“Sources of knowledge” for students entering a gateway science course

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Abstract

Epistemology has been shown to have an important role on how students learn. The current paper focuses on one epistemological dimension, which is the “sources of knowledge” for students entering a gateway science course. Eight students were interviewed and asked about their sources of knowledge, and sources of physics knowledge. The qualitative analysis revealed that the students’ sources of knowledge, and sources of physics knowledge range from relying on the teacher, lecture, on peers, textbooks, Internet resources, experiences, or on experiment. Students who mentioned experiments as their sources of knowledge emphasized the importance of lab work. These findings have implications on teaching physics, and on designing classroom and online courses, and especially on current phenomena such as, the flipped classroom, and Massive Online Open Courses (MOOCs). Based on the study, policy recommendations are provided.

Introduction

One of the major problems that students face when they enter gateway science courses is that for them the language of science is similar to a foreign language [1]. Another problem is that students enter these courses with preconceptions and epistemologies that may interfere with learning. Unfortunately, students’ scientific knowledge is characterized by a knowledge-in-pieces viewpoint rather than intuitive theories [2].
Moreover, students’ epistemological knowledge in introductory courses is mostly at the dualism stage of Perry’s scheme [3], in which students see the world in a dualistic fashion involving the opposites of Right-Wrong, Good-Bad, and We-They, Truth is absolute, and any uncertainty can only be temporary [3].

Epistemological knowledge (or epistemic beliefs[1]) may not always be explicit, articulate, and consciously-held [5, 6], but it can have an important effect on learning and performance [7], on self-regulation [8]. Epistemic beliefs are multidimensional [9, 10]. Some of these dimensions (that are mainly the result of factorial analyses of the instruments measuring epistemological beliefs) are the following: (1) source of knowledge, (2) sophistication of knowledge, (3) certainty of knowledge, (4) justification of knowledge, and (5) attainability of truth. Audi [11] distinguishes between five sources

[1] “Epistemological knowledge” and “epistemic beliefs” are used interchangeably [4] Chinn, C. A., Buckland, L. A. and Samarapungavan, A. L. A. Expanding the dimensions of epistemic cognition: Arguments from philosophy and psychology. *Educational Psychologist*, 46, 3 (2011), 141-167.

of knowledge. These sources of knowledge are: (1) perception, (2) memory, (3) consciousness, (4) testimony, and (5) reflection. Perception is a source of knowledge which comes through the senses by seeing, hearing, smelling, feeling or tasting an external matter, memory is a "storehouse of what we have learned in the past", consciousness is "revealing our inner lives", reflection (including rationalism and empiricism) is "a way to acquire knowledge of abstract matters", and testimony is a "source of knowledge originally acquired by other people" [11]. These five sources of knowledge are "sources" of knowledge in the sense that they are processes for acquiring, forming or developing it. This means that these sources of knowledge are actually "ways of knowing", which when employed result in different forms of produced knowledge. Since these ways of knowing are qualitatively different, they may result in different kinds of produced knowledge.

Purpose

Uncovering students' epistemologies before instruction is crucial for forming the baseline of students' knowledge. Indeed, understanding students' epistemologies can help an instructor choose the pedagogical tools and resources, which can establish favorable learning environments for the students. Specific interventions are thought to affect, and help students change their epistemologies, enhance their approaches to learning conceptual knowledge, and develop a more coherent framework of scientific knowledge [12]. For example, specific instructional activities were shown to be effective in scaffolding students and making them view the course in a holistic manner [13]. Some of these activities include the Reflective Writing Tool [14], which can enhance students' understanding of concepts found in textbooks. Another example of these activities is the Conceptual-Conflict Collaborative-Group exercise [15], which can also enhance students' conceptual understanding [16].

There is ample evidence that identifying student prior knowledge plays a crucial role in designing successful learning environments [17]. Historically the focus of researchers was on identification of student prior content knowledge [18, 19] and their potential difficulties in learning. Student epistemologies are an important facet of prior knowledge that affects student expectations and approaches to learning [20]. Nevertheless, researchers and educators have often neglected this knowledge. Uncovering how students think about science and its ways of knowing is important in design and implementation of successful learning environments [21]. It is especially important in designing virtual technology enhanced learning environments where students have much more control over their learning than in a face-to-face classroom. The purpose of this qualitative pilot study is to probe one aspect of epistemologies of first year science students: how students perceive the sources of knowledge in general and knowledge in the context of a science (physics in particular).

Methods

In the current study, a convenient sample[2] [22] of eight students, and conduct an interview that examines their epistemological stances, and specifically as to how these stances affect learning. The students are undergraduate first-year students enrolled in an introductory physics course in a college in Canada. The reason we decided to conduct the study in this context is that introductory physics, more than any other first year science course, requires students to think conceptually, which often clashes with their preferred mode of learning [20].

Although the sample size may appear small, it is sufficient for the purpose of our qualitative study, based on the factors to be considered for determining sample size [23]. Specifically, these factors are: (1) the scope of the study, (2) the nature of the topic, (3) the quality of the data, (4) the design of the study, and (5) the use of shadowed data (where participants talk about the experience of other participants). Based on these criteria, the sample size is enough to provide us with the quality of data that helped in answering our research questions.

The interview was designed to tap into students' epistemological knowledge and their learning. In the current paper, we focus on the analysis of the two questions that related to the sources of knowledge. The first question is: How do you get knowledge? Or How do you acquire knowledge? In this question the student is asked about their sources of knowledge in general. The question is open-ended, and is not related to any specific kind of knowledge. This is done purposefully, so that the student can answer without any restrictions. The second question is: How do you get physics knowledge? Or How do you acquire physics knowledge? In contrast to the first question, which was asked about knowledge generally, this second question asked about physics knowledge specifically. The purpose is to see what sources of knowledge students rely on in order to "get", or "acquire" the scientific knowledge of physics.

The interviews were recorded, and transcribed. Transcripts were then coded according to a coding scheme that represents the different sources of knowledge. The coding is described in the Data Analysis section.

Data Analysis

Students' interview data relating to the sources of knowledge, and sources of physics knowledge were coded according to the following five codes. According to [11], it is possible to classify the sources of knowledge into the following sources: (1) perception (Code 3: current experience), (2) memory (Code3: past experience), (3) consciousness, (4) reason (Codes 1 and 2: reasoning and experiment), and (5) testimony (Codes 4 and 5: Teacher, School, Lecture and Book, Movie, TV or Internet). Consciousness relates to the knowledge of the self, and is not applicable as a code here. Perception (which was coded as "current experience"), and Memory (which was coded "past experience") were combined in the code "Experience". Reasoning refers to inductive or deductive logic, and thus could refer to using logical deductive reasoning, or inductive reasoning based on making conclusions, and acquiring knowledge based on the results of an experiment.

[2] A "convenient sample" is an easily accessed sample, and does not require a lot of time, money or effort to obtain

The first code is “Experiment”. This code means that the student acquired knowledge through an empirical procedure. We used this code to see how the student tries to reason inductively. This means that the student tries to form knowledge based on inductive logic arising from the knowledge constructed based on the results of an experiment. The second code is “Reasoning”. This means that the student relies on thinking and reasoning to conclude what knowledge is, or how they acquire knowledge. Reasoning in general includes both deductive and inductive reasoning. However, in this study, we used the code “reasoning” only for deductive reasoning. The third code is “Experience”. This means that the students rely partially on their historical or memorial knowledge as a source of knowledge. The fourth code is “Teacher, Lecture, or Peers”. In this category, the students relied on external sources of knowledge. They relied on testimony from a person, which could be the teacher or a friend. The fifth code is “Book, Movie, TV, or Internet”. In this category, the students relied on informational resources. Sometimes they mentioned “Google”, or “YouTube”. Sometimes, they mentioned “Discovery Channel”. This code also is also related to “Testimony” as a source of knowledge, but the testimony here comes from a source of information that is not a person they meet face to face.

Results

The results are shown in Table 1. They show that the most common source of knowledge for the students is the teacher, followed by the textbook and other sources such as the Internet. Some students reported that they rely on experience to get knowledge, or physics knowledge. Some students also reported that they rely on experiment.

Students who reported that they rely on experiment as a source of knowledge emphasized the importance of using an experiment and using actual “physical” procedures. Table 1 shows coding of the students’ sources of knowledge, and sources of physics knowledge. Table 2 shows excerpts of the students’ data “verbatim”.

Discussion

Implications for Learning, and Instruction. An important point that our analysis revealed is that for knowledge acquisition, the students we interviewed still relied mainly on lecture, and on instruction, followed by textbooks. This means that the students did not feel empowered to be able to generate valid physics knowledge by themselves and they have to turn to experts for it. This places students in a very passive knowledge receiver position that is not conducive to helping them develop critical thinking and reasoning skills that are the core of science. This might explain why the majority of science students enrolled in traditional lecture introductory science courses are doing so poorly on conceptual tests [24] that require critical thinking and reasoning, while they do relatively well on traditional tests requiring students to reproduce the knowledge they acquired during lectures. This may also explains why instructional methods asking students to provide explicit reasoning, reflect and evaluate scientific ideas, in other words, revisit the way how they learn science had been shown to be effective in that regard [13-16].

Another important point to highlight is that some of the students that we interviewed expressed that they relied on experiments to acquire knowledge. Courses that offer "theoretical" content knowledge without relating it to practical applications and students' everyday life tend to make students rely on "authority" for knowledge acquisition, without being able to see how this knowledge has come about. Experimentation is a vital part of science (especially physics) and it should be integrated in instruction not only in order to illustrate theoretically derived physics concepts, but also to engage students in the process of scientific discovery to help them discover these concepts for themselves [25].

Another important finding of the study is that none of the students that we interviewed reported that they use their own reasoning when first asked about where they get knowledge, or, physics knowledge. However, most of the students would agree that they use reasoning, once they are asked if they use it as a source of knowledge. Yet it is disappointing to see that despite all the availability of resources[3] that can help students to learn how to think independently, and ample evidence in support of active learning, many undergraduate science students are still passive learners.

A major problem in attempting to deal with these concerns is that approximately 50% of incoming college students have not reached the intellectual stage of development where they can think abstractly (i.e. scientifically) [26]. Such students prefer concrete facts to concepts. Moreover, courses that lack activities, demonstrations, labs, and experiments are short of an important aspect of helping these students develop their epistemologies that help them in learning. Demonstrations and experiments carry very little pedagogical value, unless students are challenged to think independently in order to analyze and predict the results of these demonstrations: they might help students enjoy the class, but the students will not learn much from them [27]. Recent attempts to address this problem in large classes use modern technologies, such as electronic response systems and live data collection technologies to engage students more actively in the learning process and encourage their reasoning as opposed to passive acceptance of knowledge from authority [28].

Implications for Technology-Enabled Education (TEE). TEE offers very important tools for learning and instruction. However in utilizing such tools and in designing classroom, online courses, as well as MOOCS, instructors and designers need to take into consideration pedagogical factors, such as the importance of using experiments to help students acquire knowledge in an "empirical" way, and especially for those students who have greater difficulty understanding the basic concepts presented in the course unless the course includes experimentation, and hands-on activities. As mentioned above, modern technology provides unprecedented opportunities to engage students in active knowledge acquisition as opposed to passive knowledge acceptance from authority. Electronic response systems pioneered by Eric Mazur in late 80s allowed instructors to utilize conceptual questions helping students develop reasoning skills [29]. Even in large introductory science courses the implementation of these systems in order to engage students actively in learning has shown to be very effective [24]. Modern research-based computer simulations such as PhET [30] provide students with an unprecedented opportunity to test their ideas and ask "WHAT-IF" questions. Moreover, there is

[3] See www.compadre.org and www.perug.org

scientific evidence that virtual scientific experimentation is often more effective for the students than a hands-on science activities [31]. Data collection and analysis technologies allow instructors and students to collect and analyze data easily and in-expensively both in terms of time and resources [32]. Also, Technology-enabled learning tools employing social-based interaction such as PeerWise [33] that asks students to design their own science questions and critique the questions of others, is another way of how technology can be used to help develop student scientific epistemologies.

However, there are also challenges associated with designing successful technology-enhanced learning environments. Educators have to acquire Technological-Pedagogical Content Knowledge (TPCK) [34], the knowledge of how technology can be used to promote student learning in a particular subject context. The "source of knowledge" facet of epistemology construct discussed in this paper should be taken into account while designing learning environments. Based on our discussion, we provide a brief list of policy recommendations in the next section.

Policy Recommendations

In this section, we draw on our conclusions and discussion to provide a brief list of policy recommendations. These recommendations are:

1- Instructors should take into consideration students' epistemologies when they start a course, because these epistemologies affect how they learn during the course.
2- Instructors should take into consideration students' ways of knowing, or how they acquire knowledge, because these sources of knowledge affect how they learn, and what they focus on during learning.
3- Instructors are encouraged to use instructional methods, and activities that promote deeper learning, more conceptual knowledge construction, and more sophisticated epistemological beliefs.
4- Instructors are encouraged to employ technology-enabled tools and resources that have been show to promote students' learning.
5- Assessment should include evaluating students' epistemic knowledge, because this knowledge can show the depth of their learning, and whether it is passive or active.
6- The design of learning environments should be based on principals of learning, and to facilitate knowledge acquisition, and knowledge creation.
7- Science curricula should include authentic experiments, simulations, demonstrations, or hands-on activities that aim at helping students understand and construct knowledge.
8- Online courses, blended learning environments, and MOOCs should incorporate learning that goes beyond teaching content knowledge and problem solving. We recommend that these learning environments incorporate real lab work, experiments, or similar activities that engage the students in modes of learning that promote different kinds of knowledge acquisition, including deductive, and inductive reasoning.

9- We recommend using social learning tools that show favourable learning results, and especially those that help students become more active learners who seek to acquire and construct knowledge.
10- We recommend using evidence-based instructional methods, as well as theories and frameworks that integrate learning, teaching, assessment, epistemology, and technology to guide instruction, and instructional design.

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Table 1: Students' sources of knowledge, and sources of physics knowledge

Epistemic Knowledge	Inductive Reasoning		Perception or Memory		Deductive Reasoning		Testimony			
Codes	**Experiment**		**Experience (Current or Past)**		**Reasoning**		**Teacher, Lecture, Peers**		**Book, Movie, TV, or Internet**	
Student	**K**	**PK**	**K**	**PK**	**K**	**PK**	**K**	**PK**	**K**	**PK**
KK			X				X	X		X
CJL			X				X	X	X	
ADM	X	X					X	X	X	X
BB							X	X	X	X
HT				X			X		X	
DW				X			X	X	X	
JL		X					X	X	X	X
HW			X						X	X
Frequency of Codes	1	2	3	2	0	0	7	6	6	5

X = code is present

K = Knowledge

PK = Physics Knowledge

Table 2: Comparison between pre and post students' sources of knowledge, and sources of physics knowledge

JL	Before I study in here, I study physics in Korea, I usually get the knowledge from textbook, read some book. But here, I think, I am getting the experience from experiment. So it's very, you know, awesome. You know, I see the situation you know, in real, you know. Oh, now I understand why it happens, so, I like studying here.
JL	Then experiment is very fun. It makes me understand very well
ADM	Ah…physics has a lot of…ah…experimental. So I find that learning through lecture is beneficial, but also doing…ah…watching demonstrations, and the lab portion of the course really helps me visually understand why we are learning, not just like mathematical formulas, but actually seeing it applied in real life.
CJL	I am not very good at physics. Everything is kinda like math thing for me. But if you just talk about how you like, how you calculate the thing and I don't really get it through by math. In order to really understand, doing the demo is the best thing for me. Or the thing that I can really feel it. Otherwise, by drawing the forces, not really. I don't really feel to know. I don't know. You have to really feel it. Cuz it's PHYsics, it should be physical…