

A Conceptual Physics Class Where Students Found Meaning in Calculations

Michael M. Hull* and Andrew Elby†

**Department of Physics, University of Maryland, College Park, MD 20742.*

†*Departments of Teaching & Learning, Policy & Leadership, University of Maryland, College Park, MD 20742*

Abstract. Prior to taking a translated version of the Maryland Open Source Tutorials (OSTs) as a stand-alone course, most students at Tokyo Gakugei University in Japan had experienced physics as memorizing laws and equations to use as computational tools. We might expect this reformed physics class, which emphasizes common sense and conceptual reasoning and rarely invokes equations, to produce students who see a disconnect between equation use and intuitive/conceptual reasoning. Many students at Gakugei, however, somehow learned to integrate mathematics into their “constructivist” epistemologies of physics, even though OSTs do not emphasize this integration. Tadao, for example, came to see that although a common-sense solution to a problem is preferable for explaining to someone who doesn’t know physics, solving the problem with a quantitative calculation (that connects to physical meaning) can bring clarity and concreteness to communication between experts. How this integration occurred remains an open question for future research.

Keywords: Open Source Tutorials, mathematical sense-making, Japan

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INTRODUCTION

Many students avoid physics because they are daunted by the associated mathematics. Partly as an attempt to reach such students, conceptual physics classes, which teach physics concepts without the associated math, were developed [1–3]. While proponents of such classes argue that students can learn some physics that will be comprehensible to them and perhaps inspire them to pursue later physics classes that bring in the mathematics (e.g., [1]), others maintain that mathematics is intimately connected to physical concepts and challenge the notion of removing it (e.g., [4,5]).

This paper tries to shed some preliminary empirical light on this mostly “philosophical” debate by focusing on the experiences of a student who took a conceptual physics course under unusual conditions. The Maryland Open Source Tutorials [6] (OSTs) have simple calculations scattered throughout but are designed to build conceptual understanding of core physics concepts. They were created for use in discussion sections of algebra-based college physics courses that also emphasize mathematical problem-solving [6–9]. However, at Tokyo Gakugei University (TGU), translated versions of those tutorials served as the *core* of a newly-reformed course called Physics Exercises. Specifically, in spring 2011, students in the course met once per week for a 10-minute lecture and an 80-minute stretch during which they worked on the OSTs [10]. The previous semester, the students had

taken at least one traditionally-taught physics class that most of the students perceived as emphasizing rote memorization of equations and principles for problem solving while largely ignoring conceptual understanding. So, in effect, these students took a conceptual physics course *after* taking a “regular” physics course. Although idiosyncratic in many ways, their experiences mirror those of American students who take a conceptual physics course in college after taking standard high school physics classes.

The question we explore in this paper is, in what ways did the students’ physics epistemologies—their views about what counts as knowledge and knowing in physics—integrate conceptual understanding and mathematics? We were concerned that, given their experiences, the students would view conceptual and mathematical physics as two separate ways of knowing/thinking, or would completely discount one at the expense of the other.

METHODS

Students in the TGU Physics Exercises course were invited to participate in semi-structured interviews to probe how they were responding to the new physics class and whether they had experienced other classes centered around small-group collaborative sense-making. Interviewees were also asked to think aloud while solving a quantitative physics problem. The

complete protocol can be found online¹. The first author, MMH, conducted and transcribed the interviews in Japanese, and then translated them into English. Translated transcripts are available upon request. Transcript presented in this article was also translated by Dr. Maki Kishida, a graduate from the Linguistics Department at the University of Maryland. She grew up speaking Japanese and also speaks English fluently. To complete these translations, background information (about the physics course, for example) was provided by MMH as needed. Comparisons of the two transcripts reveal little substantive differences, none of which affect the arguments of this paper.

RESULTS

We now discuss one student's epistemology of physics (as evidenced in the interview) in detail, before bringing in other students at the end of this paper.

Epistemological Change

As part of the standard interview protocol, Tadao was asked to freely talk about Physics Exercises. After confirming that he could really say whatever he wanted, he began by explaining that he came into the class "hating" physics. He elaborated:

[16:00] Uh, the calculations of physics, for example, that kind of thing, I thought it was a real pain. Physics really was not a class where I was thinking "I like this and want to do it!"; however, the Tutorial class is pretty much the thing that I like... because it's the kind of class where you think in a group, where you organize your own thoughts. Um, you think in a group and uh, the things that you yourself are thinking, just as they are you can write them down and organize them. So I'm thinking that it's pretty much a class that makes you like physics.

Tadao here links two epistemological aspects of his experience in the class, "think[ing] in a group" and "organiz[ing] your own thoughts," to his liking Physics Exercises more than his previous physics class. The interviewer asked Tadao about how he had reacted initially to the new style of physics class, and Tadao replied that he had been surprised to learn that physics can be approached in "this way." In an attempt to paraphrase what Tadao had said, the interviewer tried to confirm that the previous approach

had been using equations, but Tadao clarified: last year's class had felt like stuffing knowledge into your head. Physics Exercises, on the other hand, is about putting answers out from within (26:46). Tadao's hand gestures emphasize his meaning. While talking about the previous class, he waved his hands, palms facing his head, towards and away from his head on either side, as though actually stuffing his head. When describing Physics Exercises, on the other hand, he reversed the motion, starting with his hands close to his head on either side, and flinging them away as though releasing something from within. He repeated both of these gestures several times. These words and gestures speak to a description of a new way of learning physics, where one's own ideas are valued.

Later, the interviewer asked if physics is something that anyone can do if they try long enough, or if it's a subject that only some people can do. Actually, the interviewer did not complete the question, because Tadao adamantly interrupted him half way through.

[58:09] They can I think. Because I originally hated physics, but I think I'm beginning to be able to do it a little. Anyone can do it I think.

Tadao's experiences in Physics Exercises have led him to think that physics is a subject he (and others) can learn, by building on and organizing one's own thoughts instead of just stuffing knowledge into one's head. In addition to thinking that physics can be learned from one's own ideas, Tadao explained at other parts of the interview that he now thinks that everyday experiences are relevant to learning physics as well. At 21:51, he briefly mentioned that Physics Exercises has helped him really understand that "equations are applicable to the real world." More substantively, at the end of the interview, Tadao was asked if he thinks intuition is useful in the class. He answered that, since the goal of the class seems to be "connecting one's own experiences in the real world" with "the physics way of thinking," intuition is indeed necessary (1:01:41). The interviewer then asked if Tadao thought that that process of "connecting" is an effective means to learn physics. He answered that if he only used the physics way of thinking, then he wouldn't really understand the material, even if he could succeed in the class. He further argued that

[1:02:33] Even if you can succeed in the world of physics, I think you have to apply that knowledge in the real world or it's meaningless. So I think it's important.

For Tadao, truly understanding the material is not only a matter of learning it through one's own ideas and experiences (16:00, 1:01:41), but also a matter of

¹<http://umdperg.pbworks.com/w/file/52737286/Full%20interview%20protocol.docx>

“apply[ing] that knowledge in the real world.” In brief, Tadao has shifted toward a more “constructivist” view of physics as something that can be made sense of and connected to real-world experiences and phenomena. What isn’t yet clear is how mathematics fits into his physics epistemology.

Where Does Mathematics Fit Into Tadao’s Epistemology Of Physics?

In this subsection we present how Tadao reasoned through and then reflected upon a quantitative physics problem during the interview. The problem was,

Suppose you are standing with two rocks on the balcony of a fourth floor apartment. You throw one rock down with an initial speed of 2 m/s. You just let go of the other rock, i.e., just let it fall. I would like you to think aloud while figuring out what is the difference in the speed of the two rocks after 5 seconds—is it less than, more than, or equal to 2 m/s? (Acceleration due to gravity is 10m/s^2 .)

From other work [11], we know that many students approach this problem by substituting numerical values into the equation $v = v_0 + at$ for each rock. The speed of the thrown rock after five seconds works out to be 52 m/s, whereas that of the dropped rock is 50 m/s. Students subtract to find that the thrown rock is 2 m/s faster than the dropped rock. In this article we will refer to this as the “plug and chug solution.” Tadao demonstrated an alternative solution, however, and in so doing drew upon his own experiences in the real world. He began by talking about what *would* cause the rocks to reach the same speed: if they had been dropped from high enough, they might have both reached their “maximum speed” (38:20).

[37:23] [Given sufficient height] I do think that the falling speeds will come to be the same. But with it taking place on the fourth floor balcony, uh, when I considered whether or not the rocks’ speeds would become the same, I thought that in the realm of my own experiences until now, I’ve never experienced that.

Whether or not Tadao had actually experienced rocks falling from a balcony, he was satisfied with an explanation that depends heavily upon what he perceived to be his own experiences. The interviewer next asked what would happen if there were no air. Tadao found this to be an easier situation; with no resistance pushing back on the rocks, there is no reason for the gap in initial speeds to close. They will

continue to fall “just like that,” with one rock 2 m/s faster than the other. Tadao envisioned air resistance physically having an effect on the speeds of the two rocks (39:56). He visualized the air as shrinking the gap in speeds, again, attaching a physical process to the formalism of the physics problem he was solving. Tadao at last did solve this problem using the above equation, but not via plug and chug. He associated the term *at* with the amount that each rock increases its speed. He argued that since gravity acts on both rocks the same, and since both rocks “become faster by just the same speed” (42:13), the initial difference in speeds between the two rocks would not change as time passes. Again, we see Tadao using “his own idea” that if two things change by the same amount, the difference between them stays the same.

Given this solution and his physics epistemology as discussed above, we might expect Tadao to leave Physics Exercises having forsworn calculations as something of his misspent youth, and to pursue only the conceptual reasoning that OSTs promote and that he displayed in solving the two rocks problem. Or, we might think that he would view calculations as useful for generating numerical answers in cases where he can’t figure things out conceptually. Tadao, however, folded calculations into his physics epistemology in a striking way. When the interviewer presented Tadao with the plug and chug solution to the two rocks problem (framed as a solution the interviewer had previously seen), Tadao responded:

[43:35] I think this is good too. But, this is, um, I do think that this is a way of answering for people who are accustomed to calculations and good at mathematics, you know. For someone good at mathematics, this way of explaining is easier to understand I think... this kind of style, um, showing properly in numbers—it’s easier for it to really click I think. “No matter what numbers you put in, the difference becomes 2 you know,” doing a calculation in this style is easier to understand, isn’t it. I prefer this direction.

At first glance, Tadao’s defense of a plug and chug solution seems to contradict his earlier claim that he hated the plug and chug style of his previous physics class. However, Tadao here expressed a nuanced view of why the plug and chug solution is valuable. He said that the orderly mathematical presentation of the answer is “easier to understand” for someone “accustomed to calculations and good at mathematics” and he framed the plug and chug solution not as a way to churn out an answer but as a “way of explaining” something, namely the fact that “no matter what numbers you put in” for the time of fall, “the

difference [in speeds] becomes 2.” To probe this issue further, the interviewer asked,

[59:57] Interviewer: Tell me again, why was it that you preferred this one [the plug and chug solution]?

Tadao: Um, this one is more, right away you can put out an answer, and it is easy to understand, you know. Um, between people who understand, when talking, this way of thinking is more, um, easy to transfer to the other person, and I do think it is more quickly transferred, you know. If it's a kid who doesn't understand, he would absolutely not understand this, zero, the percent of understanding is 0, but if it is between people who understand, I think it's 100, 100 (moves hand to gesture two people), you know. And, as for my own thinking, I myself answered this way [his own solution], did I not? If it's the way of answering that I answered, even if it's a kid who doesn't understand, um, 50% for example, an understanding of 60%, he would understand...”

Contrary to what one might expect, Tadao did not champion a conceptual solution to this problem over a calculation-based solution. In fact, he saw the calculation-based solution as preferable for facilitating communication among “people who understand” this way of thinking, while seeing the more conceptual solution as better for helping other people understand. In short, he was defending plug and chug mathematical manipulations not as an approach to generate answers, but rather as a communicative tool for expressing an explanation to certain audiences.

CONCLUSION

Given Tadao's (and other TGU students') disjointed experiences in physics—a course they perceived as encouraging a plug and chug solution rather than conceptual understanding, followed by an essentially conceptual physics course involving minimal use of mathematics—we expected to see somewhat disjoint epistemologies of physics, with mathematics not integrated into their views about what it means to understand physics. Tadao, however, saw mathematical manipulations as productive for helping math-savvy people communicate understandings to each other. Other students in Physics Exercises also integrated mathematics into their physics epistemologies. Miu, for example, said that her approach towards physics prior to Physics Exercises was just to do plug and chug, but now there is a physical understanding of what's going on backing that up. Rina described how the best way to solve a problem is to first think about what you expect it to be, then just do the calculation and get out an answer, but

you can't just stop there; rather, go back and make sure they agree. Madoka emphasized that he still thinks calculations are important... it's just that physics isn't *only* calculations.

Our results here mirror those of Lindsey *et al.* [12], who found that some students in courses using *Physics by Inquiry* modules [13]—which like the OSTs involve minimal mathematics—shifted away from plug-and-chug views about the role of equations in physics. What we add is evidence that the way Tadao and other such students actually approach a quantitative physics problem meshes with the epistemological views they espouse. How is it students leave these kinds of conceptual physics courses with more sophisticated epistemological views about the role of mathematics in physics? That remains an open question to pursue in future research.

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