their beliefs about ability related to performance in math and other subjects become more differentiated” (p. 403). In fact, Dweck (2002) argued that such differentiation of students’ beliefs likely begins in middle school and progresses throughout one’s schooling.

Implicit theories of ability have been shown to be core assumptions that color the way students view the world around them (Dweck & Leggett, 1988; Hong, Chiu, Dweck, Lin, & Wan, 1999). In the field of science, researchers have found that students who viewed their failures as normal rather than as an indication that they did not possess the talent to do well in science exhibited better academic and motivational outcomes (Harsh, Maltese, & Tai, 2013; Hernandez et al., in press). Chen and Usher (2013) found that implicit theories of ability modified the ways in which students attended to the sources of self-efficacy. That is, students with an incremental theory of ability were more likely to attend to a variety of adaptive sources of self-efficacy, whereas students with a fixed theory of ability were more likely to attend to negative physiological states as a source of self-efficacy.

The distinction between students with a fixed theory of ability and those with an incremental theory of ability is most salient when students face challenging obstacles (Dweck & Leggett, 1988). For this reason it is possible that students may navigate an open-ended, inquiry-oriented, virtual world in different ways due to the challenging tasks that are presented to students throughout. Students who find it challenging to figure out a scientific problem may report different levels of motivation (e.g., interest and self-efficacy) based on whether they see these challenges as threats (fixed theory of ability) or as opportunities to learn (incremental theory of ability). Although Dweck and her associates have demonstrated this phenomenon within both laboratory and classroom settings, the empirical evidence within virtual contexts does not to our knowledge exist.

2.5. Science identity

Much like implicit theories of ability, science identity can act as a core assumption that colors the way that students view the world around them. In a broad sense, identity can refer to a sense of who one is (“I am not a science person”). Waterman (2004) defined identity as the goals, values, and beliefs to which people commit. Recent research dealing with identity has shown that science identity can have a significant effect on students’ motivation and learning in science (Hernandez et al., in press; Packard & Nguyen, 2003; Pugh et al., 2009; Roese, Peck, & Nasir, 2006). For example, Bergin (1999) has argued that subject-specific identities can have an effect on the development of interests in that particular subject. Pugh et al. also found that students who identified with science also pursued science tasks simply for the sake of learning science, and that this combination of beliefs predicted a deep level of engagement with science.

Finally, immersive virtual environments such as the one utilized in the present study allow students to take on the identity of a scientist. This affordance of immersive technologies can allow students to “willingly suspend their disbelief” (Dede, 2009), and for a moment feel as if they are actually at the pond collecting real data, which EcoMUVE simulates. If students are willing to suspend their disbelief and take on the identity of a scientist, this immersion can translate into a greater interest in science.

3. Description of the EcoMUVE curriculum

We used an immersive virtual world to explore the effects of participating in this technology-rich environment on the above-mentioned beliefs. EcoMUVE is a middle school science curriculum about complex causality in ecosystems in which students learn through inquiry activities in a Multi-User Virtual Environment (MUVE), a 3-D digital world used to simulate complex tasks and processes within an interactive, collaborative, environment. For this study, students used the EcoMUVE Pond module, a two-week curriculum in which students explore a virtual pond ecosystem in order to determine the complex causes of a fish kill in the pond. Ecosystems are incredibly complex because of the many non-obvious causes and the long time delays between cause and effect. For example, there are many microorganisms that students simply cannot see “at work” in producing causes. Similarly, because ecosystems involve complex processes that take place over long periods of time, the introduction of one causal variable may be forgotten by the time its effects are fully noticed by students. EcoMUVE is designed to incorporate virtual tools that help students see the invisible or non-obvious agents within an ecosystem (e.g., microscopic zooplankton). It is also designed to give students virtual abilities that would be impossible in real life (e.g., the ability to travel through time), so that students can more easily see the effects of a process over time.

Students begin EcoMUVE by exploring the pond and its surrounding area by walking their virtual avatar around the 3D environment. They can even walk under the water. A virtual submarine lets them shrink down to view microscopic organisms in the pond. They use a camera tool to photograph the many organisms they find, and learn about them through a virtual field guide. A food web tool lets them learn about the energy relationships between these organisms and the sun. A time travel tool lets them visit the pond on eight different days over a virtual summer. Each day the pond and surrounding area look different, and there are different virtual characters in the world to find and talk to. On one day late in summer they make the surprising discovery that all of the large fish in the pond have mysteriously died. Students are then challenged to figure out the cause of the fish kill, and divided into teams of four to investigate. Each student takes on the role of one of four scientists (e.g., water chemist, microscopic specialist) within the team, and has different tasks and learning quests to complete.

Students use virtual tools to collect data on weather, populations, and water measurements (e.g., temperature, pH, turbidity, etc.). Students can import data from their teammates, and view the data over time using multi-variable graphs. Students also gather clues from their own observations, and by talking to the virtual residents, such as a landscaper putting down fertilizer on the lawns of a nearby housing development. Each team works together to
collect and interpret the data, coming up with a hypothesis of the causal factors relating to the death of the fish. As the culminating activity, they create a concept map representing their hypothesis and present it to the class.

The collaborative and interactive nature of this environment was designed to engage students’ interest in the scientific inquiry task of solving the mystery of the fishkill. EcoMUVE is also designed to facilitate student understanding of ecosystem processes by zooming into the microscopic level, traveling to different points in time, and seeing effects emerge across time and distance. Additionally, EcoMUVE scaffolds the processes of observation and data collection by making it easy to click to retrieve data, by making salient the specific features that are relevant for the investigation, and by organizing data into tables and graphs for analysis. In fact, data suggest that participation in EcoMUVE is indeed linked to students’ improvement in ecosystem content understanding (Metcalf, Tutwiler, Kamarainen, Grotzer, & Dede, 2013). Students take on the role of a scientist (through an avatar), and experience data collection and analysis in ways similar to what scientists do. We suggest that, by using the supports that EcoMUVE provides to help students conduct fairly sophisticated scientific inquiry, students are building their self-efficacy (through mastery experiences) by learning how to connect observations to causal ecological processes using data, tables, and graphs that students have generated themselves. Going beyond mere observation by connecting observations to data, and data to specific causal processes in nature is a key element of scientific inquiry. In addition, preliminary data show evidence both of strong student interest in the curriculum (Metcalf, Chen, et al., 2013), and gains in measures such as self-efficacy (Kamarainen, Metcalf, Grotzer, & Dede, 2012).

We also suggest that specific aspects of EcoMUVE tap students’ beliefs about the nature of scientific knowledge—their epistemic beliefs. In particular, EcoMUVE’s design challenges students to re-think their assumptions regarding where legitimate scientific knowledge can originate. For example, when students explore the pond, they meet people who have different types of expertise. A man doing yoga says the pond smells like sewage, a utility worker says she checked the pipes and found no problems, and a golf course manager explains how he’s careful using fertilizer. Students have to weigh these claims from the different sources against the data that they have collected and come to a conclusion.

Finally, we note that, while students engage in EcoMUVE, their teachers actively facilitate student understanding and discuss the roles of scientists. Teachers introduce activities, provide guidance and support to students as they work individually on computers or together with their teams, and lead whole-class discussions on real-life ecosystems linked to the students’ experiences in the virtual world. The following is an example of what a whole-group discussion looks like: On Day 3 of the 10-day curriculum, teachers ask students to help identify the biotic and abiotic parts of the ecosystem they have been observing for the past two days. Teachers then explain to students why scientists need to understand these different parts of the ecosystem. Teachers then discuss as a whole group what scientists do, what types of scientists study ecosystems, and what types of tools they use to study them. Finally, at the end of the day, teachers explain that for the rest of the curriculum, students will need to act like scientists in order to determine the cause of death for the large fish.

4. Research questions and hypotheses

Given the objectives of the present study and the theoretical framework outlined above, the following research questions and hypotheses guided us. First, we asked what is the effect of the EcoMUVE curriculum on students’ interest in science, and their self-efficacy for scientific inquiry? Based on prior research with EcoMUVE (e.g., Kamarainen et al., 2012; Metcalf, Chen, et al., 2013; Metcalf, Kamarainen, et al., 2013), and based on Wouters et al.’s (2013) results indicating that immersive virtual worlds like EcoMUVE can be motivating especially if it is not used in conjunction with traditional forms of teaching, we hypothesized that students’ interest in science would increase after participating in EcoMUVE. Because EcoMUVE provides students the opportunity to decide what they will collect and how they will analyze and interpret information, students are provided a great deal of autonomy. Students are also able to do all of this in collaboration with their peers. These inquiry-based aspects of the environment enhance interest in scientific inquiry (Blumenfeld et al., 2006). These features alone cannot promote students’ motivation, however, as students may become frustrated by the complicated features of the inquiry environment. For this reason, EcoMUVE incorporated scaffolds that were designed to support the developing science inquiry skills of students. By supporting students’ mastery experiences in scientific inquiry, we hypothesized that students would become more self-efficacious in scientific inquiry after participating in EcoMUVE.

For our second research question we asked what is the effect of the EcoMUVE curriculum on students’ science epistemic beliefs? There is some evidence that interactive learning environments that allow students to design experiments and collect and analyze data may promote epistemic thinking (Solomon, Scott, & Duveen, 1996). For this reason, we hypothesized that students’ epistemic beliefs would evince a shift toward more constructivist stances. That is, students should come to understand that scientific knowledge can originate from themselves and their own reasoning. Students should also learn how to use expert sources (e.g., textbooks or teachers) to decide on the truth of a knowledge claim rather than solely rely on experts to tell them the “correct” answer.

For our third research question we asked what extent do students’ implicit theories of ability and their science identity modify the effect of the intervention on students’ self-efficacy, interest, and epistemic beliefs in science? There is some evidence that students’ implicit theories of ability form meaning systems that alter the way they process information, including information related to self-efficacy (Chen & Usher, 2013; Hong et al., 1999; Molden & Dweck, 2006). For this reason, we hypothesize that students with a fixed theory of ability would evince lower self-efficacy, less interest, and less constructivist epistemic beliefs about science compared to their peers with an incremental theory of ability. We also hypothesized that students who identified less with science would evince lower self-efficacy, less interest, and less constructivist epistemic beliefs about science compared to their peers who identify more with science.

5. Methods

5.1. Participants

Participants (n = 202) were Grade 6 students (11–12 years old) at a relatively affluent and 70% White suburban school in the Northeastern United States. The student sample included all Grade 6 students at the school; two science teachers each taught five classes of Grade 6 Science, with about 22 students per class. In this particular school, Grade 6 science focuses on life science. Complete pre–postdata were received for 94% of students due to student absences at either the pre-test or the posttest, so data for n = 189 students were analyzed.

5.2. Instruments and procedures

Pre- and post-surveys were group-administered to students using an online survey (administered via Qualtrics) during science
class immediately before and after implementation of the EcoMUVE curriculum. The pre- and post-surveys were comprised of 40 Likert scale questions, and were designed to assess self-efficacy for science inquiry, interest in science, beliefs about the nature of science, science identity, and implicit theory of ability\(^1\) (see Appendix A for a list of all items).

5.2.1. Self-efficacy for science inquiry

Students' confidence in being able to perform the tasks involved in scientific inquiry was assessed before and after participation in the EcoMUVE activity using an 8-item instrument \(\chi^2(14, N = 317) = 23.457, p = .06\) with standardized factor loadings ranging from 0.628 to 0.809 and a factor determinacy of 0.949.

5.2.2. Interest in science

Students' interest and enjoyment for science class and in doing science-related activities was assessed before and after students participated in the EcoMUVE activity by using the interest/enjoyment subscale \(\chi^2(1, N = 90)\) of the Intrinsic Motivation Inventory (IMI; Deci, Eghrari, Patrick, & Leone, 1994; Ryan, 1982; Ryan, Mims, & Koestner, 1983). Because we wanted to assess students' subjective experience of interest and enjoyment related to participating in EcoMUVE, this subsection of the Intrinsic Motivation Inventory (IMI) was the only one we used. The IMI has been shown to be valid and reliable (Koka & Hein, 2003; McAuley et al., 1989).

5.2.3. Epistemic beliefs

Epistemic beliefs were assessed before and after participating in EcoMUVE along three dimensions of the construct, as outlined by Greene et al. (2010) with a 13-item instrument. These dimensions include the Simple/Certain Knowledge dimension \(\chi^2(1, N = 90)\), the Personal Justification \(\chi^2(1, N = 90)\) and Justification by Authority \(\chi^2(1, N = 90)\) dimensions. Simple/Certain knowledge describes students' beliefs about how static or dynamic scientific knowledge is. Justification of scientific knowledge refers to the degree that individuals believe that personal sources in the form of personal experiences or logic, versus an Authority in the form of an expert, teacher, or another reputable source is sufficient to warrant a knowledge claim. Greene et al. (2010) showed that the instrument was both reliable and valid for the personal justification and the justification by authority dimensions. In their study, however, the simple/certain dimension for mathematics did not appear to be reliable. In our study, we also report low reliability coefficients for the Simple/Certain Knowledge dimension as well as the Personal Justification dimension, which would make it difficult for us to make inferences regarding its relation to other constructs in our study. For this reason, we report results only from the Justification by Authority dimension.

5.2.4. Science identity

The degree to which students identify with science and the work that scientists do was assessed before and after students participated in EcoMUVE by using a 4-item instrument \(\chi^2(1, N = 93)\) developed by Pugh et al. (2009). Using a series of exploratory and confirmatory factor analyses, Pugh et al determined that the science identity construct was distinct from interest value, utility value, self-efficacy, and goal orientations. In the Pugh et al. study, the scale also demonstrated high reliability \(\chi^2(1) = .93\).

5.2.5. Implicit theory of ability

The degree to which students endorsed a incremental view of science ability versus a fixed view of science ability was assessed using a 6-item instrument. This instrument was adapted from one originally developed by Dweck (1999), and consists of six items that ask students specifically about their abilities in science rather than just their general intellectual abilities. Because Stipek and Gralinski (1996) posited that adolescent students may have subject-specific ability beliefs, we modified the wording of Dweck’s (1999) original scale so that students focused on their science abilities rather than their abilities in general. The Self form for children 10 years and older (Dweck, 1999) was used and worded to ensure that students focused on their ideas about their own science ability. Three items assessed students’ fixed conception of science ability and three others assessed their incremental conception of science ability. For the analysis, we reverse-scored the fixed theory of ability items and calculated a mean theory of ability score with the incremental items. Higher scores represented stronger agreement with incremental theory of ability. When implicit theories of ability have previously been assessed, alpha coefficients have ranged from .77 to .98 (e.g., Blackwell, Trzesniewski, & Chen & Pajares, 2010; Dweck, 2007; Dweck et al., 1995; Hong et al., 1999; Robins & Pals, 2002). In the present study, alpha coefficients of .83(1) and .90(2) for the incremental conception subscale and .75(1) and .85(2) for the fixed conception subscale were obtained. The scale has also been shown to be a valid measure of students’ beliefs about the nature of their ability (Dweck et al., 1995).

Although the original scale uses the term “intelligence” and the adapted scale employed in the present study uses the term “science ability” this distinction between intelligence and ability was addressed by Dweck (2002). She stated, “although there are meaningful differences between the terms ‘intelligence’ and ‘ability,’ I will use them more or less interchangeably here because the phenomena I am examining most typically apply to both” (p. 58).

6. Analysis

For the first two research questions we wanted to explore changes (if any) in students’ self-efficacy for science inquiry, their interest in science, and their epistemic beliefs. First, we examined zero-order correlations between Time 1 and Time 2 of the same variable to determine the extent to which certain variables changed—high correlations suggest little mean change whereas lower correlations suggest larger mean change. We also conducted a repeated measures t-test to explore mean changes from time 1 to time 2. For the third research question we wanted to explore the extent that students’ implicit theories of ability and their science identity modified the effect of EcoMUVE on students’ self-efficacy, interest, and epistemic beliefs in science. We conducted a fixed effects regression analysis in which self-efficacy, interest, and epistemic beliefs were dependent variables. Time, implicit theory of ability at pre-test, and science identity at pre-test were the independent variables. Because implicit theory and science identity are core assumptions, and because we wanted to treat them as exogenous

\(^1\) We also included four items to assess students’ Grit (Duckworth & Quinn, 2009) because we were interested in students’ persistence in the virtual world. However, due to the scale’s poor reliability we did not conduct any analyses with this construct.
variables to ensure that the covariates are not correlated with the residuals, we used Time 1 identity and implicit theory as covariates rather than the difference between Time 1 and Time 2.

To control for possible variance in the outcome due to teacher effects, we included a vector of dichotomously coded teacher fixed-effects variables. We included a dichotomously coded variable, “Teacher 1” in our model. Students who were in a classroom taught by that teacher had a value of one, whereas students in classes taught by the other teacher were coded as zero. This, in effect, makes the other teacher a comparison in the vector. We did not directly analyze the results of the coefficient on this variable because it was included only as a statistical control. We chose to control at the teacher level in lieu of the class level based on the results of previous studies of EcoMUVE-based interventions, which found little to no intra-class correlation (ICC) at the class level, but moderate to strong ICC at the teacher level (e.g., Metcalf, Tutwiler, et al., 2013). This can be expressed in the following hypothesized population-level model:

\[ Y_{ij} = \beta_0 + \beta_1 \text{TIME}_{ij} + \beta_2 \text{INCR}_{ij} + \beta_3 \text{IDENT}_{ij} + \beta_4 T2 + \epsilon_{ij} \]

where \( Y_{ij} \) represents one of our dependent variables. We will answer research question 3 by exploring the statistical significance, magnitude, and direction of \( \beta_2 \) and \( \beta_3 \) in models fitted to each outcome.

Because the present study was nonexperimental, fixed effects regression is a good way to statistically control for variables that were not measured but may have been important (Allison, 2005). Fixed effects methods ignore between-person variations and instead focus on within-person variations. Even though this method results in somewhat inflated standard errors, this is acceptable for our study because between-person variations are likely contaminated by unmeasured background characteristics of our sample such as previous achievement, facility with technology, or computer gaming experience. Therefore, a fixed effects approach allowed us to derive less biased estimates.

7. Results

7.1. Mean changes in self-efficacy, interest, and epistemic beliefs

Our first two research questions concerned the changes in students’ self-efficacy to do science inquiry, their interest in science, and their science epistemic beliefs from Time 1 to Time 2. Table 1 shows the results from our fixed-effects regression analyses. The fixed-effects regressions revealed that students were more self-efficacious after participating in EcoMUVE (\( \beta = .201; p < .05 \)) and that students who reported higher initial science identity showed higher gains in self-efficacy (\( \beta = .224; p < .001 \)). Also, students who, at the beginning of EcoMUVE, more strongly believed that their science abilities could grow with effort showed greater gains in self-efficacy (\( \beta = .107; p < .05 \)).

The main effect of time on change in the beliefs about the justification of scientific knowledge by authorities was not significant, controlling for science identity and implicit theory of ability. However, the results also showed that students who more strongly identified with being a scientist at the start of EcoMUVE showed a greater shift toward the belief that scientific knowledge comes mostly from an external authority like a textbook or teacher (\( \beta = .089; p < .05 \)). We offer possible explanations for this counter-intuitive finding in the discussion below.

Finally, there was no main effect of time on change in students’ interest in science, controlling for all other covariates in the model. However, the fixed-effects regression analysis showed that students who more strongly identified with science reported interest stayed relatively constant whereas self-efficacy and epistemic beliefs about authority may have changed.

Table 2 shows the results of a paired samples t-test. After participating in EcoMUVE students, on average, reported greater self-efficacy for inquiring scientifically and evinced a shift toward a more constructivist views about the role of authorities in justifying scientific claims. That is, on average, students believed less in the notion that external authorities are the primary source for scientific knowledge. Although not shown in Table 2, there was no significant change in students’ theory of ability and no change in students’ science identity beliefs from Time 1 to Time 2. We expected that these variables would not change, given that these are assumed to be core assumptions that students hold throughout participation in EcoMUVE. One unexpected result was that, on average, there was no significant change in students’ interest from Time 1 to Time 2. However, further analysis, described below, revealed a different story.

7.2. Implicit theories and science identity modify the relationship between EcoMUVE participation and student outcomes

Our third research question concerned the extent to which implicit theories of ability and science identity modified the relationship between participation in EcoMUVE and changes in students’ self-efficacy, interest, and epistemic beliefs. Table 3 shows the results from our fixed-effects regression analyses.

Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>M</th>
<th>SD</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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</tr>
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<tr>
<td>T1 Self-Efficacy</td>
<td>4.24</td>
<td>0.85</td>
<td>.249***</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>T1 Interest</td>
<td>4.62</td>
<td>1.08</td>
<td>.428***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1 Fixed</td>
<td>2.99</td>
<td>1.17</td>
<td>−.095</td>
<td>.115</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1 Incremental</td>
<td>4.58</td>
<td>1.03</td>
<td>.336***</td>
<td>.315***</td>
<td>−.503***</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1 Authority</td>
<td>4.17</td>
<td>3.46</td>
<td>.074***</td>
<td>.290***</td>
<td>.057</td>
<td>.136</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>T1 Identity</td>
<td>3.46</td>
<td>1.46</td>
<td>.065***</td>
<td>.707***</td>
<td>−.142</td>
<td>.332***</td>
<td>.132</td>
<td></td>
<td></td>
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<tr>
<td>T2 Self-Efficacy</td>
<td>4.44</td>
<td>0.95</td>
<td>.567***</td>
<td>.373***</td>
<td>−.113</td>
<td>.217***</td>
<td>.063</td>
<td>.384***</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>T2 Interest</td>
<td>4.61</td>
<td>1.11</td>
<td>.362***</td>
<td>.816***</td>
<td>−.152</td>
<td>.263***</td>
<td>.178***</td>
<td>.641***</td>
<td>.556***</td>
<td></td>
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<tr>
<td>T2 Fixed</td>
<td>2.90</td>
<td>1.31</td>
<td>−.121</td>
<td>−.138</td>
<td>.604***</td>
<td>.516***</td>
<td>.051</td>
<td>−.183</td>
<td>−.128</td>
<td>−.134</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2 Incremental</td>
<td>4.66</td>
<td>1.21</td>
<td>.274***</td>
<td>.254***</td>
<td>−.447</td>
<td>.604***</td>
<td>.081</td>
<td>.220***</td>
<td>.363***</td>
<td>.366***</td>
<td>.533***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2 Authority</td>
<td>4.09</td>
<td>1.06</td>
<td>.054***</td>
<td>.199***</td>
<td>−.142</td>
<td>.027***</td>
<td>.680***</td>
<td>.079***</td>
<td>.146***</td>
<td>.204***</td>
<td>.169***</td>
<td>.080***</td>
<td></td>
</tr>
<tr>
<td>T2 Identity</td>
<td>3.50</td>
<td>1.44</td>
<td>.387***</td>
<td>.629***</td>
<td>−.212</td>
<td>.377***</td>
<td>.105</td>
<td>.827***</td>
<td>.468***</td>
<td>.675***</td>
<td>−.192***</td>
<td>.322***</td>
<td>.151***</td>
</tr>
</tbody>
</table>

* \( p < .05 \)
** \( p < .01 \)
*** \( p < .001 \)
greater interest in science at the end of EcoMUVE compared to at the start ($\beta = .489$; $p < .001$). Theory of ability, however, did not significantly predict change in science interest.

8. Discussion

We investigated the relationships between participation in an immersive virtual world designed to simulate real-world scientific inquiry and changes in students’ motivation and beliefs about the nature of science. Results suggested that participation in EcoMUVE was related to gains in students’ self-efficacy for doing scientific inquiry as well as shifts toward more constructivist views about the use of experts’ knowledge in justifying scientific claims. However, it appeared that, for those who reported stronger identification with science, there was a move toward less constructivist beliefs about the role of authority in producing scientific knowledge. On average, students’ interest in science did not change after participating in EcoMUVE. However, students who reported stronger identification with science did evince greater gains in science interest. Below, we interpret these findings in light of theory and practice.

8.1. Changes in self-efficacy

Recall that self-efficacy is formed through mastery experiences, vicarious experiences, social persuasions, and physiological states. Although the present study did not experimentally test the following claim, we surmise that students evinced gains in self-efficacy from the mastery experiences provided by EcoMUVE. By providing just-in-time scaffolds and information to students as they explored the virtual pond, students may have been able to build from initially making observations to being able to make and test inferences using data. Past research using MUVEs like EcoMUVE (Ketelhut, Nelson, Clarke, & Dede, 2010) has shown that students do get better at solving scientific problems systematically, thereby supporting our contention that EcoMUVE may provide students with mastery experiences in scientific inquiry. This is the primary way EcoMUVE is designed to support students’ self-efficacy.

8.1.1. Self-efficacy caveats

Our results demonstrate that helping students to view science inquiry as a skill that is acquirable may facilitate greater gains in self-efficacy as they participate in an inquiry oriented virtual world. This is in line with Dweck and her colleagues’ work showing that implicit theories of ability create a meaning system that influences the ways that students approach learning tasks (Blackwell, Trzesniewski, & Dweck, 2007; Dweck & Leggett, 1988). As Bandura himself stated, “viewing ability as an inherent capacity lowers perceived self-efficacy, retards skill development, and diminishes interest in the activity” (p. 119). Paralleling this statement, we observed that students who believed that their ability to inquire scientifically was a skill that could be augmented with effort also evinced greater gains in self-efficacy. However, students who viewed scientific inquiry as an inborn trait may have become more discouraged when faced with the many challenging tasks that EcoMUVE presented. These results suggest that helping students to understand scientific inquiry as a skill that can be developed may be beneficial to students’ self-efficacy.

Our results also demonstrate that students participating in EcoMUVE who already identify with science evinced greater gains in self-efficacy than did their peers who identify less with science. These results are in line with other research suggesting a link between self-efficacy and identity in science (Estrada et al., 2011; Hernandez et al., in press; Syed, 2010; Syed, Goza, Chemers, & Zurbriggen, 2012). Students who identified more strongly with science may have a self-schema or identified a possible self (Markus & Nurius, 1986) that frames students’ actions within the virtual world and allows them to perform the tasks and strategies that are required to successfully navigate the virtual world. In contrast, those who had a weak identification with science may not have had the appropriate interpretive frameworks that such a self-schema provides, and therefore may have been less confident that their actions had been successful. Indeed, Markus and Nurius argued that possible selves, or identities, have consistently been “shown to have a systematic and pervasive influence on how information about the self is processed” (p. 955). And as Syed, Azmitia, and Cooper (2011) posited, students’ identities create “prototypes” that help students put into action particular behaviors relevant to that identity that can then build one’s sense of efficacy in that domain. For this reason, we believe it is possible that students’ greater identification with science facilitated students’ self-efficacy gains by putting into place the appropriate interpretive frameworks or self-schema that helped students become more self-efficacious in solving complex scientific problems.

8.2. Changes in interest

EcoMUVE was designed to target students’ situational interest in science by keeping them engaged in an interactive inquiry-based science activity that many students perceive as being interesting and enjoyable (see Metcalf, Chen, et al., 2013). EcoMUVE was also designed to help students see the relevance of doing scientific inquiry by engaging students in a life-like situation in which they engage in the kinds of scientific inquiry tasks that actual scientists do. In fact, in the design process a pond ecologist was employed in making the design decisions for the simulation. The expert in pond ecology helped make sure all tasks that students performed closely mirrored what pond ecologists really do. This type of authenticity, combined with the scaffolds to help students understand complex scientific phenomena, was intended to allow students to feel as if they were scientists solving a real environmental problem about a real-life pond.

### Table 2
Changes in variables from Time 1 to Time 2.

<table>
<thead>
<tr>
<th>Variable name</th>
<th>t-Value</th>
<th>p-Value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-efficacy</td>
<td>3.23</td>
<td>0.0015</td>
<td>0.235</td>
</tr>
<tr>
<td>Interest</td>
<td>−0.26</td>
<td>0.7923</td>
<td>n/a</td>
</tr>
<tr>
<td>Justification (Authority)</td>
<td>−2.89</td>
<td>0.0043</td>
<td>0.210</td>
</tr>
</tbody>
</table>

Note: Negative t-value for justification by authority represents a weaker belief in the role of authority as a source of knowledge. n/a = not applicable.

### Table 3
Fixed-effects regression with implicit theory and identity as covariates (N = 186).*

<table>
<thead>
<tr>
<th>Parameter estimate</th>
<th>SE</th>
<th>t-Value</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>4.078</td>
<td>0.25</td>
<td>16.13</td>
</tr>
<tr>
<td>T1 Implicit</td>
<td>−0.061</td>
<td>0.057</td>
<td>−.98</td>
</tr>
<tr>
<td>T1 Identity</td>
<td>0.081</td>
<td>0.037</td>
<td>2.18</td>
</tr>
<tr>
<td>Time</td>
<td>−1.167</td>
<td>0.103</td>
<td>−1.16</td>
</tr>
</tbody>
</table>

Dependent variable = justification by authority

| Intercept | 2.566 | 0.205 | 12.52 | <.0001 |
| T1 Implicit | 0.078 | 0.046 | 1.55  | 0.122  |
| T1 Identity | 0.489 | 0.030 | 15.82 | <.0001 |
| Time     | −0.011 | 0.084 | −0.14 | 0.888  |

Dependent variable = science interest

| Intercept | 3.018 | 0.210 | 14.35 | <.0001 |
| T1 Implicit | 0.109 | 0.047 | 2.32  | 0.021  |
| T1 Identity | 0.228 | 0.031 | 7.34  | <.0001 |
| Time     | 0.201 | 0.086 | 2.34  | 0.020  |

Dependent variable = self-efficacy for scientific inquiry

Note: * Models control for teacher fixed-effects.
We hypothesized that all these design decisions could facilitate the development of students' situational interests for EcoMUVE into the more enduring form of individual interest in the process of doing science. This hypothesis was only partially supported, however, as only the individual interests of students who identified with science seemed to develop. We discuss this below.

8.2.1. Interest caveats

Although there was no main effect of time on students' individual interests in science, there was an interaction with science identity. That is, participants who identified more strongly with being a scientist at the start of EcoMUVE evinced greater gains in science interest than did their peers who did not identify with science. This result supports past research positing that identity plays a crucial role in the development of students' interests within a scholastic domain (Bergin, 1999; Brophy, 1999). In this case, those who more strongly identified with science may have evinced greater gains in science interest because EcoMUVE not only provides a simulation of a pond ecosystem, but also allows students to perform the types of tasks that scientists really do (Grotzer et al., 2013). The alignment of students' science identity with the virtual world's simulated representation of what scientists do may have aided in the development of these particular students' interests in science.

However, science educators are concerned not only with students who already see themselves as scientists, but also with those who do not already identify with science. The results of this study provide evidence that using an immersive 3-D virtual world like EcoMUVE alone may not necessarily develop students' interests, especially if these students have a difficult time seeing themselves as scientists. As mentioned earlier, technology may be well positioned to tap students' situational interest, but may not be sufficient to develop it into a more enduring personal commitment to science. In EcoMUVE, it may be that students enjoyed using EcoMUVE, but did not develop that interest into a firmer personal commitment to science in general. As Hickey et al. (2001) showed in their study with The Adventures of Jasper Woodbury, technology-rich activities like EcoMUVE may need to be part of a more systemic, reform-oriented, science curriculum if they are to have a more enduring impact on students' individual interest in science. Future research should investigate this possibility by incorporating activities like EcoMUVE within a larger teacher-facilitated instructional unit to explore the benefits of the technology within varying forms of constructivist teaching practices.

Another possibility is that, despite all of our efforts to make EcoMUVE mirror the types of tasks that scientists actually perform, students who did not identify with science may not have completely understood or appreciated the utility of inquiring scientifically. Hullemen, Godes, Hendricks, and Harackiewicz (2010) have shown that helping students to understand the utility of a subject or skill can facilitate the development of more enduring forms of interest. Because teachers did not explicitly discuss the relevance of scientific inquiry to students' every day lives, the utility of scientific inquiry may have been lost on students, particularly those who did not identify with science. Hullemen et al. noted that utility interventions are most effective when students discover it on their own rather than having others tell them directly. Thus, to develop students more enduring personal interests, technology-rich activities may need to be more intentional about helping students to discover the relevance of subjects like science to students' personal lives.

8.3. Changes in epistemic beliefs

On average, students' beliefs about the role of authorities in creating scientific knowledge evinced a shift toward more constructivist views (i.e., experts are not the only ones who can come up with answers in science). EcoMUVE was designed for students to construct their own knowledge by collecting data and making causal inferences about ecosystems using scientific tools, graphs, and tables to support their claims. Therefore, this result aligned with our hypothesis. However, as discussed below, there were findings that ran counter to our hypothesis.

8.3.1. Epistemic belief caveats

Students who identified more strongly with science believed more strongly that scientific knowledge comes mostly from an external authority (considered a less constructivist view). One possible explanation for this counterintuitive finding is that EcoMUVE, although providing an exploratory inquiry-oriented experience for students, also includes many modules and tools that tell students necessary information so that they can solve a problem. For example, students refer to a field manual that tells them information about the plants and animals that they come across. This design decision was made to help students more easily navigate the virtual world. That is, students who are unfamiliar with declarative facts that could be found in a textbook might find it especially frustrating not knowing important pieces of information while trying to solve a complex problem. For this reason, we made available basic information about what they were collecting.

It could be that many students who identified more strongly with science also understood that scientists often must refer to the canon of scientific facts that make up the field of science. Although this portrayal of science is considered less constructivist in the literature on epistemic beliefs, Bråten, Strømsø, and Samuelstuen (2008) argued that whether beliefs are considered constructivist or not must be couched within the context of the activity. For science in particular, it is adaptive to understand that knowledge provided within EcoMUVE is handed down from an authority like a field guide. There are, however, aspects of scientific knowledge within EcoMUVE that are more tentative and that are open for personal construction and interpretation, as mentioned earlier with the man doing yoga, the utility worker, and the golf course manager. Viewing oneself as a legitimate authority in generating science knowledge may be beneficial in that students should consider their own data as legitimate evidence. But students also need to use these three other characters' judgments to come to a conclusion. Therefore, as Bråten and his colleagues have shown, beliefs about justification of knowledge from multiple sources may be an important component in how students interact in complex learning environments like EcoMUVE. This dimension of epistemic beliefs has been shown to be a good predictor of adaptive student outcomes in text comprehension (Ferguson & Bråten, 2013; Ferguson et al., 2012). Future work could investigate the role of this dimension of epistemic beliefs within a complex inquiry-oriented learning environment like EcoMUVE.

9. Limitations and delimitations

In this study we were unable to collect achievement information such as science grades or knowledge of ecology. For this reason we were unable to assess the practical impact of EcoMUVE on students' knowledge or achievement gains. However, past research has shown that participation in EcoMUVE does relate to knowledge gains (e.g., Metcalf, Tutwiler, et al., 2013). What has not yet been addressed, however, and should be further explored in future research, is whether prior achievement or prior knowledge of ecology modifies the relationships that were presented in this study. Some scholars have shown that prior knowledge or achievement can affect how students interact with an inquiry-oriented curriculum (e.g., Chen & Wu, 2012; Olympiou, Zacharias, & dejong, 2013; Wang, Wang, Tai, & Chen, 2010).
The students in this sample were mostly White and middle to high socioeconomic class in the Northeastern US. The students in this sample were also in Grade 6. According to Dweck (2002) students at this particular age are just beginning to see their abilities located within a web of relationships to other variables such as effort and the goals that they pursue (e.g., Dweck, 2002). It may be that younger students’ implicit theories of ability are not as closely tied to their self-efficacy or interests, as Dweck has argued. Therefore, we urge readers to be cautious about applying these results to other samples that differ by demographic features, including age.

Finally, the present study was not experimental—it was correlational by design. Therefore, we cannot assume that the particular designs that were implemented in EcoMUVE lead to particular belief changes among adolescents in science. However, our results do point to some design decisions that may contribute to students’ belief changes. Experimental work that manipulates these specific design features is needed to more convincingly establish causality.

10. Future research

Our results suggest that identity may be an important belief that modifies the relationship between participating in an inquiry, technology-rich, science curriculum and student outcomes. Despite the fact that teachers did connect the experiences of actual scientists with what students were doing in the virtual world, students’ science identities, on average, did not change. Although engaging with a simulated ecosystem can help students feel like they are doing the actual tasks of a scientist, it may be that interacting within a virtual world on a computer still feels somewhat contrived. Augmenting the EcoMUVE curriculum with activities that allow students to interact in real (rather than virtual) ecosystems, while also explicitly linking students’ activities and experiences to the work of professional scientists may facilitate students’ stronger identification with science. Researchers could investigate this possibility in future work.

11. Conclusion

Students may benefit motivationally from innovative technologies that provide both an interactive, life-like, context in which to solve complex scientific problems, and appropriate tools to scaffold students’ progression through the learning goals. Such innovative technologies also have the ability to effect changes in students’ epistemic beliefs. These technologies, however, are not silver bullets—they require the involvement of designers and educators who can implement specific features that target specific educational outcomes. In addition, designers and educators should be aware that, by supporting one type of belief (e.g., self-efficacy), they must also take care not to detract from other beliefs (e.g., communicate the idea that science is nothing more than a canon of truths handed down by an elite few). Instructional designers and science educators who wish to design innovative technologies that develop students’ knowledge, skills, and beliefs in science would do well to provide appropriate scaffolds that facilitate students’ mastery of increasingly more complicated tasks; allow students opportunities to identify with the work of scientists; and, at the same time, challenge students to reconcile multiple perspectives derived from various sources of information.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cedpsych.2014.02.004.

References


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