The impact of epistemology on learning: a case study from introductory physics

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Summary. – This paper presents a case study of the influence of epistemology on learning for a student (Jan) in a reformed, introductory college physics course. Analysis of videotaped class work, written work, and interviews shows that many of Jan's difficulties in class are epistemological in nature. Our primary goal is to show instructors and curriculum developers that a student's epistemological stance—her tacit or explicit views about knowledge and learning—have a direct, causal influence on her physics learning.

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1– Introduction

In recent years, physics education researchers have begun to look at student attitudes, expectations, and epistemologies (tacit or explicit views about knowledge and learning) [1-3]. Our study of epistemology and learning builds on previous research with college and pre-college learners. The majority of these studies look at correlations between epistemological measures and learning outcomes, finding that specific clusters of epistemological beliefs correlate with academic outcomes such as grade point average [4], integrated conceptual understanding in middle school [5], and ability to reason on applied tasks [6]. In college physics, students' gains on standard conceptual measures were found to correlate with their epistemologies as inferred from weekly written reflections on their own learning [7]. A few studies have gone beyond these correlations to investigate not just *whether* learning is affected by epistemology, but *how*, finding epistemological interactions with sociocognitive engagement patterns [8], self-reported activities during investigative project work [9], interpretations of inquiry tasks [10], cognitive strategies [11, and physics problem solving [1].

These studies established a more causal link between epistemology and learning and also raised new questions and issues. One is the distinction between "personal" and "public" epistemologies. Public epistemology encompasses a student's ideas about the nature of knowledge and learning for the community as a whole, or for a specific disciplinary community. Personal epistemology, on the other hand, concerns a student's views about her own knowledge and learning. A student's public and personal epistemologies can differ significantly and Hogan's work showed the latter affects learning behavior far more profoundly. Yet many studies do not make this distinction. The various studies cited also vary in the extent to which they disentangled students' personal epistemologies from their *expectations* about what's rewarded in a particular course (or in "school science"). These can be quite disparate at times, and both Hammer [12] and Elby [13] show how important this distinction is for learning. Yet another issue arising in previous studies is the context-sensitivity of students' epistemologies. For example, students show differences across disciplines [14] and also differences between their professed and their enacted epistemology. Thus, to make progress exploring the causal relationships between epistemology and learning, we must study *personal* epistemologies as students are *in the process of actual learning*, while remaining sensitive to context-differences in different learning environments.

In our study, we look at a single student ("Jan") learning physics, analyzing both personal epistemology and learning from the same set of classroom data. For a supplementary analysis, we use a separate set of data from interviews, carefully accounting for contextual differences and for factors that point to public epistemology, expectations, and other influences. From these analyses, we draw direct, causal links between Jan's epistemology and her learning in the classroom.

2- Data and Results

The subject of this study, Jan, was a third-year student in a algebra-based introductory physics course at the University of Maryland. Each week the students attended three hours of lecture, two hours of laboratory, and one hour of tutorial (worksheet-led conceptual group work [15]). We have two hours of video of Jan and her group working in tutorial.

The first of these tutorials asked the students to answer some questions about electric force and then find the electric field. Jan participates quite a bit, as do her fellow group members Veronica and Nancy. During the first part of the hour, Jan answers the tutorial worksheet questions using mathematical reasoning. Specifically, she reasons using the functional dependencies between force, charge, and field in Coulomb's law and in the field definition $E = F/q$. In doing this, she makes a series of errors that other students and the teaching assistants catch and help her to correct. Early on Jan tries to use Coulomb's Law, $F=kq_1q_2/r^2$, which says that the force between two charged objects depends on a constant, (k), the product or their charges (q_1 and q_2) and decreases according to the square of the distance (r) between them. Jan makes a math error, calculating the strength of the electric force as depending on the *difference* in magnitudes of charges rather than the product.

Jan: So, if you had like a 1 and 4 here, that's gonna be like a bigger difference as opposed to having 2 and 4.

[The teaching assistant catches the error and Jan laughs.]

Jan: Oh, so the vector would be bigger.

Later, Jan reasons with the formula *E=F/q*, and on three separate occasions forgets that the force *F* depends on *r* and *q*. Each time a peer corrects her Here is an example**.**

Jan: No, but what I am saying is E is equal to F over q, right? That doesn't include radius in it.

Nancy: But F includes um, includes r.

Jan: Because further away is smaller.

Jan is using sophisticated mathematical reasoning, drawing inferences from the functional dependencies of the formula, rather than using it only to calculate numbers. However, despite her facility with mathematics, she repeatedly makes similar math errors. Jan's problem here seems to be her failure to check her mathematical reasoning against her common sense reasoning. We know from this and other data that Jan has an intuitive understanding of how force changes as the charges or distance change, and each time she is corrected she acknowledges the correctness and simplicity of the other's argument. Yet, she is not calling on this knowledge to check her own mathematical reasoning each time she answers a question. We think this behavior is both a window into Jan's epistemology and evidence of how it is affecting her learning. We propose that Jan's epistemology is causing her to act as if a “wall” separates formal reasoning from intuitive, common sense reasoning and that this accounts for her not checking her math against her common sense understanding.

Eight weeks later, the same four students are working on the Light and Shadow Tutorial from *Tutorials in Introductory Physic*s. The group has a screen, a board with several small apertures, and several light bulbs. After they have been moving the bulbs around, observing the changing patterns bright spots on the screen, the worksheet asks them "What do your observations suggest about the path taken by light from the bulb to the screen?" Jan asks if the path is not a straight line and a conversation ensues.

Jan: But I mean, if it, if if it was direct, right, then the light wouldn't come through if it wasn't aligned.

Veronica: If it was direct, then it would go like this. [Moving hand horizontally from bulb, bangs into board above aperture to show that light would not pass through.]

Jan: Right. That's what I mean.

[More conversation, with Veronica trying to explain and others questioning her.]

Veronica: It, it spans out, and whatever part goes through that circle is the part we're going to see.

Jan: [Drawing as she talks] So the light is like that and these are the rays, and the vector points that way will go through the hole.

Nancy: Okay, so then if you move it up, then it's going to be?

Carl: So if here is the hole and the light is down here, the light is going to go in the direction …

Jan: Right, so like it has

[Nancy, Jan, and Carl talking, unintelligible]

Veronica: Really, it's just normal.

Jan: All the rays are going like this. So, it's kind of like polarized.

Veronica: Mmm, not really. It's just, well, it's just, guys, you're making it, you're trying to make it more difficult. It's just, the light goes out. It only goes through that one circle. So, obviously, if it is down here, and I'm looking through that circle. Look, you're sitting down here. You're looking at this big cardboard. You're looking through that little circle. All you're going to see is what's up there. It's a direct line.

Jan: Look, I see what you're saying, alright. But, I'm just trying to make it like physics-physics-oriented. [Laughs]

Veronica: It is, it is physics-oriented. That's just the way it is.

Jan: Alright.

Jan initiates this conversation and a discussion ensues using common sense language, as encouraged by the worksheet. However, then Jan begins to exhibit some puzzling behavior. Jan appears to be having some difficulty understanding Veronica's explanation. But Veronica thinks Jan's trouble stems not from a conceptual difficulty, but rather from Jan's "trying to make it more difficult." Why would Jan do that? Luckily for us, Jan is quite explicit in describing her own motives. "I'm just trying to make it like, physics- physics-oriented." Jan is rejecting the common sense explanation in favor of a more formal one. So, to supplement our earlier hypothesis about Jan's epistemology, not only does she act as if common sense and formal reasoning were entirely disparate (separated by a "wall"), she also acts as if common sense reasoning is not appropriate for physics.

At this point we wanted to look at Jan's epistemology in more detail, so we conducted 6 hours of interviews. Since we were interested in Jan's epistemology in the learning context, we gave her physics problems to work on for the first 4.5 hours. The remaining time consisted of more direct probes of her thoughts about the course and her learning. In analyzing this data, we took a resource perspective. That is, we assumed that Jan's epistemology might not consist of stable beliefs, but of a context-dependent pattern of activation of epistemological resources. In other words, we assumed Jan probably has at her disposal lots of ways of viewing knowledge and will use certain ones more often in certain contexts. Thus, in characterizing her epistemology we were searching for both consistencies, as seen above, and inconsistencies, especially differences between her behavior in interviews and her behavior in the classroom. To do this, we coded the type of reasoning she uses to solve problems as common sense or formal, and also coded what she does when she has a difficulty or when two lines of reasoning are in conflict, whether she addresses the issue or ignores it. What we found was dramatic. In interviews, in sharp contrast to class, Jan is far more likely to reason with common sense than formal reasoning (71 codings vs. 22.) So with respect to this aspect of her epistemology, the interviews are a sharply different context for Jan. With respect to resolving conflicts and difficulties, we first noticed that when Jan tries to solve a problem using two lines of same-type reasoning (two lines of common sense reasoning or two lines of formal reasoning), Jan reconciles about half of the time (13 out of 28 opportunities were addressed). This means that when she has two lines of same-type reasoning, she is often seen exploring whether they are two ways of saying the same thing, or whether one line could inform the interpretation of the other, or whether one line of reasoning might need to be modified or refined to agree with the other. She is quite facile with this type of checking and reconciliation. However, when she uses two disparate lines of reasoning for a problem (one formal and one common sense), she almost never reconciles. Only 1 of 9 opportunities we were coded as a reconcile. Thus, in both the interviews and the classroom, Jan is remarkably consistent in treating common sense and formal reasoning as if they cannot speak to one another. The interview data support the classroom diagnosis that Jan sees a "wall" between formal and everyday/intuitive thinking

Having made this diagnosis of Jan's epistemology, we then used the full set of data, including her explicit statements, to explore other possibilities that could explain her problematic classroom behavior. We easily ruled out the idea that Jan lacks skills in informal reasoning, in mathematics, or in checking two lines of reasoning against each other. We found some evidence that Jan's expectations and confidence in her intuitions play a role, but these effects, without epistemology, cannot account for all of what we observe [16]. We concluded that Jan's epistemology, specifically her tacit view of formal and common sense reasoning as disparate, has a direct causal effect on her learning, leading to the problematic behaviors discussed above.

3– Implications

As instructors and curriculum developers diagnosing student learning, we must consider strengths and difficulties not just of a conceptual but also of an epistemological nature. Specifically, we must learn to identify which epistemological resources students are activating during the learning process, so that we can help them to use, reliably, the more productive approaches to learning.

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[16] For more detail, please see LISING, L. J. AND ELBY, A., under review with *Am J Phys*.