Examining Student Responses for Meaningful Understanding in the Context of Wavefront Aberrometry

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Abstract. We present a qualitative study from group learning and teaching interviews that were conducted as part of ongoing research to examine how students use their physics knowledge in novel situations. The data were analyzed for meaningful understanding using techniques previously presented by Lawson et al. and Nieswandt and Bellomo. Preliminary results indicate that students primarily utilize lower-level concepts and concept links when attempting to construct an understanding of wavefront aberrometry.

Keywords: physics education, meaningful understanding, resources, human eye, wavefront aberrometry.
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INTRODUCTION

As part of an ongoing study we focus on how students use their knowledge of physics to construct an understanding of a novel concept, wavefront aberrometry. Previously we have investigated exclusively the efforts of individuals before they had instruction in light and optics in their introductory-level college physics courses. The goal of this component is to expand upon the previous studies in two ways: by focusing on students who had completed the normal introductory optics-instruction and by conducting group learning/teaching interviews instead of individual sessions.

The overarching research question guiding this study is: *How do students use their existing knowledge to understand wavefront aberrometry methods of diagnosing vision defects and what resources do they use in constructing their understanding?*

LITERATURE REVIEW

Wavefront aberrometry is a relatively new method of diagnosing vision defects in the human eye by using the properties of light instead of the subjective judgments of the patient [1, 2]. Wavefront aberrometry is currently primarily used before corrective surgery (LASIK), but is gaining popularity and will likely become more commonly used for routine eye examinations and determining corrective lens prescriptions.

While many introductory courses include the topics of light, lenses and optics of the eye, very few discuss aberrations of wavefronts or advanced optical instruments. However, most traditional courses include enough material about light and optics that the foundation for understanding these principles exists. For these reasons, wavefront aberrometry is appropriate for a study of knowledge construction in a novel context.

Building on our previous analysis, the data will be examined to identify and analyze the resources students utilize when attempting to understand physics in a novel context. Resources can be thought of as the fragments of information, knowledge and experience that individuals bring to a new situation or context [3].

To identify the resources and the ways in which the resources are being used by the students, we have adapted a method used by Nieswandt and Bellomo to measure meaningful understanding. This analysis technique has been used primarily to analyze student conceptions related to evolution [4]. Nieswandt and Bellomo’s analysis of extended-response questions utilized a method of categorizing levels of concepts and then examined what types of connections were made between different concepts. The categorization of concepts builds on work involving the three sources of meaning presented by Northrop [5] and follows work by Lawson and colleagues who used this as a foundation and proposed three types of conceptions: descriptive, hypothetical and theoretical. According to Lawson, these categories are distinguishable by their ability to be observed [6]. *Descriptive concepts* can be easily observed (e.g. nocturnal, species, carnivore), *hypothetical concepts* could be observed if one could live for a long-enough timeframe (e.g. fossils, natural selection, evolution) and *theoretical concepts* can never be observed (e.g. osmosis, genes, combustion) [7]. In order to adapt this method for physics, a slightly modified version of the concept categories was used in this study and is described below.

In determining how students constructed understanding, Nieswandt and Bellomo examined not only the categories of concepts that students used, but how they formed connections between levels of concepts [4]. Connections were categorized as one-concept-level links (e.g. descriptive connected to another-descriptive concept or hypothetical-to another hypothetical, etc.), cross-concept-level links (e.g. descriptive-hypothetical or hypothetical-theoretical) or multi-concept-level links (descriptive-hypothetical-theoretical).

METHODOLOGY

The research question was addressed by conducting semi-structured interviews with university physics students. The data sources for this study consist of the video and audio recordings of the interviews, full transcriptions, student sketches and field notes. The data were analyzed by considering a modified version of meaningful understanding within an overall phenomenographic approach [8].

Learning/Teaching Interviews

Learning/teaching interviews [9] were conducted with groups of students who were post-instruction in light and optics. A total of 13 students were interviewed in three groups of three students each and two groups of two students each. The groups were formed on the basis of scheduling availability and as such were not controlled for any other factors such as gender or course grade.

All students were enrolled in the second semester of an introductory-level algebra-based physics course at Kansas State University. The course could most easily be described as a traditional lecture-recitation-laboratory class. At the time of the interviews, students had completed their entire unit of light and optics including lectures, recitations, textbook homework problems and an exam. The coverage included the topics of light, mirrors, lenses and basic information about the human eye such as the optics of nearsightedness and farsightedness.

Each group was interviewed for approximately 45 minutes. All students were encouraged to think aloud as they responded and to comment on each others' responses when necessary. The interviews followed the protocols used in previous phases of this study, and used the model of the eye seen below. For further details about the model aberrometer and the interview protocol and procedures, please see [10].

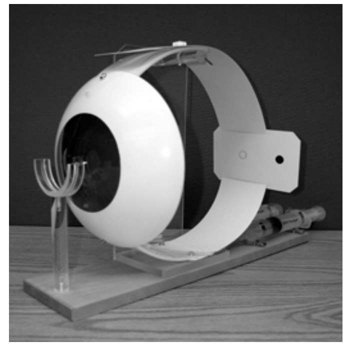

FIGURE 1. Model of the human eye used during data collection.

Analysis for Meaningful Understanding

The key feature of meaningful understanding analysis as used in the context of biology is whether or not a concept is observable and if so, over what timescale. While this is useful for examples such as fossil creation and other processes discussed by Lawson, it loses utility when transferred to the realm of physics. In the context of many physics concepts, the issue of time does not play an important role in the classification of concepts as observable or not. In order to retain the emphasis on the observability of the concept while at the same time increasing the usability of meaningful understanding analysis in physics contexts, we propose the following operational definitions for the concept categories.

> *Descriptive concepts* are those that can be directly observed in the current situation.
>
> *Hypothetical concepts* are those concepts that could be observed given appropriate apparatus or set-up, but that are not directly observable in the current situation.
>
> *Theoretical concepts* are those concepts that cannot possibly be observed, and no additional apparatus or change of set-up enables their observation.

Perhaps the most important issue is that we will define the ability to observe from the perspective of the student. This clearly aligns with our goal of understanding the learning process from the students' perspective and creates distinctions between categories that would not exist from the perspective of an expert physicist. As an example of why this is important, consider the concept of propagation of light. An expert physicist can easily understand and quantify the direction of propagation of light, making it a hypothetical/descriptive concept. To a novice physics student, however, the propagation of light is perceived as something that cannot possibly be measured and is therefore a theoretical concept.

Table 1 shows some possible concepts in each of the three categories. All examples are given in the context of optics as that is the overarching context of this study. However, it is possible to provide examples in a range of physics contexts.

TABLE 1. Examples of Optics Concepts in each Category

Descriptive Concepts	Size Brightness/Intensity Position
Hypothetical Concepts	Focal point of a lens Atomic Spectra Ultraviolet light
Theoretical Concepts	Wavefronts Phase Propagation of light

RESULTS AND DISCUSSION

The results presented here focus on one part of the learning/teaching interview in which students were asked to predict what would happen to the grid pattern formed by the aberrometer if the lens of the eye had a defect and then to test their predictions using the aberrometry model and resolve any discrepancies. Excerpts from the corresponding portion of the interviews were coded for the three types of concepts, as well as for any concept links.

Types of Concepts

From the excerpts of the five groups, a total of 29 concepts were coded.

As an example of how concepts were identified, an excerpt from one of the groups follows:

Interviewer: So what do you think would happen to the grid pattern if the lens of the eye had some sort of defect?

Student 1: I think instead of being like, right now you have one of these shapes [hexagon], like, I think that one of the points would move in toward center. Because it would, like instead of light going uniformly through [the lens] and creating this pattern, one would kind of like warp in this direction.

Student 2: Yeah, well, I think light would be hitting the smaller [array] lenses at a different angle because of the increased or decreased focal length of the lens [at the site of the defect].

In this case, we've identified the following concepts used by Student 1: shape of grid pattern (descriptive) and light going through lens (theoretical). Student 2 then uses the concepts of light going through lens (theoretical) and the focal length of a lens (hypothetical).

The breakdown of concept categories can be seen in Table 2. As predicted by Lawson and by Nieswandt, very few theoretical concepts were used by the students. Perhaps surprising is that the number of descriptive and hypothetical concepts is somewhat equal. We believe that this result is in part because the participants were all post-instruction and had therefore learned many of the physical concepts about light and lenses.

TABLE 2. Types of Concepts found in each category

Total Concepts	**29**
Descriptive Concepts	15
Hypothetical Concepts	11
Theoretical Concepts	3

Linking of Concepts

As described above, it is not only the types of concepts themselves that are interesting, but the ways in which different concepts are linked together.

To illustrate the identification of concept links, consider an expert from a second group:

Interviewer: What do you think would happen to the grid pattern if the lens of the eye had a defect?

Student 1: [Look at] where it doesn't focus correctly.

Interviewer: Where what doesn't focus correctly?

Student 1: The reflecting light. Like the intensity of the light.

Student 2: The reflected light is going through one of the little lenses. If one of them, if something is wrong with the dot, like it's a whole lot dimmer than the rest of them or something, then there's something wrong with that part of the eye.

Student 1 seems to be using a few different concepts in order to predict what changes will occur on the grid pattern. He is able to connect the descriptive concept of *light being different intensity* to the hypothetical concept that *light going through the aberration won't focus correctly*.

Student 2 expands upon this with another connection – the descriptive concept of *identifying* *dimmer dots of the grid pattern* with the hypothetical idea that *dots correspond to locations in the eye* – in order to describe how the position of a defect in the eye could be identified.

TABLE 3. Types of Concept Links and their frequency

Total Concept Links	13
One-concept Level Descriptive-descriptive (1) Theoretical-theoretical (1)	2
Cross-concept Level Descriptive-hypothetical (10) Hypothetical-theoretical (1)	11

When all groups are considered, the majority of the concept links are cross-concept, between descriptive and hypothetical concepts. Table 3 shows a breakdown of the number of concept links identified for each link type.

From this portion of the data, it appears that students construct their understanding by using primarily descriptive and hypothetical concepts. While they may have been introduced to the more advanced theoretical concepts in class, they do not seem to have these concepts in their "toolbox" of available resources.

CONCLUSIONS AND FUTURE WORK

This study is one component of an ongoing larger project to examine how students use physics learning in order to construct understanding of novel contexts, particularly the application of physics to contemporary medicine. Also, these results were the first to be analyzed using the ideas of meaningful understanding analysis.

The data set analyzed and presented in this paper is one portion of a larger interview and were examined in order to test the feasibility of analysis using concept categories and links to investigate how students construct meaningful understanding. Though it does seem possible to use this type of analysis in order to elicit the level of student understanding, it appears that further analysis will be necessary to investigate whether students have developed a meaningful understanding of the concepts of wavefront aberrometry, as signaled by the ability to form multi-concept-level connections.

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REFERENCES

1. R.A. Applegate, S. Marcos, and L.N. Thibos, *Aberrometry: Clinical and Research Applications.* Optometry and Vision Science, 2003. **80**(2): p. 85-86.
2. L.N. Thibos, *Principles of Hartmann-Shack Aberrometry.* Journal of Refractive Surgery, 2000. **16**(Sept/Oct): p. S563-S565.
3. D. Hammer, *Student resources for learning introductory physics.* American Journal of Physics Physics Education Research Supplement, 2000. **68**(S1): p. S52-S59.
4. M. Nieswandt and K. Bellomo, *Written Extended-Response Questions as Assessment Tools for Meaningful Understanding of Evolutionary Theory.* Journal of Research in Science Teaching, to be published.
5. F.S. Northrop, *The logic of the sciences and the humanities.* 1947, New York: Macmillan.
6. A.E. Lawson, Science *teaching and the development of thinking*. 1995, Belmont, CA: Wadsworth.
7. A.E. Lawson, et al., *What Kinds of Scientific Concepts Exist? Concept Construction and Intellectual Development in College Biology.* Journal of Research in Science Teaching, 2000. **37**(9): p. 996-1018.
8. F. Marton, *Phenomenography—a research approach to investigating different understandings of reality.* Journal of Thought, 1986. **21**: p. 28-49.
9. P.V. Engelhardt, and E.G. Corpuz. *The Teaching Experiment - What it is and what it isn't.* in *Physics Education Research Conference.* 2003. Madison, WI.
10. D.L. McBride and D.A. Zollman. *Investigating Students' Ideas about Wavefront Aberrometry*. in *Physics Education Research Conference*. 2007. Greensboro, North Carolina: American Institute of Physics.