A QUALITATIVE CASE STUDY EXPLORING STUDENT COMFORT WITH AMBIGUITY IN PHYSICS, MATH, AND LITERATURE

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ABSTRACT
In this case study, we examined students' comfort with ambiguity using qualitative data analysis of interviews. We interviewed four students who had just completed an undergraduate degree in the health sciences. Even though students generally differentiated among their views about physics/math/literature, in some aspects we noticed some commonalities of the approaches that students used across the disciplines. Data analysis revealed that students' epistemologies about disciplinary content and learning seem to influence their attitudes towards a discipline. Likewise, the learning strategies and performance also depended on the level of epistemological sophistication. Although students all claimed to prefer "real world" problems and context, we found that they were uncomfortable with complex contexts and preferred to rely on authority. The similarities among student epistemology and approaches toward very different disciplines warrants further study. We believe that such interdisciplinary investigation of epistemology and ambiguity has pedagogical implications for improving student learning strategies. We suggest the necessity of promoting learning environments that will nurture the development of sophisticated epistemologies, which would enable students to navigate the ambiguous and complex realities of our fields.
Keywords: epistemology, ambiguity, authority, interdisciplinary, case study

INTRODUCTION

As educators, we can say *how* students perform and we can speculate on why *we* think they perform in the ways they do. Asking students to metacognitively reflect upon their learning processes can provide a crucial piece of the puzzle for understanding student learning by revealing how *students* think they learn. In this paper, we explore four students' retrospective self-reflections on their experience and performance in the authors' respective courses (physics, calculus, and literature). In particular, we asked students to reflect upon their experiences with coping with ambiguity in these disciplines and in teaching methods.

Our focus on ambiguity arose out of discussions among the three authors about the challenges of teaching in their various disciplines in an interdisciplinary department for health science majors. We found ourselves asking each other how students handle ambiguity in our individual classes. We became curious if students coped with ambiguity using the same strategies in different academic disciplines. Did providing context help students navigate ambiguity? These initial conversations led to a retrospective, descriptive examination of how students approached and grappled with context in three courses: Introduction to Literature, Physics I, and Calculus I (Huq, Nichols & Aryal, 2016). In that study, course work data from a small sample (24) of students shared among all three courses were compiled and analyzed to see if there was any connection between student performance and apparent comfort with ambiguity. The data indicated that high performing students were more comfortable with ambiguity in all three courses, whereas lower performing students tended to be less comfortable with it. Moreover, high performers in one course tended to perform well and be comfortable with ambiguity in the other courses. While this might not be surprising between clearly related courses like Calculus and Physics, it was a bit surprising that student performance also correlated well between Calculus and Literature. There was no obvious correlation between Physics and Literature, although students that expressed more comfort with ambiguity in one subject tended to be much less comfortable with it in the other.

The intriguing nature of these findings suggested that a case study might provide additional insight into student experience and worldview. To that end, we reviewed the correlative data and chose students who fell toward the mean. From these, four students (two males, two females) agreed to be interviewed about their experiences in physics, mathematics and literature, and, in particular, how they coped when faced with ambiguity in each.

THEORETICAL FRAMEWORK

Because epistemology impacts teaching and learning, it provides a useful framework for a discursive analysis of students' interview data. Personal epistemology can be defined as a person's beliefs about knowing and knowledge (Hofer & Pintrich, 1997; Sandoval 2005), and, possibly, the nature of learning (Elby, 1999; Hammer, 1989). Research into personal epistemology and learning has focused on the impact of a teacher's personal epistemology on the learning environment, the development of personal epistemology of students, and the ways in which a student's personal epistemology impacts his or her ability/preparedness to learn (Hofer, 2001). For example, research has shown that student's personal epistemology affects success in introductory physics (Lising & Elby, 2005). However, research on interdisciplinary epistemic cognition is rare (Sandoval, 2016). Nevertheless, educators must take into consideration how students' individual personal epistemologies impact how they approach learning in general, learning within a disciplinary context, and learning across the disciplines. Thus, epistemology can help us surmise from these four students' individual experiences about student learning in general.

Students' personal epistemology and expectation about a discipline may not be necessarily the same, perhaps in part because epistemological belief does not necessarily guide action (Bishop & Trout, 2003). Moreover, students typically have not yet developed a sophisticated epistemology that would allow them to incorporate new knowledge or experiences that might challenge previously held beliefs. Students may have one epistemology both about the knowledge/knowing and views about learning in the disciplines but still because of the expectations and how the course is taught or organized by instructors may have different expectations and students may study the way that is not what they think about the knowledge/knowing and also the learning in the disciplines (Elby, 1999; Elby & Hammer, 2001; Hammer, 1989; Redish, Saul, & Steinberg, 1998). We are using Hammer's (1994) framework to analyze students' epistemology about learning. The following diagram depicts the three dimensions used in the framework to show the level of sophistication (expert vs naive).

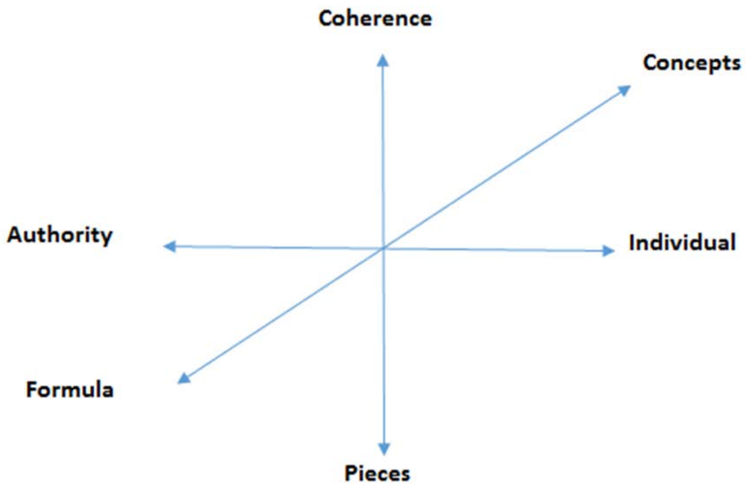

Figure 1: Three dimensions of Hammer's Framework

For example, the first axis of the framework captures the student view that learning is either acquiring new, disjointed pieces of information, which is labelled as naïve, or the view that learning is seeking or formulating a coherent meaning, which is considered more sophisticated. Another axis deals with the source of knowledge (i.e. if it is from authority or created by learners). In quantitative disciplines such as mathematics and physics, students have a tendency to rely on formula or equations rather than apply concepts in solving problems. Formula-focused views are less sophisticated than concept-focused views. In this study, we attempt to explore if and how there exists relationships or overlap between one dimension with the other dimensions. For example, if students' beliefs aligned more towards the "coherence" side of one of the dimensions, then would that necessarily mean they are aligned towards more "individual" and "concepts" in other axes?

Students' personal epistemology associate with their learning habits and that influences their learning outcomes, understanding, and performance in the respective courses. In the classroom, we often see students with diverse degrees of epistemological sophistication. The level of sophistication indicates what they believe about the complexity and certainty of knowledge. We often notice two categories of student views regarding the source of knowledge; one is experiential (observation or experiments) and the other is the authority (teacher, books and websites). The degree of sophistication impacts students' ideas about knowledge. Moreover, students' ideas for learning and reasoning have several potential consequences in various disciplines, including quantitative disciplines such as mathematics and physics. For example, in physics and mathematics, some students expect to find rich interrelations among concepts and ideas and they try to test them in order to understand them. In contrast, some students do not recognize meaningful conceptual relationship and try to memorize each concept separately. They do not question authority and are unwilling to test new ideas and concepts for their scopes and limitations.

Experts, on the one hand, have sophisticated views that knowledge is about searching for interrelation of those facts embedded in phenomena. Scientific methods, tools, and data changes impact epistemology (Kitchin, 2014). New discoveries, theories, and principles cause disciplinary epistemologies to evolve. Thus, disciplinary experts continually change their epistemological beliefs. On the other hand, students' epistemological beliefs can be dichotomized into "naive" and "sophisticated" personal epistemological beliefs. Kuhn et al. (2000) proposed a useful framework to describe the development of student intellectual and ethical views over time/experience/academic preparation as their epistemologies become more sophisticated. One might expect that students with sophisticated beliefs have higher tolerance of ambiguity. However, research on epistemology and learning indicates that epistemological change is neither linear nor consistent (Kienhues et al, 2008), nor does tertiary schooling necessarily have (much of) an impact on naive epistemologies (Rodriguez & Cano, 2007). Thus, students struggle when they are faced with the inherent ambiguities of disciplines about which they held naive beliefs.

We decided to focus on students' experience with ambiguity because it is of particular pedagogical interest as coping with it requires a more sophisticated epistemology that can recognize knowledge as contingent. Furthermore, ambiguity raises its head in all three of the disciplines discussed in this paper. First and foremost, is the problem with language itself. Language is inherently ambiguous. For example, many quantitative sciences terms are "regular" words that have very specific disciplinary meanings, and students may not always understand their technical use. For example, "acceleration" is used to mean "go faster" in common parlance; however, in physics, "acceleration" measures the time of the rate of change of velocity.

In introductory literature courses, language ambiguity is introduced as a key literary concept and students are instructed on the way meaning in literature often depends upon the multiple possibilities of language. However, doing so often requires a curiosity to learn a robust historical context and/or knowledge of complex literary theory that students struggle to master (Lee et al, 2016, p. 171). Ambiguities, paradoxes, or contradictions abound within STEM disciplines as well, like the classical example that light is both a particle and wave, or the example Byers (2010) points out that $\sqrt{2}$ has both geometric and arithmetic meanings. Even the symbolic language developed by STEM disciplines, which is meant to clarify ambiguity, often introduces new ambiguities. Contexts play roles in navigating such symbolic ambiguity. Experts and competent students naturally manipulate symbols in such circumstances. Less competent students often fail to make relevant connections and end up using a wrong expression in a situation.

METHODOLOGY

The original sample size for the quantitative results consisted of students from a small, public, U.S. Midwestern, liberal education university, and data was collected with IRB approval (#1409S53527). Our university is unique because it has only one major, Health Sciences, that is housed within an interdisciplinary department. The interdisciplinary cohort model of our institution allows us to track students as they go through their degree program and also allows us to provide students with a consistent experience in different courses. The data presented in the original study (citation redacted) was gathered from 24 students (14 male and 11 female). Students were randomly chosen from the pool of students who took at least two of the three courses, Calculus I, Introduction to Literature, or Physics I. The ACT (MATH, ENG, SCI) scores of this group of students were representative of the first year cohort (either 2010, 2011, or 2012) to which they belong. Additionally, there was no significant difference between the ACT scores of male and female students in the group. All students took the mathematics courses before either Physics or Literature, but students took Physics or Literature in any order or in some cases simultaneously.

From this group, we identified students whose overall scores made them fairly typical of the quantitative data. From this smaller group we identified students who had also recently graduated because we wanted them to feel free to be honest, and we thought that individuals who were no longer students would feel able to reflect on our courses openly and without fear of reprisal. From this smaller subsection, we selected four students, two males, two females met the above criteria and were willing to volunteer to be interviewed. One student was African-American, the other three students were white, and all were approximately 22 years old at the time of the interview. At the time of the interviews, two students were in graduate programs in health science fields, while two were in the workforce in non-health related areas. Students were interviewed once for around 45 minutes to an hour. Participants signed a consent form to be interviewed and were given a $10 gift card for their participation in the interviews.

We wanted to interview former students in order to gain more insight into their comfort level with ambiguity and context in all three disciplines. In a semi-structured clinical interview setting, we asked students open-ended questions about their experiences in each class. For example, we asked which concepts and problems did they find most difficult? How had they navigated those difficulties? and How would they gauge their comfort level in dealing with ambiguity and context in each discipline? We asked follow-up and probing questions when we thought more detail would be useful. We tried to get at the granularity of the real experience of individuals and provide insight into real-life situations. Because this is a case-study we asked open-ended questions that would enable us to get at student experience. The interviews intended to avoid confirmation bias by allowing students to talk about their experiences in their own terms.

The methodological framework that we used was derived from Colaizzi's process for phenomenological data analysis (Sanders, 2003; Speziale & Carpenter, 2007).We transcribed interviews and read them multiple times until we individually obtained a holistic sense of each student's epistemological beliefs about the disciplines in question as well as the learning process. Then we extracted significant statements from each transcript. We formulated meanings from these significant statements. The formulated meanings were tabulated into categories, clusters of themes, and themes. To ensure the trustworthiness of the data as much as possible, we worked through the coding until we came up with agreement about the major themes and created descriptions of them by integrating students' actual quotes. The following table highlights how the qualitative data were extracted and organized along the line of grounded theory (Glaser & Strauss, 1967) in order to determine the codes, categories and themes.

Table1: An example of coding and categorization of student beliefs about learning

CATEGORIES	Mode of learning	Comfort	Discomfort
EXAMPLE CODES	relation overlap repetition practice mapping	clear cut clear theory formula specific rule freedom in answer familiar content prior background	figuring out novel contexts word problems working backward exceptions

Table 2: An example of a flow table that extracts and formulates the meaning from themes

Learning and authority		Discomfort with ambiguity	
Sequence	Logic	Sequence	Logic
1	knowledge comes from authority	1	ambiguity leads frustration
2	authority has the answer	2	ambiguity requires dealing with novel situations/solution pathways
3	authority has specific path to the solution	3	customary to seek help from authority rather than dealing with ambiguity
4	anxiety about not matching answer/path to the solution to authority		

All three authors of this paper examined students' quotes to rank their level of sophistication in the various disciplines independently. Later, each of us retroactively looked at the individual student performance in the respective courses. Using the interviews, we ranked the students' overall epistemological sophistication in the following order: Student 1, Student 3, Student 4, Student 2. The ranking matched completely with their course grades and problem solving scores on exams, suggesting that high-performers generally have more sophisticated epistemologies than lower-performers.

RESULTS AND DISCUSSION

We explored how students perceived several disciplines used in the study. Specific word use was collected, coded and categorized from the interview transcripts. Figure 2 provides summary of this part of our data analysis pertaining to such disciplinary labels created by the participant students. Students' generally framed the tasks and solution pathways based on what discipline they were dealing with. The framing seems to form on the premise of the words or qualifiers they used to describe related disciplines.

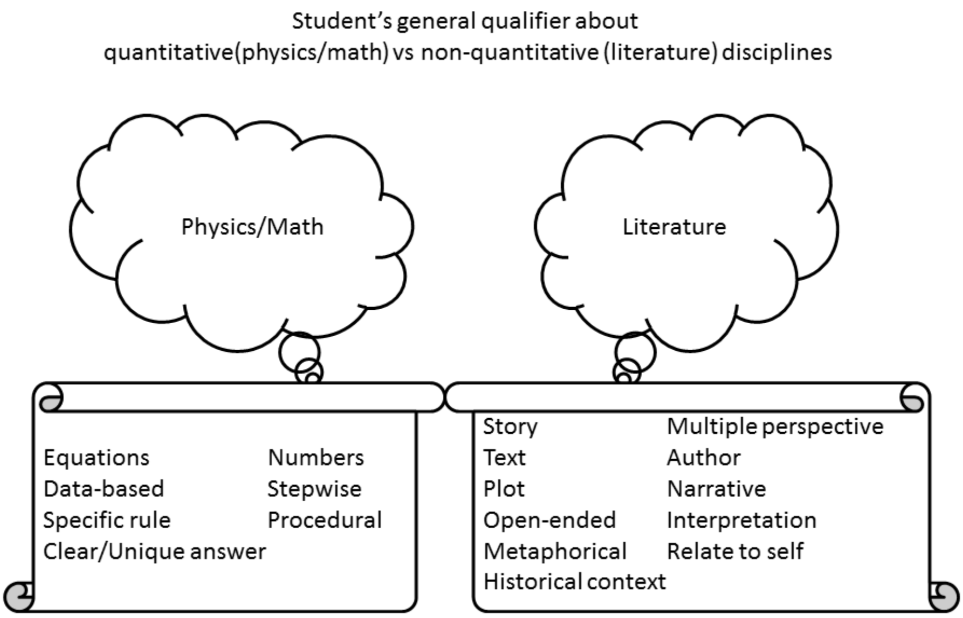

Figure 2: Students' views about various disciplines

As shown in Figure 2, these students have a naive epistemology about math and physics. They view these disciplines as rule-based and "specific," whereas experts know these disciplines are more complex. A sophisticated expert view of physics and math recognizes that, while there are many "rules," there are also ambiguities because of condition-dependent factors. Interestingly, for literature, students appear to have epistemologies closer to an expert--saying that literature has "multiple perspectives." However, as Lee et al. (2016) point out, the nature of literary reasoning is complex, complicated and contingent, requiring the problem-solver to consider linguistic structures, aesthetics, and "the nature of the human condition" (p 166). Students might recognize this complexity and ambiguity, but be unwilling or unable to cope with it. Perhaps they even state that literature has "multiple perspectives" because an authority has told them this is so. Thus, despite the appearance of a more sophisticated epistemology, our interviews revealed a great deal of discomfort in coping with ambiguity in literature and a preference to rely on the authority of the professor for answers

Our interdisciplinary investigation about students' comfort with ambiguity uses Kuhn et al's domains to explore epistemological change. According to Kuhn et al. (2000), a sophisticated epistemology is the result of the degree of coordination of the subjective and objective dimensions of knowing. Thus, sophistication depends not only on age or academic preparation, but also on the academic environment and culture. In other words, how instructors design the learning experiences can impact the epistemological progression of students. This study also revealed participants' epistemological sophistication, viz: objectivist, subjectivist and coordination. For this they used the progression levels such as absolutist, multiplist and evaluativist. A person's ability to coordinate the subjective and objective dimensions of knowing shows the development from a naïve to a sophisticated epistemological understanding. Kuhn et al reported that all groups of participants seem to change more readily in taste and aesthetic domains, whereas it is more difficult to change in the value and social truth domains. Furthermore, changes in epistemology about physical truth are the most difficult for every age and academic groups except for experts. Since it is hardest to develop a sophisticated epistemology about physical truth, students find it difficult to cope with ambiguity in mathematics and physics. However, because ambiguity in literature is not typically merely in the aesthetic domain but at the value and social truth domains, coping with it is also difficult for students (though not as difficult as in the quantitative sciences).

The interview data reveals that students felt discomfort with both linguistic and content ambiguity in these disciplines. All students expressed some degree of discomfort with ambiguity in all disciplines--they were "frustrated," "troubled," "anxious," or "lost." Some students were less uncomfortable with multiple pathways than others, but all were uncomfortable with open-ended questions. A student's epistemological beliefs about the discipline affected how comfortable they were when faced with ambiguity in that discipline. Thus, a belief that math is unambiguous results in more discomfort with ambiguity in math. However, even when students' beliefs about a discipline like literature included ambiguity as a constitutive element, they were deeply uncomfortable when faced with ambiguity in the learning environment. We think that this discomfort has to do with students' naive epistemologies about learning in general--in particular, that learning is supposed to be handed down from an authority rather than self-created by the learner. In fact, ambiguous problems or questions require students to navigate individual pathways that often require epistemological change. In addition to the above described trend regarding students' epistemological beliefs about disciplinary contents and learning in respective disciplines, we found other common trends. We coded the interview data in order that common categories and themes could emerge. From the coding, we were able to combine and collapse codes into common themes. The three that emerged most forcefully were Authority, the "Real World," and Problem choice.

Authority

Some questions of the interview highlight student reliance on authority. Although the interviewed students demonstrated different levels of epistemological sophistication, all preferred to rely on authority, even when they "knew" that knowledge is contingent and constructed. Student 3, for example, said he learned best in math and physics from "repetition" that "familiariz[ed]...the concepts." Repetition--memory work--locates knowledge in an outside authority. Student 4 expressed a similar belief:

> the thing I like about math and how it's different from ...chemistry [is] because usually there is a clear cut way to do something like... a formula or there is like very specific rules in math that never change and… very rarely you would find exception to the rule because it's really clear cut ... it's really frustrating when you can't figure something out that way because it should be, in theory, clear cut and able to use a formula and kinda just like...plug and chug but in a sense to do that to figure out the answer.

Student 4 expresses discomfort with ambiguity in the quantitative sciences because of her belief that these disciplines should be "clear cut" and formulaic. Her description seem to impact her naive view that physics and mathematics reasoning are merely symbol manipulation. Her response was echoed by the other interviewees who expressed discomfort even when problems were only slightly modified from the model problems. It would seem that students generally do not acknowledge that learning is dynamic creation of knowledge and there seems to be little tolerance of ambiguity.

Hammer's (1994) framework helps us surmise that these students seem to consider knowledge as static set of information rather than learning as an evolving dynamic process. In physics, for example, students believed that there should be a specific answer that coincided with a specific physical rule; therefore, there could be no room for ambiguity because that would "lead to bad situations in real life." Students' expectations about the quantitative sciences--their personal epistemologies--created blockages to their learning. Ambiguous or open-ended questions did not fit into their "math" or "physics" schemata that defined these disciplines as rigidly rule-bound, so they tend to experience discomfort when faced with these types of questions, a finding consistent with previous research (Schommer, 1990, 1993a; Schommer et al., 1992). However, personal epistemological expectations about ambiguity in literature did not enable students to cope with it any more successfully. In fact, students seemed just as uncomfortable with ambiguity in literature even though those interviewed expressed an expectation that literature was supposed to be more ambiguous. For example, Student 1 said that she "really liked the ambiguity in literature cause [sic] I really like to interpret things and look at how they can be interpreted different from different viewpoints because literature often doesn't have a correct answer." But when pressed on that topic, she also said she was uncomfortable when questions were too open-ended, such as when students were asked to "analyze this phrase and how can this phrase be interpreted where there are multiple interpretations.” Since that type of basic discursive ambiguity is at the heart of literary analysis, it would seem that Student 1’s first assertion of relative comfort with ambiguity in literature had more to do with her epistemological expectations than actual experience in the classroom--that ultimately, knowledge would come from the professor. The other students interviewed echoed Student 1. Student 3, for instance, expressed “frustration” when his answer wasn’t “just the right answer...why are there all these other answer? Why is it so ambiguous?” However, past familiarity with a literary work seemed to help students cope with ambiguity. Student 2, for example found it, “really cool reading into things like [*Frankenstein*] that you were familiar since you were a child.” Learning new things about a familiar topic interested him enough to be willing to cope with the discomfort of ambiguity; however, he would also “look up different synopsis or different critics online and things like that and try to get a conceptual idea.” In other words, he needed to rely on authority in order to challenge his previously held beliefs.

Novelty was not always enticing enough to produce curiosity about the STEM disciplines. Our study indicated that students generally feel that physics (and science in general) and mathematics have no scope for ambiguity. They believe that quantitative sciences are primarily rule-oriented or concept-oriented and the knowledge in those disciplines are learned by knowledge transmission from authorities. For them knowledge and skills in all disciplines are learned in the same way. According to them mathematics as well as physics always have rules to follow and that rigorous practice is essential in learning those disciplines. Such belief leads to the idea that problem solving in math and physics require application of fixed set of concepts, rules, equations and procedures and it is almost impossible to come up with novel strategies that are not presented in books or presented by instructors. According to Student 4:

> With all physics I just kind of took my equation sheet and kind of looked that over really well to see what I could apply to the problem and what was really frustrating ...was none of those equations really worked for it. And so then ... I would either go to peers or just ask [to seek for help from instructor] I guess.

This student’s naive epistemology made her unable to cope with the anxiety caused by epistemic doubt. Thus, she retreated to authority figures for reassurance and the bolstering of her belief in simple and certain knowledge.

Interestingly, students claimed they liked open ended questions--but only as long as they are assured by authority that there is no specific answer. In such situations they seem to prefer doing open ended problems and they think that contexts help them navigating solution path. For example, Student 4 averred:

> open ended questions were easier….there is kind of more easier where you have more freedom in your answer, when it’s like context or something it’s so more, I want to say, real and it’s kind of ... easier if anything for me as I can visualize it in the context rather than just numbers and kind of problems solving that way. So I like context problems better.

However, students generally believe two things. First, there is always a fixed answer for a question/problem and authorities (instructor or experts) have prior expectations regarding students’ answer for the question/problem. Second, in order to get to the answer there must be a unique pathway and they feel uncomfortable when they fail to identify the pathway. For example, Student 1 disliked open-ended essay prompts ones that were to “write a paper about this and you could go in any direction and I struggle to think… I am not sure what's wanted from me …I am not sure if I am going too far off topic here.” The freedom to construct knowledge left her, and the other students, feeling adrift and uncertain.

The “Real World”

Students responded positively to all three disciplines when they could relate what they were learning to their lives. Making connections between what they were learning in the classroom to what they experienced outside of it stimulated interest in the subjects. Student 4, for example, said she “like[d] how it’s relatable to everyday life and you experience physics every day.” Similarly, she preferred learning concepts in literature that “pertained to myself... even though they were complicated I could see them kind of happening to my own life....” Being able to relate fictional and theoretical concepts to her own life helped to build scaffolding that enabled her to expand her understanding. Students also enjoyed learning about historical and cultural contexts in literature because it helped them to make sense of seemingly opaque literary works. Student 2 explained that it was helpful to learn “the time period that this literature was created, it was created for a purpose and it’s important to know what the author was experiencing at the time where they put their efforts into that word and choose to write about some subjects rather than just a bunch of words on a page.” All four students expressed similar opinions, especially about older historical works like *Sense and Sensibility* or *Frankenstein*. Context helped make these stories and their concerns seem “real” to the students.

Similarly, context helped elucidate STEM concepts because the “real world” could provide a sense of outside authority. Student 4 explained that “Even if you don’t understand the math behind it fully at least you know the concepts behind it are easy to grasp because it is drawn on real life scenarios.” Here, not understanding is acceptable for the student because the “real world” guarantees the concept. She can accept as true what she cannot understand because she finds evidence for it in her lived experience. The apparent absoluteness and concreteness of the “real world” becomes these students’ ultimate guarantor of all knowledge. For example, Student 1 denied that physics could really be ambiguous because “look at real world applications of physics like construction those kind of things if you aren’t correct in there and if you are too ambiguous… things can go pretty badly.”

Even though students claimed to prefer problems that related to “the real world,” they also disliked actually having to work such problems. Because the domains of epistemologies are neither consistent, static, nor linear, even students who overtly said that contexts were useful revealed anxiety or discomfort with them in practice. Students preferred to deal with problems without contexts and felt that in physics and math contexts don’t help resolve ambiguity but rather makes it frustrating. For example Student 2 seems to prefer having contexts in physics; nevertheless, there is no indication that he prefers resolving ambiguity using contexts in practice:

> I think as far as physics is concerned a lot of the real world applications were real helpful because it's one of those things. Physics is always happening around us everything we are doing is physics so it definitely helped when you had examples you could kind of relate to, things that you think back to your childhood... what happened when I was on ice skates and if you drove all the way that way which way you were gonna go and what speeds so... just contextual information does help for me in physics.

This is an example of when a student’s epistemological belief does not translate into action. Even though a student may know that context should help them learn, he or she is unable actually to use context to remove or navigate ambiguity. Student 3 thought that the “most difficult problems were word problems because you have the story… all this information that’s kind of thrown into the story and you have to somehow pick and choose.” Interestingly, this student thought that training in literary analysis actually helped him navigate STEM word problems:

> It’s a bit kind of like having a literary mind to ...look back at something and say ok where/what do we start with, what is the problem, analyze this problem, how do we look at the steps that lead up to this problem kind... having a literary analytical mind helps you in understanding what’s the path to this problem, how do we solve this problem.

It appears that learning explicitly about verbal ambiguity in literature has allowed this student to use the skills taught in one very different discipline to aid him in another, suggesting that students with a more sophisticated epistemologies can make interdisciplinary connections that help them succeed.

Problem Choice

At the end of each interview, the subjects were asked to pick their choice from a series of paired STEM problems. Each pair had one contextual problem and one non-contextual problem involving the same content knowledge. Each pair of the problems were generally from the same discipline. For example, one pair required calculus content knowledge. The formulaic problem involved finding derivative of a function, whereas the contextual problem involved finding the rate of expansion of a sphere. Likewise, there were multiple paired problems involving physics content knowledge. One of those pair involved calculating current through a resistor versus comparing brightness of light bulbs in a circuit. Another pair of physics problems had to do with calculation of force on a rope versus making qualitative decisions about the pain experienced by a person whose arm is pulled. For example, the third question was asked:

> You have a block and the block is applied with a force and it is accelerating and you are asked to calculate what the tension on the rope is. The other problem is, suppose a person is pulling another person on the ground and you are asked to decide how much pain the other person feels. Which one would you like to do and why?

All four stated that they would prefer to attempt the more formulaic problems rather than the contextual problems, even when they found the contextual problems more interesting, because they were more confident in finding the “right” answer to the formulaic ones. This preference highlights their reliance on authority for epistemological certainty. They were uncomfortable applying STEM concepts to “the real world” because that would require them to create knowledge without the assurance of an outside guarantor like a professor. Thus, students seem to prefer contexts in physics and math in learning content but they don’t feel comfortable attempting them as tasks on their own. Using Kuhn et al., we can speculate that students who are able to handle the contextual real world problems comfortably could analyze a complex situation. Rather than exclusively relying on the information from class lectures, textbooks and websites they could coordinate subjective and objective aspects of the situation presented in a task and make informed decisions. Hence we consider such students as having more sophisticated epistemology developing as *evalutivists*.

In response to paired physics problems Student 1, who exhibited the most sophisticated epistemology, stated: "I will be more confident in correctly answering the first one [non-contextual problem]... I would find more interesting to know what the answer is" to the contextual problem. The same student had the following response to paired math problems:

> I preferred finding a derivative [non-contextual problem] because with like this sphere expanding [contextual problem] you have so many different variable and starting it up can be real challenge to make sure that you are analyzing your variables correctly….most challenging part of my transferring it from the context to formula.

Intellectually, this student recognizes the contextual and complex nature of knowledge. However, the lack of confidence in her own mastery of that knowledge leads her to prefer tasks in which she is more guaranteed success.

Student 3, who exhibited a somewhat sophisticated epistemology, also preferred non-contextual problems because although he felt that he had a grasp on the concepts, he was not comfortable dealing with ambiguous terms like "brightness":

> I actually might want to do the one with resistance and current…. I feel like I have ...a understanding how resistors works, how current works, how I can solve voltage ….it seems to me brightness is an ambiguous term... like what does brightness mean in terms of current? what does brightness mean in terms of voltage? so I probably need to be bit more certain in terms of what is the definition of brightness [to] go about solving a problem.

This student is sophisticated enough to recognize that "brightness" is a relative term that cannot be easily reconciled to the more clearly defined physics terminology of "voltage" and "current." This student lacked confidence in his own ability to define "brightness," and thus preferred to rely on authority for the more clearly defined terms rather than attempt to create knowledge.

Student 4, who generally exhibited a naive epistemology, preferred to do non-contextual because she could not see connections between concept (current) and observation (brightness):

> I would do the second one [non-contextual problem] and now that you said derivative [in the case of calculus paired problems]. I don't know, it kinda goes against my saying of concepts but I really understood the registers very well and you taught them so I'm comfortable with them and …I would rather do resistance problem than brightness problem....

This student seems to have *absolutist* scale of epistemology. This student had difficulty in relating context to physical concepts and preferred the assurance of a clear-cut answer in the non-contextual problems. She wanted an authority to make the connections for her.

Student 2 generally exhibited the most naive epistemology throughout the interviews; however, in this situation he did seem to recognize the paired problems as equivalent problems in some instances. Nevertheless, his explanation was incorrect. In response to the physics query about tension and pain, he stated:

> I would say they are both very similar. I mean depending on the threshold of pain you could say the person could handle or how you want to measure that it would just be the force in that you have to pull. I mean the mass doesn't matter if it's a block or a person that's just the mass that you are needing to pull so I think they are the same.

Although he could recognize that "pain" is a relative term, a more sophisticated epistemology would also have recognized that both problems required him to calculate tension (force). He preferred a simplified problem and an authority to explain what to calculate.

At all levels of sophistication, these students preferred to rely on authority to solve problems. Because the contextual problems highlighted the ambiguous nature of "the real world," "the real world" could no longer function as a guarantor for the stability of phenomena. Thus, students all reverted back to relying on an authority figure as the guardian of knowledge.

LIMITATIONS

This case study has limitations in its key finding and broader impacts. One limitation is the time gap of more than a year between when the interviews were conducted and when the interviewee (participant students) took the courses. We acknowledge that a student's epistemological reflection could have evolved due to their subsequent education and time lapse; however, that distance could also offer them space to speak more honestly without fear of recrimination. Similarly, students' post-graduation activities might have influenced their views about the disciplines. For example, two students were in graduate programs in health related fields at the time of their interviews. The challenges of graduate school might impact their reflections on their conduct during undergraduate courses. We acknowledge these limitations and the small sample size. Thus, we are unwilling to overstate the theoretical implications of our findings.

Our goal is to investigate how students holistically reflect on their learning in multiple disciplines; therefore the time gap between their learning of the courses and their reflections of the courses was beneficial. However, we hoped that matriculated students would have greater comfort with ambiguity that would have changed their epistemology. Yet the study found otherwise. None of the interviewees stated that their views about the courses had changed from the time they took course to the time of interviews regardless of what kind of professional activities they were involved with after the graduation. This suggests that unless learners gain competency/expertise through upper level courses or profession related to the courses (eg teaching and/or research in the relevant field), time lapse on learners' epistemology regarding content and learning of a course has a limited impact. Nevertheless, our study has some implications for both future research and educational impacts in similar settings.

CONCLUSION

We sought to investigate student attitudes about learning in physics, calculus, and literature in order to understand how they coped with ambiguities in each discipline. The interviews revealed that students think that they can handle ambiguity well in literature but express strong discomfort with ambiguity in math/physics. However, analysis of the interviews actually show that all four students were highly uncomfortable with ambiguity in all disciplines. Ultimately, authority-- rather than independent knowledge--had the greatest impact on their willingness to navigate ambiguity in both literature, and the STEM disciplines. Even when claiming to know that learning was contingent or constructed, ultimately these students preferred to rely on authority. Thus, any novel scenario that presented a problem they were unfamiliar with was categorized as ambiguous by them, even when an expert would characterize the problem as relatively simple or straight-forward, such as when very similar problems (but unidentical to the ones demonstrated in lecture) are used on a physics exam, or an essay is assigned in literature asking students to analyze a poem or story on their own that was not discussed in class. Because students used similar learning strategies (reliance on authority), it would appear they do not have robust or coherent learning strategies.

We wanted to explore the role of coping with ambiguity because it plays an important, if not always recognized, role in developing a sophisticated epistemology. Although it may not be surprising that students prefer not to deal with ambiguity, what is perhaps surprising is the similarities in student approaches and attitudes toward both quantitative and humanities disciplines. Because the students interviewed were all health science majors, one might surmise that they would be more comfortable in the STEM disciplines rather than literature; however, that was not the case. Student 1 and Student 3 both had more robust learning strategies that made them more successful in all three disciplines. Students 2 and 4 had more naive epistemologies and thus less robust learning strategies in all disciplines. Yet, they were very adamant that the quantitative disciplines were rule-bound. Although these students were able to superficially acknowledge the complexities of literature, in fact, they relied on authority to assure them that literature was ambiguous. This highlights the lack of coherence in their epistemologies.

The lack of coherence is exemplified in the students' views of context. Although they all resoundingly, answered that they liked having disciplinary concepts related to the "real world," the interviews revealed that students did not always like context. The more complex the context--in other words, the more provided context actually come to "the real world"--the less students liked it. Students wanted enough details to make a problem personally relevant, but still, in essence, remain formulaic. They did not actually want to navigate complex contexts to deeply explore disciplinary concepts. Thus, students enjoyed historical contexts to help make sense of literary texts; however, they preferred not to have to reconstruct historical contexts to analyze literature on their own. In the quantitative disciplines, context-rich problems were intimidating for students.

Student preference for formulaic problems is best highlighted by their consistent choice of the non-contextual physics and calculus problems during the interview. Even students who claimed to prefer "real world" problems and who thought the contextual problems more interesting still preferred to do the formulaic problem because of the assurance that an authority could decide if their answer was correct. If these attitudes are typical, this finding could raise challenges for educators who attempt to engage students by making content relatable through socio-cultural and/or historical contexts. On the one hand, if students treat these contexts as mere window-dressing, is developing them worth the significant effort to do so on the educator's part? On the other, are there ways of developing contexts that would actually spur student curiosity and desire to know?

One of the most interesting revelations from this project is Student 3's assertion that he found the skills for literary analysis useful in approaching complex contextual problems in math and physics. This student's relatively sophisticated epistemology enabled him to make interdisciplinary and metacognitive leaps. If students with more sophisticated epistemologies make similar leaps, then having a broad-based interdisciplinary educational base can help students develop robust learning strategies that may even improve transfer of learning. Perhaps integrating more explicit instruction of both expert epistemologies and metacognitive techniques would further improve student learning strategies and content mastery.

Our small interdisciplinary research project suggests that much remains to be learned. Although development of epistemology has be studies in various subject areas, little research has been done to examine the development of epistemology across disciplines. Our study not only considers epistemology development across disciplines, we also asked students to reflect on all three subjects within one interview settings. Students reflecting on all three disciplines, often simultaneously, required them to engage in a level of cognitive sophistication not required in similar studies that focused on a single discipline. We were surprised to observe how similarly students approached our very different disciplines. We did not expect that they would have similar beliefs and attitudes toward literature as toward math and physics. What would a larger interview sample reveal? Would students from a variety of majors have similar answers? Questions like this suggest that there is scope for more interdisciplinary research projects that examine both STEM and humanities disciplines. If students do have similar approaches to what are often seen as completely opposite--even oppositional--fields, how should that then impact our pedagogical approaches? How should it impact general education curricular design?

The findings of this case study encourages us to reflect on some important considerations that has both future research and instructional implications. Student focus on “the right answer” logically leads them to prefer the least ambiguous scenarios that provide them the greatest chance of getting “the right answer.” As education researchers and instructors, we should inquire into why our students are focused on the right answer instead of the incertitudes of our fields. What are the implications for student instruction in higher education? Do we provide enough space for students to explore, take risks, and to be “wrong” without failing? How do we best serve students coming from a K-12 system that overvalue simple “correct” answers tested in standardized ways? How do we, as educators, allow for more ambiguity in our pedagogy in higher education? Instructional models and goals should focus on nurturing students’ development of epistemology about a discipline and learning about the discipline. Inefficacious instructional design could deteriorate students’ epistemology, leading them to a naive interpretation about disciplines and about learning of the disciplines. We suggest creating an educational environment for the development of students’ attitude and ability of coping with ambiguity based on our investigation that reveals an attribution of student’s level of epistemology sophistication to their degree of comfort with navigating ambiguity.

REFERENCES

Bishop, M. A. & Trout, J. D. 2003. Epistemology’s search for significance”. *Journal of Experimental & Theoretical Artificial Intelligence*, 203-16. DOI: 10.1080.095281302100005513

Byers, W. 2010. *How mathematicians think: Using ambiguity, contradiction, and paradox to create mathematics.* Princeton: Princeton UP.

Elby, A. 1999. Another reason that physics students learn by rote. *American Journal of Physics*: *Physics Education Research supplement*, 67(7), S52-S57. DOI: 10.1119/1.19081

Elby, A., & Hammer, D. M. 2001. On the substance of a sophisticated epistemology. *Science Education*, 85: 554-567. DOI: 10.1002/sce.1023

Glaser, B. G., & Strauss, A. L. 1967. *The discovery of grounded theory: strategies for qualitative research.* Chicago: Aldine.

Hammer, D. M. 1989. Two approaches to learning physics. *The Physics Teacher*, 27(9), 664-670. DOI: 10.1119/1.2342910

Hammer, D. M. 1994. Epistemological beliefs in introductory physics. *Cognition and Instruction*, 12(2), 151-183. DOI: 10.1002/sce.3730790404

Hofer, B. K. 2001. Personal epistemology research: Implications for learning and teaching. *Educational Psychology Review*, 13, 353-83. DOI: 10.1023/A:1011965830686

Hofer, B. K., & Pintrich, P. R. 1997. The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research*, 67(1), 88-140. DOI: 10.3102/00346543067001088

Huq, A., Nichols, M.D., & Aryal, B. 2016. Building Blocks: Threshold concepts and interdisciplinary structures of learning. In R. Land, J. H.F. Meyer, M.T., Flanagan (Eds.) *Threshold Concepts in Practice* (135-154). Rotterdam: Sense Publishing.

Kienhues, D, Bromme, R. & Stahl, E. 2008. Changing epistemological beliefs: The unexpected impact of a short-term intervention. *British Journal of Educational Psychology*, 545-65. DOI: 10.1348/000709907X268589

Kitchin, R. 2014.Big data, new epistemologies and paradigm shifts. *Big Data and Society*, 1(1), 1–12. DOI: 10.1177/2053951714528481

Kuhn, D., Cheney, R., & Weinstock, M. (2000). The development of epistemological understanding. *Cognitive Development*, 15, 309-328. DOI: 10.1016/S0885-2014(00)00030-7

Lee, C. D. et al. 2016 Epistemic cognition in literary reasoning.” In J.A. Greene, W. A. Sandoval, & I. Braten (eds.), *Handbook of epistemic cognition* (165-83). New York: Routledge.

Lising, L., & Elby, A. 2005. The impact of epistemology on learning: A case study in introductory physics. *American Journal of Physics*, 73(4), 372-382. DOI: 10.1119/1.1848115

Perry, W. G. 1970. *Forms of intellectual and ethical development in the college years: A scheme.* New York: Holt, Reinhart, & Winston.

Redish, E. F., Saul, J. M., & Steinberg, R. N. 1998. Student expectations in introductory physics. *American Journal of Physics*, 66(3), 212-224. DOI: 10.1119/1.18847

Rodriguez, L. & Cano, F. 2007. The learning approaches and epistemological beliefs of university students: A cross-sectional and longitudinal study. *Studies in Higher Education* 32(5), 647-67. DOI: 10.1080/03075070701573807

Schommer, M. 1990. Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology*, 82, 498-504.DOI: 10.1037/0022-0663.82.3.498

Schommer, M., Crouse, A., & Rhodes, N. 1992. Epistemological beliefs and mathematical text comprehension: Believing it is simple does not make it so. *Journal of Educational Psychology*, 84, 435-443.DOI: 10.1037/0022-0663.84.4.435

Sanders, C. 2003. Application of Colaizzi's method: Interpretation of an auditable decision trail by a novice researcher. *Contemporary Nurse Journal*, 14(3), 292- 302. DOI: 10.5172/conu.14.3.292

Sandoval, W. A. 2005. Understanding students’ practical epistemologies and their influence on learning through inquiry. *Science Education*, 89(4), 634-656.

Sandoval, W. A. 2016. Disciplinary insights into the study of epistemic Cognition. In J.A. Greene, W. A. Sandoval, & I. Braten (eds.), *Handbook of Epistemic cognition* (184-93). New York: Routledge.

Speziale, H. J. & Carpenter, D.R. 2007. *Qualitative research in nursing: Advancing the humanistic imperative.* 4th ed. Philadelphia: Lippincott, Williams & Wilkins.

