wave physics will give researchers a window into how students develop their understanding of physics.

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[1] For a detailed review of the needs and goals of PER, the reader is referred to the UMd dissertation of Jeffery M. Saul. Saul focused on student beliefs and attitudes toward physics and the role of these beliefs on student performance on conceptual and quantitative problems.

[2] The method described for the analysis of transcripts generally falls under the description of phenomenography. For more details, see Marton, F., "Phenomenography – A Research Approach to Investigating Different Understandings of Reality," J. Thought **21**:3 28-49 (1986).

[3] See reference 1 for a detailed discussion.

[4] For example, the work done here at UMd has focused on student difficulties with Newtonian physics with respect to the relationship between Force and velocity or Newton's third law; see Redish E. F., J. M. Saul, and R. N. Steinberg, "On the effectiveness of active-engagement microcomputer-based laboratories," Am. J. Phys. **65** 45-54 (1997).

[5] Clement, J., "Students' preconceptions in introductory mechanics," Am. J. Phys. **50**, 66-71 (1982).

[6] See both Halloun, I. A, and Hestenes, D. "The initial knowledge state of college **53**, 1043-1055 (1985); and Halloun, I. A, and Hestenes, D. "Common sense concepts about motion," Am. J. Phys. **53**, 1056-1065 (1985).

[7] McCloskey, M, "Naïve theories of motion," in *Mental Models*, edited by D. Gentner and A. Stevens (Lawrence Erlbaum, NJ 1983) 299-324.

[8] Similar results have been discussed in another context by Trowbridge and McDermott. See Trowbridge, D. E. and L. C. McDermott, "Investigations of student understanding of the concept of velocity in one dimension," Am. J. Phys. **48**, 1020 (1980); "Investigation of students' understanding of the concept of acceleration in one **49**, 242 (1981).

[9] Hestenes, D. "Modeling instruction in mechanics," Am. J. Phys. **55**, 440-454 (1987).

[10] For example, in my classroom experience, I find that students often include inappropriate forces, such as Third Law force pairs and forces exerted by the object rather than those exerted on the object. This result has been investigated in more detail by many researchers; see, reference 9 and references cited therein.

[11] A different possible initial condition may also describe the shape of the string at all locations for a specific instant in time, though the creation of a wave using this method is quite difficult. (But, it is a simple way to use the shape of a string at a given instant in time as an initial condition for all future events).

[12] For example, Alonso and Finn, *Physics*, Tipler, *Physics*, Wolfson and Pasachoff, *Physics Extended with Modern Physics*, and others…

[13] More details can be found in the Mel Sabella's dissertation research at the University of Maryland, College Park. Sabella has found that students often treat an extended period of time as if all events occurred at the same time. Sabella, Mel, Edward F. Redish, and Richard N. Steinberg, "Failing to Connect: Fragmented Knowledge in Student Understanding of Physics," *The Announcer* **28**:2 115 (1998).

[14] Maurines, L., "Spontaneous reasoning on the propagation of visible mechanical *Int. J. Sci. Ed.*, **14**:3, 279 (1992).

[15] Snir, J., "Making waves: A Simulation and Modeling Computer-Tool for Studying Wave Phenomena," Journal of Computers in Mathematics and Science Teaching, Summer 1989, 48 - 53.

[16] See Grayson, D. J., "Using education research to develop waves courseware," Comput. Phys. **10**:1, 30-37 (1996). Also, see Grayson, D. J., "Use of the Computer for Research on Instruction and Student Understanding in Physics," dissertation, University of Washington, Seattle, 1990.

[17] See both McDermott, L. C. "Research and computer-based instruction: Opportunity **58**, 452-462 (1990) and Grayson, D. J. and L. C. McDermott, "Use of the computer for research on student thinking," Am. J. Phys. **64**, 557-565 (1996).

[18] An overview of student conceptions of sound waves can be found in Linder, C. J., "Understanding sound: so what is the problem," Phys. Educ. **27**, 258-264 (1992).

[19] The original research is described in two papers: Linder, C. J., "University physics students' conceptualizations of factors affecting the speed of sound propagation," Int. J. Sci. Ed. **15**:6, 655-662 (1993) and Linder, C. J. and Erickson, G. L., "A study of tertiary physics students' conceptualizations of sound," Int. J. Sci. Ed. **11**, 491-501 (1989).

[20] Personal communication from J. Snir. The graduate student who had been conducting the research did not complete the project and no further findings were published.

[21] See reference 8, reference 17, and also Beichner, R. J. "Testing student interpretation of kinematics graphs," Am. J. Phys. **62** 750-762 (1994).

[22] Minstrell, Jim "Explaining the 'at rest' condition of an object," Phys. Teach. **20** 10-14 (1982).

[23] For a discussion on the usefulness of asymmetric pulses in studying student difficulties with waves, see the discussion in chapter 9 (specifically, p. 202) of Arons, A. B., *A Guide to Introductory Physics Teaching* (John Wiley & Sons Inc., New York NY, 1990).

[24] McDermott, L. C., P. S. Shaffer, and the Physics Education Group at the University of Washington, *Instructor's Guide for Tutorials in Introductory Physics* (Prentice Hall, New York NY, 1998).

[25] See reference 4 for more details. Also, see Steinberg, R. N., M. C. Wittmann, and E. F. Redish, "Mathematical Tutorials in Introductory Physics," AIP Conf. Proc. **399**, 1075-1092 (1997), for a description of materials discussed in more detail in chapter 6.

[26] McDermott, L. C., P. S. Shaffer, and M. D. Somers, "Research as a guide for teaching introductory mechanics: An illustration in the context of the Atwood's machine," Am. J. Phys. **62**, 46-55 (1994).

[27] McDermott, L. C., P. S. Shaffer, and the Physics Education Group at the University of Washington, *Tutorials in Introductory Physics* (Prentice Hall, New York NY, 1998).

[28] Available as part of the materials in reference 27.