Upper-Level Physics Students' Conceptions Of Understanding

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Abstract. As part of a larger study into upper-level physics student identity development that is currently underway students were questioned about their conception of understanding. Contained with this paper are the results for students' conceptions of understanding which correlate significantly to those found by Waterhouse and Prosser [2]. However, having carried out pilot interviews of the interview protocol used to examine identity and cognitive development, the researchers noticed a large frequency in the amount of students that indicated their conception of understanding to be "when you can explain it to others or yourself." This prompted a further examination of this conception of understanding via phenomenographic interview and analysis.

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INTRODUCTION

According to Gibbs [1] understanding is a significant indicator of the quality of a student's learning. Understanding in the physics education research community has been investigated under many guises: epistemologies, conceptual inventories, method of delivery and so forth. Developing a complete understanding of the physics material that a course addresses is a fundamental learning outcome of all physics courses. Given the extent to which understanding is embedded in physics education research and the emphasis on it as a learning outcome, it is important to examine what students' conceptions of understanding are in the context of physics.

Previous research such as (Table 1) carried out by Waterhouse & Prosser [2] has examined students' conceptions of understanding using a phenomenographic approach and found a hierarchical conception of understanding with "understanding as given" at the bottom of the hierarchy. This conception of "understanding as given" relates back to Perry's model of cognitive development [3] which has knowledge/understanding being provided by authority figures as the lowest position of cognitive development.

A consistent conception of understanding which is also found in the Waterhouse & Prosser hierarchy is that understanding is "when you can explain it (a concept) to others or yourself." This conception of understanding appears in many investigations of understanding and is consistently ranked at a high level in a hierarchical ranking of conceptions of understanding.

As part of a larger study into upper-level physics student identity development that is currently underway, students were questioned about their conception of understanding.

TABLE 1. Students conceptions of understanding taken from Waterhouse & Prosser 2000 p. 6

Category	Description	Awareness	Explanation
A	no physical description	focus is on the undifferentiated whole	understanding is seen as given, no effort required
B	understand when you can solve problems	focus is on the undifferentiated whole in relation to what the student perceives	understanding is when students know they can solve given problems
C	understand when you can relate to real life situations	focus is on differentiated objects in relation to what the student perceives	understanding is when you can apply what you know to real life objects
D	understand when you can explain it to others or yourself	focus is on differentiated objects in relation to what the student experiences	understanding is when you feel confident with explanations of objects
E	understand when you consolidate your knowledge	focus is on integrated phenomenon in relation to what the student experiences	understanding is when you feel you know the phenomenon deeply

Contained in this paper are the results for students' conceptions of understanding which relate to those found by Waterhouse and Prosser.

However, having carried out pilot interviews of the interview protocol used to examine identity and cognitive development, the researchers noticed a large frequency in the amount of students who indicated their conception of understanding to be "when you can explain it to others or yourself." This prompted a deeper examination of the conceptions of understanding found via phenomenographic interview and analysis [4,5].

METHODOLOGY

The primary data for this study comes from semi-structured interviews with students who were recruited from upper-division physics courses of electromagnetism or mechanics and summer research students who were a part of the Research Experiences in Undergraduate Education (REU) program. We developed a 45-minute semi-structured interview protocol drawing on identity formation, epistemological sophistication, and metacognition literature. The analysis for this paper concentrates on the discussion which referred to the metacognition elements of the interview and these parts were transcribed and analyzed. Eighteen students chose to participate in the study. The interviews were carried out over a two-week period near the end of the second semester for the electromagnetism/mechanics students and in the first week of the REU program.

Data Analysis

The responses to the questions were analyzed initially by an individual researcher and the robustness of the categories was tested by a fellow member of the research team. The robustness testing and the analysis process are described in detail below:

1. Each video was watched repeatedly, often in one sitting, in order to become acquainted with the video set as a whole and to transcribe the appropriate section.
2. The transcript was then analyzed repeatedly with the focus of awareness on one particular aspect of students' discussions on their conceptions of understanding. For example, on one occasion the focus may have been on how the students described their approach to understanding a physics concept, on another occasion careful attention would be paid to students' descriptions of the relationship between knowledge, understanding, and learning and so forth. The next step was to make a set of notes that recorded all information that was perceived to be critical to the students' conception of understanding.
3. The analysis moved to seeking out the critical similarities and differences between the notes. However, the focus was not solely on the notes and instead involved working concurrently with the notes and videos as the notes often lacked the depth of completeness that the videos contained.
4. Cases of agreement and variation of the discerned critical aspects within the transcripts were identified pertaining to the students' conceptions of understanding.
5. The variation of critical aspects was then utilized to preliminarily form descriptions (an outcome space) of the different conceptions of understanding.
6. Once tentative categories had been constituted, the categories and the videos were examined for the structure of the categories. In searching for the structural aspects of the approaches it was important to identify what was focused upon within each overall meaning.
7. For each category constituted, the groupings of transcripts and notes were re-examined to find cases of both agreement and contrast within the transcripts. This was to ensure that the categories actually did describe the variations in the conceptions of understanding for this set of students faithfully and empirically.
8. The last step was to give the videos and preliminary categories to another member of the research group who then examined the robustness of the categories with discussion and further development of the categories resulting.
9. Finally, extracts and statements were taken from the transcripts which seemed to give substance and support to the categories.

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RESULTS

After initial analysis of the interview transcripts it was revealed that the students within the study did not display the range of conceptions of understanding found within the Waterhouse and Prosser findings.

Instead, the group of students interviewed could only be placed into three of the previously discovered categories: that of "understand when can solve

TABLE 2. REU and Upper-Level Physics Students' Conceptions of Understanding

Category	Description	Explanation
A	Understand when can use and apply	Understanding is when students know they can apply understanding to solve problems
B	Understand when can use, visualize and apply in different contexts	Understanding is when students can apply understanding in different contexts and can be applied to gain a visualization of a concept
C	Understand when can teach someone else	Understanding is when you feel you can communicate your interpretation of a concept to someone else
D	Understand when can explain in more than one way, use analogies	Understanding is when you feel you can explain your understanding in multiple ways and use analogies
E	Understand when can apply mathematical description, consolidate knowledge	Understanding is when understand concept deeply and can apply mathematical model to it

problems," "understand when can explain it to others or yourself," and "understand when can consolidate knowledge." However, based on the students' descriptions of their conceptions of understanding it became apparent that although the focus of their conception could be attributed to one of the previously detailed conceptions, to do so would give an inaccurate and incomplete representation of this cohort of students' conceptions of understanding.

Table 2 illustrates, based on phenomenological analysis of the descriptions provided by the cohort of students in this study, five different categories of descriptions of conceptions of understanding. There are obvious crossovers between these categories and the categories found in the Waterhouse and Prosser paper. This paper will focus on the distinct significant differences with the first significant difference being the absence of the "no physical description" category, which is the lowest hierarchically. This is an expected result for this cohort of students as it would be very difficult for students to have gotten to the point where they are in upper-level physics courses or into the REU program with such a low level conception of understanding.

Another significant difference is the renaming of the "understand when can solve problems" category to "understand when can use categories." The cohort of students interviewed frequently described understanding as the ability to use the understanding of concepts they had developed in some capacity.

Interviewer: Could you explain (concept of understanding) further?

Claire: To me, it is just a mastery of the subject, that no matter what I am asked on, that I feel comfortable answering any question you could ask me on that.

Interviewer: Right.

Claire: Yeah, I don't know if there is more to that.

It was also clear from their descriptions that there were two distinct levels to students descriptions of understanding as application. One of the level's strongly related back to the Waterhouse and Prosser conception of "understand when solve problems" as this was the main intention they intended to use their understanding for. The students with the more evolved conception though intended a more dynamic sense of the word use with a focus on using their understanding to construct visualizations of concepts and to be able to apply them in multiple contexts, not just to solve problems.

Interviewer: What does understanding a concept mean to you?

Kate: Em, to be able to apply it to something and to be able to think about it in different ways but still apply it back to the same concept.

Similarly, the "understanding as explaining" conception of understanding is split into two distinct levels of categories. The lower hierarchical level conception is categorized by students who view understanding as the ability to communicate their understanding to others so that the person who it has been communicated to can explain it back to them.

John: I think a good indicator of if you understand something is if you can teach it...you really understand something if you can teach it to someone...I think you understand something if you can apply it in a lot of different abstract ways...I think Einstein had a quote to that effect, you can't understand something until you can explain it to someone.

Whereas the higher hierarchical level conception is categorized by students who described being able to communicate their understanding in multiple ways, using analogies if necessary, and helping others visualize the concept and apply it to the real world.

Charlie: I think for me to understand something is to be able to explain it to someone...you can simplify it in a way that allows someone to understand it, you can explain it...you can give different sort of explanations depending on who you're explaining to...and if I can see a drawing...if I can see it...and then explain what I see.

The final category of conception of understanding demonstrates a lot of similarities to the original conceptions of understanding in that it is categorized by students who want a deep understanding and wish to integrate their understanding into the understanding and knowledge of concepts that they already possess. However, one significant difference from the original conception of understanding category is the emphasis that this cohort of students who made up this category placed on applying a mathematical description or developing a mathematical model of the concept they were trying to understand. They felt that in order to have a true understanding it was necessary to have a mathematical description of the concept.

Jack: So to understand something...to understand something, I think you have to be able to look at it in more than one way…think that should be a requirement...I need to relate a concept to other things, I need to create a sort of network, I need to understand it from other perspectives like em, like being able to relate it to something more fundamental...I look for other ways to understand...a concept can't stand alone otherwise it is outside the framework of physics.

DISCUSSION

One of the main points of discussion that emerge from the results of this study is why in this context we have found different conceptions of understanding with this cohort of students. As pointed out previously, the lowest level of conception of understanding from the original Waterhouse and Prosser study would not be expected due to the students who took part in the interviews being at an advanced point in their physics degree. In regards to changing of name from "understanding means you can solve the problem" to "understanding means you can use" is probably due to the contextual nature of the interview data. All interview data, especially phenomenographic interview data, is context dependent. For example, if the same study involved interviewing a group of students within the frame of a specific learning environment, say problem solving tutorials, then when students are asked to describe their conception of understanding, they might frame it specifically within this environment so that students who have the "understanding when can use" conception may use wording such as problem solving instead of application or use. The authors felt that the two different levels of "understand when can use" conception of understanding are justifiable despite the possible problem with context as the interviewer specifically did not refer to a particular context and made sure the students knew they should be describing in a general context.

In regards to the categories of "understanding is when you can explain," we think the frequency of description of this conception of understanding and the resultant different hierarchal levels might be due in some part to the presence of a possible norm within this community of physics students and the presence of the Einstein quote within popular culture. This emphasis on explanation as understanding could also be a result of the exposure, although not overexposure, to group learning environments where they are expected to “teach” and become aware of a need to learn how to “teach” well. This would be the norm referenced above, a norm of the practice of explaining one’s understanding among these students. A further investigation of these two categories would be interesting as the "understand when can teach someone else" category is dependent on the quality of explanation/teaching that the student intends in their description.

As indicated in the introduction, it is crucially important given the emphasis placed on understanding in physics curricula to develop students conceptions of understanding. This study identified different conceptions of understanding of upper-level physics students’ which will hopefully help lecturers/tutors/ teachers identify and develop students’ conceptions of understanding in the future.

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