Investigating Students' Ideas about Wavefront Aberrometry

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Abstract. We describe a qualitative study of student understanding of the functions of the human eye and the resources used in understanding wavefront aberrometry, a relatively new method of diagnosing vision defects. Twelve students enrolled in an introductory physics class participated in a semi-structured clinical interview in which the functions of the eye, traditional diagnosis methods such as the eye chart, and wavefront aberrometry were discussed. Results from this study indicate that students do not initially understand the subjective nature of traditional diagnosis techniques and that the use of physical models of the eye and aberrometer can facilitate the transfer of prior knowledge to these concepts.

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INTRODUCTION

Our group has undertaken several studies to investigate how students transfer their learning from a typical physics course and/or everyday life to contexts that they have not previously seen. These studies help us understand what reasoning and knowledge the students use appropriately or inappropriately as they learn physics. The goal of this component of the study is to investigate the ways in which students transfer prior learning to understand the physics related to a relatively new vision diagnostic tool, wavefront aberrometry. Rather than beginning with the aberrometry techniques, however, we first examined students' understanding of how the human eye works.

The main 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 shining light into the eye and measuring the properties of the reflected light, an aberrometer utilizes physical properties of light instead of subjective judgments of the patient for identifying aberrations within the eye [3-5]. Such methods are becoming increasingly important as the use of surgery (LASIK) becomes significant in correcting vision difficulties. It is also likely to become a common method for determining corrective lens prescriptions.

Aberration of wavefronts of light due to defects in optical instruments is not commonly taught in introductory physics courses. Thus it is an appropriate topic to use when studying how students transfer their learning to a new context. Transfer is defined as the application of knowledge from one context to another [6] or as the mediated association of information between contexts [7]. A useful approach to investigating student transfer is to identify and analyze the resources which they 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. An overview of resources and their use in physics can be found in reference 8.

METHODOLOGY

To address our research question, we conducted formal, semi-structured interviews with 12 students (3 females, 9 males). All of the students were enrolled in a calculus-based introductory level physics course. All students were interviewed before they had instruction about mirrors/lenses, but while they were in the process of learning about the electromagnetic properties of light.

Each participant was interviewed for approximately 45 minutes and all were encouraged to think-aloud as they responded to the questions. To place the interview in a context of diagnosis, students were first given a copy of a typical eye chart. This introduction led to a discussion of how light travels and how we are able to see. Following this, a model of the eye was used for clarification and often times prompted further discussion. A photo of the model is shown in Fig. 1. One convenient feature of this model is the pliable “lens” that is attached to a syringe system. By varying the amount of liquid in the lens, students change the radius of curvature. Students were also provided with paper and many made sketches to help illustrate their answers.

Figure 1. Model used during interviews [9].

The final part of the interview involved the aberrometer. We adapted the method of modeling an aberrometer used by Colicchia and Wiesner [10]. In this adaptation, the model shown in Fig. 1 was used along with an array of small lenses, an LED light source, and a paper screen. The lens array was placed in the slot (visible in the above model) in front of the “pupil.” After a brief discussion with the participants about light being reflected from surfaces, students agreed that the light source could be clipped to the “retina” of the model to simulate a reflection of light being shone into the eye. The combination of the light source and lens array provided the formation of a grid pattern on the paper screen. This grid pattern is representative of the grid pattern obtained by wavefront aberrometry diagnosis techniques. Figure 2 shows the grid pattern formed by the model used by Collicchia and Wiesner, which is very similar to the pattern seen in our setup.

After the aberrometer was set up, the participants were asked to describe what was being modeled and then to predict what would happen if the lens of the model were somehow aberrated. The pliable nature of the lens enabled us to aberrate the lens by pushing or deforming it and reacting to the differences being created in the grid pattern.

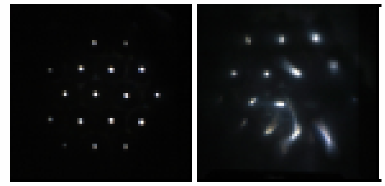

Figure 2. Grid pattern formed with Collicchia and Wiesner model [10] from normal lens (left) and aberrated lens (right).

Finally, students were asked to describe how a system such as the one being modeled could be used by a doctor in order to diagnose vision defects. This also led to a discussion of the advantages and disadvantages of a wavefront system as compared to a more traditional method of diagnosis. When the interview had ended, students were given the opportunity to ask any questions about the eye, defects, and the aberrometry setup.

The interviews were video and audio recorded and afterwards transcribed. The transcriptions, student sketches, and field notes from the interviewer served as the data sources for this study.

A phenomenographic approach was taken during data analysis in order to illicit variations in student ideas instead of researcher conceptions [11]. Student responses were then examined in an effort to identify any resources that were being used. We considered the resources used by a single participant as well as all participants in order to extract possible themes.

RESULTS AND DISCUSSION

In the analysis we paid particular attention to the resources that students used along with their reasoning patterns. As the long term goal of the project is to create teaching and learning materials about wavefront aberrometry, these resources will be beneficial for creating learning materials to help the students in their understanding.

Resources

A list of some of the resources used by participants is included as Table 1. The listed resources were chosen because of their use by multiple participants and applicability to understanding wavefront aberrometry.

The first resource, *light can be represented by a line*, was extracted partially from statements from participants, but mostly from their sketches. Of the 12 participants, nine made sketches of ray diagrams,

TABLE 1. Selected Student Resources

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Light and Lenses												
Light can be represented by a line	x	x	x		x	x	x		x	x	x	
Light is a wave	x	x		x						x		
Concavity/thickness/curvature of a lens changes the focus	x			x	x	x	x			x	x	
Aberrometry												
Light entering a lens differently will focus differently	x		x	x	x	x	x	x	x	x		x
An aberration is an anomaly					x			x		x		x
Size of change in grid reflects size of aberration	x				x				x			x
Symmetry has value						x				x	x	
Can only measure one thing at a time					x			x				
Objectivity												
"Objective" means no human opinion/interpretation			x	x	x		x					x
"Objective" means consistent (always same for everyone)		x		x	x		x			x		

(though to varying levels of correctness) and each clearly represented light as a straight line coming from a source. Fewer mentioned the wave properties of light, but it should be noted that students were not directly asked about wave properties of light.

Students utilized many resources that can be applied appropriately to wavefront aberrometry. For instance, the fact that *light entering a lens differently will focus differently* is a very important concept for understanding aberrometry. Three students commented on the symmetry of a grid from a perfect eye and the lack of symmetry from an aberrated eye. Using the resource of looking at patterns and symmetry is also useful in understanding how the grid patterns resulting from wavefront aberrometry are interpreted.

However, some of the above resources may not necessarily be appropriate for understanding wavefront aberrometry. Alone, the resource that *light can be represented by a straight line* is not an inappropriate resource – however, if participants believe that light only travels as a straight line, this could hinder their understanding of the altered wavefronts that result from aberrations. Many participants noted that *a big change in the grid represents a big aberration*. This could be considered to be a phenomenological primitive (p-prim) as described by diSessa [12]. However, this is not entirely true; the type of aberration is determined by the properties of the resulting grid pattern, but the "size" of the aberration is determined in terms of severity and not spatial size as participants seemed to suggest. Two students also brought up the fact that *controlled experiments only measure one thing at a time*. A closer look into this resource is required to determine if it could hinder the understanding that an aberrometer measures the function of the eye as a whole and not as individual components.

Transfer of Prior Knowledge

Most participants had a great amount of prior knowledge that they clearly used to describe how the eye works, including naming parts (iris, cornea, retina, as well as rods and cones) and that the image produced is upside down and must be "flipped" by the brain. However, it was found that when students had relatively little prior knowledge about how the eye works, it was far more difficult to get them to talk about the aberrometry model and techniques.

When it came to wavefront aberrometry, students had significantly less prior information to transfer. Most of the transfer came in the understanding of the two-lens system created by the eye lens and the lenses in the array. As one student put it, "the [eye] lens focuses light onto the area of the array, and then the [array] lenses are breaking up light … and focusing it to their own point."

Students also seemed to believe that there was an "ideal" grid, though different ideas existed of what that ideal might be. Some indicated symmetry as discussed above, while others thought that a specified intensity or the size of the dots should be known. Perhaps this ideal reading concept is transferred from ideal vision, e.g. 20/20.

The issue of subjectivity in measurement is one that we purposefully raised during discussion of both detection instruments. Most students (8 of 12) did not initially realize that any subjectivity was involved during diagnosis with an eye chart. In fact, five participants clearly stated that the eye chart was an objective diagnosis tool because it was exactly the same for every patient. This result indicates that the students' view of objectivity only may have a component of fairness. In any case where the issue of objectivity was not directly addressed by the student, they were prompted with questions such as "Did you ever try to guess at a letter you couldn't really see?" or "Did you ever have trouble telling the doctor how much clearer one line was than the next?" This scaffolding was in all cases adequate to get participants thinking along the lines of subjectivity. Interestingly, one student justified this type of guessing and subjectivity with the assertion that all people probably guess, so the results average. It should also be noted that no differences were noted between students who had glasses or contact lenses and those who did not.

After discussing aberrometry, students were asked what the advantages and disadvantages of that type of system could be. The issue of subjectivity was raised by nine of 12 students. Based on these responses, the idea of objectivity now included a component of "not open to human interpretation."

Reflection and Refraction

The words 'refraction' and 'reflection' were used improperly by nine of 12 participants (with one student using 'diffraction' as well). Common statements include light is: "refracted off a lens," "reflected through a lens," and "reflected into the eye."

We found no previous studies about this word usage. Further investigation will determine if this confusion is related to vocabulary or learning issues.

CONCLUSIONS AND FUTURE WORK

This study is one component of a larger project to understand transfer of physics learning to novel contexts and to design teaching and learning materials on the application of physics to contemporary medicine, including wavefront aberrometry diagnosis and techniques. The results of this study indicate that while most students have a large body of prior knowledge about the human eye and basic optics, much scaffolding will be needed in order to facilitate the transfer of that knowledge to wavefront aberrometry techniques. Students have a significant body of resources that they use to understand aberrometry – some appropriately and some inappropriately. These resources need to be considered carefully as we move forward in the design of teaching and learning materials. This study also indicates that while students do not immediately recognize the subjective nature of traditional diagnosis, once prompted they both acknowledge and appreciate the value of objective methods such as the aberrometer.

Reliability checks need to be performed on the data before continuing and we would like to further investigate the issue of reflection/refraction that has been raised. We have also uncovered some rather unusual (to us) views on the concept of objectivity. Further investigation is necessary to see if these views affect students' views on the nature of science. As the study progresses, we plan to continue to carefully analyze what resources students use and to examine what scaffolding is needed to assist in the transfer of previous knowledge to the diagnosis techniques of wavefront aberrometry.

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REFERENCES

1. K.M. Hamed, PhD Dissertation, Kansas State University, Manhattan KS, 1999.
2. E. Corpuz, PhD Dissertation, Kansas State University, Manhattan KS, 2006.
3. R.A. Applegate, S. Marcos, & L.N. Thibos, *Optometry and Vision Science*, **80**(2), 85-86 (2003).
4. R. Krueger. *Ophthalmology*, **108**(4), 674-678 (2001).
5. L.N. Thibos, *Journal of Refractive Surgery*, 16(Sept/Oct), S563-S565 (2000).
6. J. Greeno, D.R. Smith, & J.L. Moore, "Transfer of Situated Learned," in *Transfer on Trial*, edited by D. Dellerman & R. Sternberg, Norwood, NJ: Ablex. (1993) pp. 99-167.
7. N.S. Rebello. "Dynamic Transfer: A Perspective from Physics Education Research," in *Transfer of Learning from a Modern Multidisciplinary Perspective*, edited by J. P. Mestre, Greenwich, CT (2005) Information Age Publishing. pp. 217-250.
8. D. Hammer, *American Journal of Physics Physics Education Research Supplement*, **68**(S1), S52-S59 (2000).
9. A similar model is available, for instance, from American 3b Scientific. Item Number: W16002
10. G. Colicchia & H. Wiesner, *Physics Education*, **41**(4), 307-310 (2006).
11. F. Marton. *Journal of Thought*, **21**: 29-39 (1986).
12. A. diSessa, *Cognition and Instruction*, **10**(2-3): 105-225 (1993).