Alignment between student epistemological views and experiences with course structures in introductory physics: A case study

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Designing physics courses that support students' activation and development of expert-like physics epistemologies is a significant goal of Physics Education Research. However, very little research has focused on how physics students' interactions with course structures resonate with different epistemological views. As part of a course redesign effort to increase student success in introductory physics, we interviewed introductory physics students about their experiences with course structures and their learning and belonging beliefs. We present here a case from this broader data corpus in which a student, Robyn, discusses his epistemological views of physics problem solving and his experiences with physics lectures, office hours, and discussion sections. We find that Robyn's physics epistemology manifests consistently across his interactions with each of these different course structures, suggesting a possible resonance between students' beliefs and their experiences with course structures and the value of further investigation into the potential merits of comprehensive course design.

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I. INTRODUCTION

Physics classes impart not only content knowledge but also messages about the nature of physics knowledge and learning. Students' personal epistemologies of physics have been classified along different dimensions, such as beliefs about the structure of physics knowledge, beliefs about the content of physics knowledge, and beliefs about learning physics [1, 2]. Beliefs along each of these dimensions range from more expert-like to more novice-like in character. For example, an expert-like belief about learning physics might be that learning physics is about working to develop one's understanding and intuition of concepts, while a novice-like belief about learning physics might be that learning physics is about memorizing information received from an authority, like an instructor or textbook.

Helping students activate and develop epistemological views that can support their long-term success has emerged as an explicit learning goal in Physics Education Research. Expert-like epistemologies of physics have been associated with students' deeper engagement with content knowledge [3, 4] as well as better course performance and higher rates of retention [5]. Unfortunately, traditional physics instruction has often had the opposite effect; most studies which survey university physics students' beliefs before and after instruction find that students leave physics courses with less expert-like beliefs about the nature of physics knowledge and learning than they initially reported [6]. However, a few specialized approaches, such as an explicit focus on epistemological development [7] and modeling instruction [8], have produced positive shifts in students' epistemological stances, as measured by the CLASS and MPEX surveys.

Compared to the many pre-post survey change studies, very little research has focused on how specific course features in physics courses and students' experiences of them resonate with different epistemologies of physics. However, a few studies which interviewed STEM students about their experiences with course structures and their epistemological views have found evidence to suggest a relationship between the two. For example, high school mathematics students' interactions with didactic or collaborative learning environments have been linked to their adoption of views that mathematics knowledge is definite and received from authority or constructed through independent thinking respectively [9]. Additionally, undergraduate engineering students' interactions with assessment and grading policies which do not reward deep understanding have similarly been linked to their views that this type of thinking is not valued in the engineering program [10]. Further study of how students experience and interact with physics course structures at the college level can help inform future instructional design efforts.

In this paper, we present a case of an introductory physics student, Robyn (pseudonym), discussing his epistemology of physics learning and problem solving as well as his interactions with course structures. Our analysis addresses the following research question: how can students' epistemological views become evident in their interactions with course structures? We will illustrate that Robyn's epistemology of physics manifests in consistent ways across his interactions with a variety of different course structures. This finding suggests the value of further research on how course structures can be designed coherently such that they resonate more strongly with the epistemologies we desire for our students.

II. METHODS

In the Fall of 2022, as part of a larger course redesign effort and investigation into the interaction between students' experiences of course structures and their beliefs related to learning and belonging in physics, we conducted semi-structured interviews with students enrolled in Physics 100, an introductory physics course at a large, public, midwestern university. Enrollment in Physics 100 consists primarily of freshman engineering majors. The course provides these students with a one-semester introduction to kinematics and dynamics to prepare them to take Physics 211, a calculus-based introductory mechanics course which is required by many major programs, including all engineering majors. Weekly course meetings consist of one lecture (preceded by an at-home video pre-lecture) that incorporates peer instruction-style questions and one discussion section where students solve problems in small groups. Students also complete two homework assignments each week and are encouraged to attend office hours to receive help from peers and instructors with the homework questions.

Semi-structured interviews followed a protocol designed to probe both students' experiences with different Physics 100 course structures and their beliefs about learning and themselves as learners. Interviewers selectively diverged from the pre-planned protocol questions to pursue experiences and topics that were salient for the students, particularly if they were related to students' learning beliefs. Students were asked both open-ended questions about their Physics 100 experience as a whole, the challenges they faced, and their views on learning physics as well as questions about the usefulness of specific course features. Students' responses to a pre-interview survey on these topics were used to guide parts of the interview. All interviews were video and audio recorded, and the recordings were transcribed and discursive turns numbered. Interesting segments related to the project research questions were flagged for subsequent, more in-depth analysis which included viewings and discussion in larger research team meetings.

Robyn (whose preferred pronouns are he/him) was interviewed in week 12 of his first semester of college. At the time of his interview, Robyn was enrolled in the engineering college as "undeclared," meaning he had not yet selected a specific engineering program, though he reported interest in pursuing systems engineering on his pre-interview survey. During the interview, Robyn described having had a very negative view of physics at the start of the semester based on his experiences with physics in high school. However, at the time of the interview, Robyn claimed that his very positive experience in Physics 100 had altered this view to the point where he was considering selecting physics as his major.

Robyn's interview was selected for this case study because he was especially articulate about his epistemological views in physics and his views on Physics 100 course structures. Consequently, Robyn represents an exceptional rather than representative case from the data corpus, which we use to explore theoretical ideas of how students' beliefs may be connected to their experiences with course structures.

III. RESULTS

A. Robyn's epistemological view of problem solving in physics: general application of a few key concepts

We will start by characterizing Robyn's general epistemological view of problem solving in physics. Early in the interview, Robyn indicates that learning physics has been challenging. The segment of transcript below begins with a followup from the interviewer, prompting Robyn to elaborate on those challenges. Robyn proceeds to explain that he perceives a difference in problem solving in physics versus in other disciplines.

9 ***I:*** *When you say [physics] is challenging, what aspect of it is challenging?*

10 ***R:*** *Just understanding physics... it requires a completely different way of thinking than other STEM courses like calculus, chemistry, biology. In high school, I had a lot of chemistry, a lot of biology, I mean the standard calculus, precalculus, algebra two courses. All of those, they're more like just, it's a lot of computational work where you're given numbers, and you're given one problem, and you're just told to solve it using one strategy that you learned how to solve in class or lecture. But physics, it requires thinking in a different way. Rather than thinking about how to get the, like, just your one goal is to get the answer, it's thinking about the many different ways there are to get the answer, and there's more I'd say theory versus just a plain, just a simple question. And, yeah, just adapting to that way of thinking has been challenging, but really, I feel like it's three big concepts. You have, everything is based around Newton's laws, so I feel like once I understood those, and I'm still learning how to understand those, but I feel like that understanding has been key to my success as the course has gone on. So first understanding that was challenging, but now it's gotten easier, I think. And you learn how to think about the questions you're given, and you learn how, like, to write out equations and draw diagrams is just the general strategy for any physics problem you're given.*

Epistemologically, Robyn's description of physics problem solving focuses on general, underlying concepts rather than memorizing and applying prescribed procedures. Robyn describes physics problem solving as focused on theory and key concepts, such as Newton's laws. He then contrasts this experience with problem solving in other courses, which can be summarized as plug-and-chug: he is assigned mainly "computational work where you're given numbers" and taught one prescribed strategy to apply to each type of problem.

Next, we will examine Robyn's reported experiences in three different parts of the course: lecture, office hours, and discussion sections. We focus on these course structures because Robyn is especially descriptive about how they support his learning in ways that we will argue are aligned with his epistemology of physics.

B. Robyn's experiences with course structures: valuing understanding through independent thinking

In recounting his experiences with three different course structures - lecture, office hours and discussion sections - Robyn expresses repeatedly that he values opportunities to develop a deep understanding of concepts rather than memorize and apply procedures, which we contend is aligned with the epistemology of physics learning Robyn describes earlier in the interview.

In the next section of the interview, the interviewer asks Robyn what parts of the course have been most helpful. Robyn starts by explaining that answering Peer Instruction-style questions in lecture with clickers is useful because they encourage students to think deeply about problems and their solutions rather than just accepting correct answers provided by instructors.

19 ***I:*** *What aspects of the course do you find most helpful?*

20 ***R:*** *... the iClicker. We use that in lecture a lot, and I kind of compare it to the use in chemistry, and even though they're the same device, I use it in a completely different way in physics. And our results in physics, we actually discuss them, and [the] Professor, he goes over why the wrong answer is wrong versus just why the right answer is right, which is what we do in chemistry. It's like, 50% of students put answer A, 50% put D, and D's the right one. In chemistry, our professor just goes "Ok, here's why D is right." But in physics, we talk about why A is wrong, and then he asks for student opinions. So if I put A, and it's wrong, he asks me to... defend why I thought A was right, and then he asks a student who put D to defend why D is right. And then he asks us to talk with our table again and re-answer the question. So the iClicker questions encourage more collaboration and more thinking, which leads to better results and more success in the class.*

21 ***I:*** *Got it, ok. So, is there... something in Physics 100 that you would like to see implemented in other courses?*

22 ***R:*** *... I know the iClicker is implemented in other courses, but I would like to see the way that we use the results of the iClicker to be used in other courses, like more discussion on why something is wrong. Because if I put a wrong answer, obviously I thought it was right, so I want to know why it's wrong, versus why the people who put the right answer got it right. Because you don't necessarily gain anything from just seeing the right answer, in my opinion.*

Overall, Robyn describes two valuable elements of iClicker questions in physics lecture that go beyond just learning the correct answer and why it's correct. One is discussion of the questions with peers, which encourages students' independent thinking and deeper understanding. The second element is an intentionally designed addition to Physics 100 classroom discussions: explicit discussion of why seemingly sensible, incorrect answers are wrong.

The benefit Robyn ascribes to this lecture activity highlights an epistemological stance towards learning physics aligned with his general view of physics problem solving. Here, Robyn values opportunities to practice his thinking with the underlying ideas, not just learning the correct answer. He even goes as far as to say "you don't necessarily gain anything from just seeing the right answer in my opinion." This epistemological view of learning fits with the epistemological category "independence in learning physics" [1, 2]. It also fits with the epistemology of problem solving as application of a few general concepts rather than applying learned procedures that Robyn described previously, since applying concepts to physics problems requires more independent thinking and deeper understanding than applying learned procedures.

Later, the interviewer prompts Robyn to discuss the skills he feels he's developed as a consequence of taking Physics 100, and Robyn's answer, which focuses on office hours, again reflects his belief that learning physics requires understanding concepts rather than memorizing procedures.

33 ***I:*** *Could you give me some examples of the skills that you have gained from Physics 100?*

34 ***R:*** *... Another skill that I find myself using a lot is inquiry... Sometimes, like in office hours last week, [the] Professor explained something to me, and it really made no sense, but I was able to ask him to explain it another way, and it made perfect sense. So the same idea but just explained two different ways. So it's really enhanced my skills of asking questions and being comfortable asking for another way of solving a problem rather than just, like, having one way to solve it and not understanding it but kind of just going with it.*

In describing his experience with office hours, Robyn once more expresses a reluctance to accept and internalize procedures without deeper understanding. Robyn's belief in the utility of "inquiry" as a learning strategy seems rooted in his view that "just like having one way to solve it and not understanding it but kind of just going with it" is not the way to learn physics, as supported by his statements regarding problem solving in Turn 10 as well. Robyn's description of his experience in office hours is also very similar to the statement he makes about the value of discussing the wrong answers to iClicker questions, where Robyn was similarly dissatisfied with the idea of having to accept a solution approach that he didn't fully understand.

Later, Robyn is presented with a hypothetical scenario in which he is asked to reflect on his experiences in discussion sections and given a choice between joining a group where one person knows the right answers and leads the rest of the group in solving the problem (Samira's group) and another group where the students are all more uncertain but work together to arrive at a solution (Meena's group). Robyn has just explained that his experience in discussion sections has been very similar to Meena's in that his group works together to construct answers to problems and that he prefers this method over relying on the guidance of a single group member. The interviewer follows up by prompting Robyn to consider the possible merits of Samira's group, and Robyn's response is similar to the interactions he describes with the previous two course structures and aligned with his epistemological views on physics problem solving.

123 ***I:*** *... it seems like Samira's group works very efficiently and completes the task quickly. Does that seem like a good thing to you as well?*

124 ***R:*** *I mean, yes, efficiency is always good, especially when you don't have that much time, but it says (reading from and pointing to print out of scenario), "one person who always knows the right answer, so we pretty much follow her lead." So I don't know if that's necessarily, like if you know the right answer, I'm just going along with you even if I don't understand it. So that's definitely not effective, and... I'd rather know how to do a problem than have the work done on time but not know how to do the problem.*

When asked to choose between completing a task and understanding concepts in the context of discussion sections, Robyn values the experience he's had collaborating on problems with his group members and explains that "I'd rather know how to do a problem than have the work done on time but not know how to do the problem." Once more, this statement is extremely similar to Robyn's reluctance to accept a solution from an instructor that he doesn't understand in either office hours or lecture, and to the more general beliefs Robyn expresses early in the interview about learning physics as learning to apply concepts and understand the underlying theory rather than prescribed procedures.

In summary, Robyn's epistemology of physics - that learning to apply and understand concepts is more valuable than memorizing and applying procedures - is evident in his assessment of physics problem solving as well as his descriptions of his experiences in lecture, office hours and discussion sections. Robyn repeatedly expresses dissatisfaction with accepting solutions that he does not fully understand and seeks out opportunities to use course structures to help him refine his physical reasoning, illustrating the connection between his epistemology and interactions with course structures.

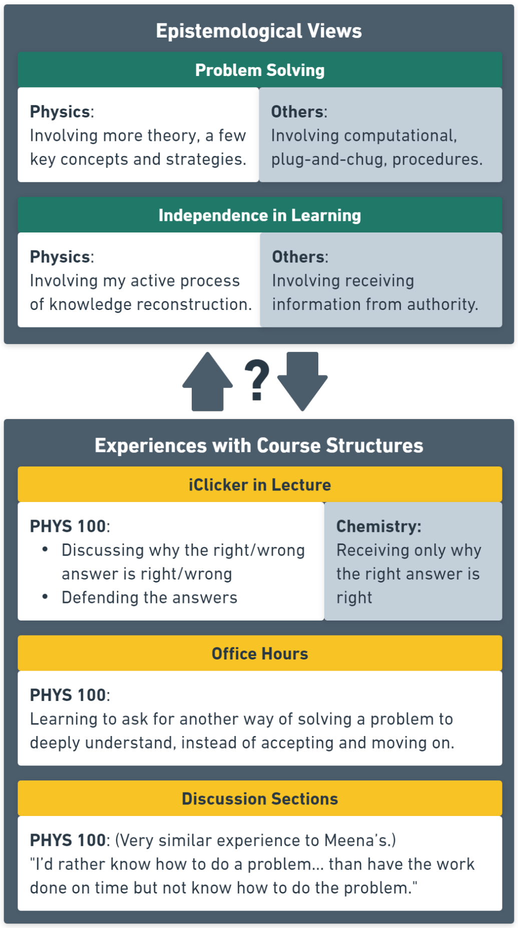

FIG. 1. Robyn's epistemological views and experiences with iClicker in lecture, office hours, and discussion sections. The up-down arrows indicate hypothesized mutually reinforcing relationship between epistemological beliefs and experiences with course structures, which can be clarified through future research.

IV. DISCUSSION

This case study provides an example of how a student's epistemological views can be aligned with their perceptions of their interactions with course structures, such as lectures, office hours, and discussion sections. Figure 1 summarizes Robyn's espoused epistemological views and experiences with course structures and indicates a hypothesized cyclic reinforcement loop between students' epistemological views and their experiences with course structures. In Robyn's case, interactions with course structures resonated with a sophisticated view of physics learning. However, not all of the students in our study reported interacting with these course structures in the same way as Robyn, and their accounts of the epistemological aspects of their experiences are generally less explicit and consistent. Our future work will attempt to apply a similar analysis to other students' reports of their experiences to investigate other possible resonances between students' interactions with course structures and their epistemological views. Additionally, we plan to survey students' epistemologies as well as collect observational data of course activities and compare these findings with epistemological aspects of students' reports of their course experiences. We hope this analysis will help us better understand the details of our hypothesized resonance loop and advance our instructional design principles for supporting students' development of expert-like epistemologies.

The alignment in Robyn's experiences with different course structures suggests another key issue for future research: the importance of aligned messaging between multiple course structures. Physics instructional design often focuses on deliberate efforts to develop students' knowledge and beliefs, such as Hammer and Elby's instructional approaches to help students become aware of and refine their everyday thinking [11]. However, we propose that other course structures can inadvertently reinforce or clash with the epistemological goals of these explicit instructional efforts. For instance, grading that focuses on the correctness of numerical calculations may support epistemological views that learning physics means learning to apply formulas for computation, thereby undermining the effectiveness of other efforts to develop students' expert-like epistemologies. A better understanding of how different course structures can resonate with different epistemological views could help explain why pre-post survey data show that many piece-wise PER-based instructional reforms fail to positively develop students' epistemological views and why courses that produce positive pre-post epistemology/attitude survey shifts, such as an explicit epistemological curriculum or modeling instruction, shift multiple course structures to align with the learning goals.

Similarly, our findings also suggest that it may be fruitful in future work to attend particularly to the alignment between the epistemological messages of both instructor practices and course structures. In Robyn's accounts of his experience in lecture and in office hours, he attends particularly to the practices of the instructor: in lecture to their choice to discuss wrong answers when using iClicker questions and in office hours to their willingness and ability to explain a concept multiple ways. In our analysis, we considered these practices as part of the course structures in which they occurred, but future work can break down the ways in which instructor practices and course structures can reinforce each other to support students' development of expert-like epistemologies.

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