Students' Sensemaking Skills and Habits: Two Years Later

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Recent efforts aim to make sensemaking instruction more explicit with the hope of having lasting impact on students' success in a broad range of physics settings. A sophomore-level theoretical mechanics course developed at Oregon State University emphasizes sensemaking on par with physics and math concepts. This emphasis includes explicit instruction and assessment of student sensemaking. We have found that student sensemaking improves during this course but were curious to see what lasting impacts the course has on students. Seven students were interviewed approximately two years after taking this course. We asked students about their current understanding and use of sensemaking and to what extent the course contributed to their sensemaking skills and habits. We found that students have a variety of ideas about what sensemaking is—from answer-checking to how you understand anything—but that they felt this sensemaking-focused course was instrumental in developing their sensemaking.

I. INTRODUCTION

Physics sensemaking has traditionally been discussed with a "we know it when we see it" approach. Therefore, researchers, instructors, and students struggle to agree on what sensemaking is and how to perform it. Most physics courses provide little explicit instruction about sensemaking; it is taught mainly through demonstration and is rarely presented in textbooks or other course materials [1].

Many different ideas about physics sensemaking are discussed in the research literature [2–9]. We define physics sensemaking as seeking meaning in or coherence between representations of knowledge. This definition draws on several sources in the sensemaking literature, particularly Danielak, Gupta, and Elby [9] who state that sensemaking is "pursuing a deep understanding that integrates formalisms, concepts, and everyday or intuitive thinking."

Courses throughout the physics program at Oregon State University (OSU) explicitly teach sensemaking. We are interested in learning how this explicit instructional emphasis influences student ideas about sensemaking and their sensemaking practices. We interviewed seven physics students who had, two years prior, taken a course designed to explicitly teach sensemaking. In this paper we address the following two research questions:

RQ1 What do these students' think sensemaking is two years after taking a sensemaking focused course?

RQ2 What experiences helped form these students' ideas about sensemaking?

II. INSTRUCTIONAL CONTEXT

This study focuses on a new course called Ph335, *Techniques of Theoretical Mechanics*. The first iteration of this course was taught by author EG in Spring 2017 and was completed by 27 students. The course met for 50 minutes 3 times per week for 10 weeks. The physics topics included Newtonian, Lagrangian, and Hamiltonian mechanics, and special relativity.

Ph335 emphasized physics sensemaking as much as physics and math topics; sensemaking was listed in the syllabus, explicitly discussed in almost every class meeting, appeared on every homework problem, and included on exams. We used a scaffolding-and-fading approach: explicitly prompting for different sensemaking strategies at the beginning of the course and then expecting unprompted sensemaking at the end of the course [10]. In class meetings, students were asked to practice sensemaking in small-group activities, as well as to present their sensemaking approaches to the whole class. In the first iteration of the course, sensemaking was taught mainly through the lens of evaluating the correctness of answers.

Other upper division physics courses discussed by participants included the junior-year *Paradigms in Physics* courses and senior-year *Capstone* courses [11]. The *Paradigms* are taught using student-centered pedagogies that emphasize multiple representations and similar mathematical structures across physics subdisciplines. *Capstone* courses are taught in a more traditional lecture format. Physics sensemaking is emphasized differently in each course based on instructor preference/experience, time constraints, and course content.

III. METHODS

We performed semi-structured interviews with 7 students who completed the first iteration of Ph335 in Spring 2017, two years ago. We have previously reported about one of these student's—Shane's—perspectives of and experience with sensemaking from interviews conducted while he was enrolled in Ph335 [12]. The current interviews were approximately one hour in length and consisted of many prompts about sensemaking and the Ph335 course (a relevant subset can be seen in Table I). Students were provided whiteboards so they could write or draw in addition to their verbal responses.

TABLE I. Relevant sections of the semi-structured interview protocol used in all 7 student interviews.

Q1	I want to talk to you today about sensemaking. To begin, can you tell me what sensemaking means to you?
Q2	What influence did Ph335, *Techniques of Theoretical Mechanics*, have...on your reasoning? on your other courses? on your research? on the GRE? on Grad School? on internships? on your everyday life?
Q3	Did other courses, besides Ph335, develop your sensemaking skills? Were any other courses more helpful at this than Ph335?

All interviews were audio and video recorded and pictures of whiteboards were taken. Full transcripts were made of each interview. A thematic analysis of the transcripts was performed [13]. Author ML listened to the recordings twice while transcribing and read the transcripts multiple times to gather an initial sense of each student's individual experience with sensemaking. We then identified each student's ideas and categorized them into themes. The OSUPER group then read a subset of the data and discussed similarities and differences among the ideas and experiences identified by ML. Further clarification, re-structuring, and identification of new ideas were identified by a few final readings of the data.

IV. STUDENTS' IDEAS ABOUT SENSEMAKING

Each interviewee had distinct ideas about what sensemaking is and what experiences contributed to this understanding. We discuss each student in detail below.

Shane: A process used to understand physics questions

Shane is the only student to initially state that their idea of sensemaking changed over time. At first, sensemaking was equivalent to using strategies to check answers but over time became a process of understanding a problem that is performed at almost every step. Sensemaking is integrated with problem solving in such a way that it has become one and the same for Shane.

> **S:** *[Sensemaking] used to mean a way to check if I got the correct answer but now, like, it means the process by which I answer a question...understanding what I'm actually working with.*
> **ML**: *When did that change...?*
> **S**: *It was during the, because I think that, because questions became so complicated that I would need to do sensemaking after like every step and then it just became natural to always be on top of what exactly I'm doing.*

Shane said that Ph335 was instrumental in his becoming a physicist in many ways, one of which was the introduction of sensemaking.

> **S:** *That was when it was first laid out in front of me...I kind of consider that class the beginning of my identifying myself as a physicist.*

Shane states that "it's really just physics courses" that have influenced his ideas about sensemaking. Shane viewed Ph335 as the most instrumental in developing sensemaking. "I think that [was] just by design, like other classes don't have sensemaking in the syllabus" and other courses "always [had] sensemaking on the side."

Charles: A collection of strategies used to evaluate reasonableness

To Charles, sensemaking is closely tied to strategies for checking the reasonableness of an answer or process. "I think sensemaking is a collection of strategies that enable you to evaluate the reasonableness of some kind of answer to a question." He mentioned many strategies for answer checking throughout the interview. Charles said he believes sensemaking is not exclusive to checking answers but continued to emphasize the idea of sensemaking being strategies for checking correctness.

> **C:** *I think [sensemaking] could happen anywhere...I guess you could say sensemaking is how you know whether or not you've done something right.*

Charles was unable to think of an example of sensemaking outside of physics. Ultimately, though, he said he believes that learning about physics sensemaking has changed his overall way of thinking.

> **C:** *I think maybe I do it now sort of like it's been drilled into me so much. It just sort of happens without me thinking about it. So I would say that practicing sensemaking in physics is sort of giving me those strategies and now I sort of use them for most things...I guess I feel like I've changed sort of the way I think but I don't know how to really describe that.*

Charles said Ph335 helped him identify and practice sensemaking strategies and that the course's emphasis affected his use of sensemaking strategies.

> **C:** *We really worked on sensemaking in [Ph335]. I think that was a really good opportunity to practice those skills and increase the list of ways to think about an answer.*

Charles discussed other influences on his ideas about sensemaking, particularly math classes and the idea of "mathematical proofs" being impactful. Charles had previously taken and was co-enrolled in *Paradigms* during Ph335 and started—because of Ph335—noticing that sensemaking was being and had been asked for in his other physics classes. Having more explicit instruction about sensemaking helped him notice when sensemaking was expected: "After I learned about sensemaking, I recognized when professors were sort of asking for it."

Thomas: Using multiple methods to check reasonableness

During the interview, Thomas initially described sensemaking in physics/problem-solving-oriented terms. He discussed sensemaking as a process of answer checking that incorporates the physics of a problem and one's own prior knowledge. He mentioned dimensional analysis as one method for making sense of an answer.

> **T:** *[Sensemaking] is the process of using orthogonal methods to determine if your answer is reasonable or not...by orthogonality I mean like you're taking into account physical reality or boundary conditions or even dimensional analysis.*

Later in the interview, Thomas described sensemaking as how you evaluate claims. Thomas said he made sense of the world around him by questioning the accuracy of claims and the motivation behind those claims.

> **T:** *In a much broader kind of way...sensemaking means evaluating what claims are, what claims might be accurate and inaccurate and sort of the motives behind the claims that people make.*

Thomas said that Ph335 taught him new sensemaking strategies—such as boundary conditions—but prior to that Thomas did not think about sensemaking very much. Before, he said sensemaking was a thing that teachers told him to do and not an active part of his learning, but he felt Ph335 changed that for him.

T: *You know if the teacher told me you should do this before, like after you solve a problem. Where as in [Ph]335 I know we spent probably a week just talking [about] ways to make sense so it made me aware that you could think about how you could think about problems or how you think about whether or not things make sense.*

Thomas said that "2 classes in high school...AP biology and then AP literature," were also instrumental to his understanding of sensemaking. He talked about how these were the first classes that had him using more of a Socratic method to learning as opposed to memorizing information.

Brett: Checking to make sure your assumptions hold throughout your problem solving

Brett described sensemaking strategies in a way similar to Charles—you can check an answer or process by using sensemaking strategies.

B: *If you have a problem and a solution then you can say this problem makes sense, or the solution makes sense because of whatever, you know, quote-unquote sensemaking strategies you use.*

After discussing these strategies, Brett said that he views sensemaking as checking to make sure that the initial condition or assumptions about the problem you are solving still hold true. No other student was so adamant about connecting problem solving or an answer to the assumptions one is making about the physics. To Brett, drawing on one's assumptions to make sense of the physics and/or math was essential to sensemaking.

B: *It's almost like you're checking axioms...you have a list of assumptions and you're checking those assumptions to make sure "hey this thing is still working."*

Brett provided many examples of how he used sensemaking; one notable, non-physics example was rock climbing. He discussed an axiom of rock climbing: "I should not be detached from the wall at any point unless I'm trying to get frisky." He then used that axiom to take his next step in solving the problem of getting up the wall: "how are you sensemaking is I say, well what knots do I have to tie and what do I have to do to...make sure I'm never detached."

Brett spoke at length about how sensemaking compensated for his unfamiliarity with the math content of Ph335. He was not prepared to just accept the math that was given to him, so using sensemaking strategies was a big help."[Sensemaking is] just an assistant that kind of like roams around and like helps you with your problems."

Brett said that Ph335 and more advanced physics courses solidified sensemaking for him "All of the classes have...had their own little effect on furthering my ability to sensemake about things."

Mathew: Comparing your expected results to your actual results to make sense of your answer

To Mathew, sensemaking is checking the correctness of a result by comparing to an expected result. This idea is similar to Thomas in that Mathew compares two things to make sense of an answer. The difference is that Mathew's comparisons focused on the prior knowledge that he already possesses about the physical situation rather than a process of checking answers without prior knowledge.

M: *[Sensemaking] starts before you even start the problem...you're like okay here's my problem what do I expect from it?...[when you're done solving] you can look at it and go "okay was this what I expected?"*

Mathew sees sensemaking as directly connected to understanding the physics of a situation. He stated that "if you get an answer and you don't know if it's right or wrong, then you don't really understand the physics behind it." Sensemaking to Mathew is very conceptual in this way; one has to understand the physics of a situation to be doing sensemaking.

Mathew stated that Ph335 "gave [him] new techniques for sensemaking that [he] never really thought of before and [Ph335] kind of refined other techniques that [he has] used before without actually knowing they were sensemaking." He explained that before Ph335 another physics course called Ph315—*Physics of Contemporary Challenges*—introduced the idea of sensemaking. Only one sensemaking strategy was taught in Ph315—Fermi Estimates— and this strategy was "a piece of sensemaking and kind of similar [to] dimensional analysis."

M: *It wasn't really sensemaking in the way that we went about it in [Ph]335 but I kind of feel like that kind of led into the sensemaking.*

Mathew also mentioned specific *Paradigms* courses that influenced his ideas about sensemaking: "*Spins* [Quantum mechanics Paradigm] with [EG] and then...the *Paradigm* [Static Fields] with [PJE]." Mathew explained that explicit instruction in sensemaking helped him. "The classes that really helped getting sensemaking going were the classes that required it."

Austin: An algebraic process used to check your answers

Similar to Charles and Brett, Austin discussed sensemaking as strategies used to check the reasonableness of an answer or process. Similar to Thomas, Austin discussed sensemaking as using an alternative method to check yourself. However, Austin's strategies were more algebraic.

A: *Just looking back on what I've done and maybe taking a different approach to the problem or working it backwards or just finding some way to check myself and make*

sure that whatever answer I came up with at least makes sense to some degree.

He also discussed sensemaking as a generative, answer-making process rather than a process of drawing on conceptual understandings. For example, when discussing sensemaking in his upper division Quantum mechanics course:

A: *I mean in quantum we've been working on perturbation theory so you think about like here's something I know the solution to and I'm just going to add this little piece to it that makes it look more like some big ugly thing that I can't solve.*

Austin said that Ph335 gave him many things—more confidence was an important one for him—but Ph335 was also the course that gave him the sensemaking strategies that he still used: "[Ph335] kind of like laid the foundation so I had the tools that I need, needed moving into Paradigms."

He explained that sensemaking was not necessarily the confidence-maker but he "learned how to slow down and take a look at what [he] was doing more closely." This idea of slowing down was important to Austin as it helped him in "finding errors early and making sure that [his] understanding was right or that [he] was approaching a problem the right way."

Austin believed that Ph335 was the most helpful course for developing his ideas about sensemaking but some of the *Paradigms* were also influential. He directly mentions the *Spins Paradigm* taught by EG stating that it "just kind of kept...the ball rolling with sensemaking." He also reported using sensemaking in other courses and finding it useful, but that these courses did not really further his understanding about sensemaking.

Gabe: A set of strategies used to compare your answer to what you expected to be your answer

Gabe's view of sensemaking is much more restricted to checking an answer to physics problems. He described a primarily procedural approach. Gabe mentioned different strategies but they all included comparing an answer to an expected result. This comparison is different from Mathew's ideas in that the expected result need not be thought of at the beginning of the problem solving process; for Gabe all sensemaking can be done at the end.

G: *Just checking if basically the right side of the equation is equal to the left side of the equation and seeing if like dimensions work out or examining special cases.*

When asked about Ph335's effect on Gabe's reasoning he immediately brought up sensemaking. He said that sensemaking did help when actually solving problems in the sense that all the problems in Ph335 were physical scenarios that you could think about in reality.

G: *Well [Ph]335 basically always asked and wanted us to make sure to put some kind of sensemaking on there and it did help when you actually got to a question because it was mostly always about some physical object...just something that you can actually picture or make in real life.*

Outside of Ph335, sensemaking was more difficult for Gabe. Gabe is the only student in these interviews who said that he was not really using sensemaking anymore; sensemaking is time consuming in his already busy schedule and therefore he does sensemaking when prompted: "To be honest I haven't done sensemaking in a little bit, quite a bit of time."

The only other courses that Gabe mentioned as being influential to sensemaking were *Paradigms* taught by EG and PJE. Gabe goes on to express that "in between [the *Paradigms* mentioned previously] there wasn't a lot of assistance" in sensemaking.

V. DISCUSSION

Despite having gone through the same physics program, and experiencing the same sensemaking-focused mechanics course, the students in this study had a breadth of ideas about sensemaking. Shane, Thomas, Charles, and Brett all said that sensemaking is not exclusive to physics and problem solving while Mathew, Austin, and Gabe talk about sensemaking as mainly exclusive to physics or math.

We also notice several commonalities among the students' descriptions and ideas. All 7 students discussed sensemaking strategies that were emphasized in the Ph335 instruction through explicit homework prompts and class discussions. All students mentioned that Ph335 impacted their ideas about sensemaking.

In Ph335, all sensemaking strategies were predominately evaluative. Despite this evaluative emphasis, 5 of the 7 students thought of sensemaking as something you do throughout solving a problem. This more comprehensive view of sensemaking may have been supported in later *Paradigms* courses.

Other courses that also changed and/or helped form their ideas were the *Paradigms* after Ph335. Overwhelmingly, the most influential aspect of any course was explicit instruction. Most notably, we can look to Charles who did not realize his instructors in the *Paradigms* were asking him to make sense of his answers until he was co-enrolled in Ph335.

All but one of the students interviewed, Gabe, reported continued use and views about the importance of sensemaking. Sensemaking is valued by these physics students and helped some students achieve a sense of belonging within our field.

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