References Cited

1. Barrow, G.M. (1991). *Journal of Chemical Education,* **66**, 449.

2. Beichner, R. J. (1994). Testing student interpretation of kinematics graphs. *American Journal of Physics, **62***, 750.

3. Beichner, Robert J. (1996). The impact of video motion analysis on kinematics graph interpretation skills. *American Journal of Physics, **64,*** 1272-1277.

4. Berg, Craig A. and Philip Smith. (1994). Assessing students' abilities to construct and interpret line graphs: Disparities between multiple-choice and free-response instruments. *Science Education, **78**,* 527.

5. Black, K.A. (1993). *Journal of Chemical Education,* **70**, 140.

6. Brooks, D.W. (1984). *Journal of Chemical Education,* **61**, 858.

7. Burke, K.A, T. J. Greenbowe, and M. A. Windschitl. (1998). Developing and using conceptual computer animations for chemistry instruction. *Journal of Chemical Education*, ***75,*** 1658-1661.

8. Chi, M.T.H., P.J. Feltovich, and R. Glaser. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science **5***, 121-152.

9. Clement, J. (1988). Observed methods for generating analogies in scientific problem solving. *Cognitive Science **12*,** 563-586.

10. Dancy, Melissa Hayes (2000). *Investigating Animations for Assessment with an Animated Version of the Force Concept Inventory*. Ph.D. dissertation, North Carolina State University, Raleigh, North Carolina. UMI #9982749, Bell and Howell, Ann Arbor, MI.

11. diSessa, Andrea A. (1996). *From Pictures to Scientific Representations: An Investigation of Students' Meta-Representational Competence*, NSF Proposal REC-9553902, http://www.soe.berkeley.edu/boxer.html/marc/proposal.html

12. Dufresne, Robert J., William J. Gerace, and William J. Leonard. (1997). Solving physics problems with multiple representations. *The Physics Teacher, **35,*** 270.

13. Elby, A. (2000). What students' learning of representations tells us about constructivism, *Journal of Mathematical Behavior **19,*** 481-502**.**

14. Fredette, N. H. and J. Clement. (1981). Student misconceptions of an electric circuit: What do they mean? *Journal of College Science Teaching, **11,*** 280-285.

15. Goldberg, Fred M. and Lillian C. McDermott. (1986). Student difficulties in understanding image formation by a plane mirror. *The Physics Teacher,* ***24,*** 472.

16. Goldberg, Fred M. and Lillian C. McDermott. (1987). An investigation of student understanding of the real image formed by a converging lens or concave mirror. *American Journal of Physics,* ***55,*** 108.

17. Goldberg, Fred M. and John H. Anderson. (1989). Student difficulties with graphical representation of negative values of velocity. *The Physics Teacher,* ***27,*** 254.

18. Greenbowe, T.J. (1994). An interactive multimedia software program for exploring electrochemical cells. *Journal of Chemical Education*, ***71,*** 555-559.

19. Guilford, J. P. and W. S. Zimmerman. (1981). *The Guilford-Zimmerman aptitude survey: Manual of instructions and interpretations.* Consulting Psychologists Press, Palo Alto, CA.

20. Hake, Richard R. (1998). Interactive engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics,* ***66,*** 64.

21. Harrington, Randal R. (1995). *An Investigation of Student Understanding of Electric Concepts in the Introductory University Physics Course.* Ph.D. Dissertation, University of Washington (Seattle). Ann Arbor; UMI Dissertation Services (UMI Number: 9537324).

22. Hestenes, David. (1997). Modeling methodology for physics teachers. In: *Proceedings of the International Conference on Undergraduate Physics Education*, edited by E. F. Redish and J. S. Rigden. Woodbury, New York, American Institute of Physics, Part One.

23. Hestenes, David, Malcolm Wells and Gregg Swackhamer. (1992). Force Concept Inventory. *The Physics Teacher,* **30**, 141.

24. Hitch, G. J., M. C. Beveridge, S. E. Avons and A. T. Hickman. (1982). Effects of reference domain in children's comprehension of coordinate graphs. In: *The Acquisition of Symbolic Skills,* edited by Don Rogers and John A. Sloboda. New York, Plenum Press.

25. Jacobs, G., (1989). Word usage misconceptions among first-year university physics students. *International Journal of Science Education* ***11***, 395-399.

26. Janvier, Claude, editor. (1987). *Problems of Representation in the Teaching and Learning of Mathematics.* Hillsdale, New Jersey, L. Erlbaum Associates.

27. Johsua, Samuel. (1984). Student's interpretation of simple electrical diagrams. *European Journal of Science Education,* ***6,*** 271.

28. Jones, Donald R. and David A. Schkade. (1995). Choosing and translating between problem representations. *Organization Behavior and Human Decision Processes* ***61,*** *214-223.*

29. Keig, Patricia F. and Peter A. Rubba. (1993). Translations of representations of the structure of matter and its relationship to reasoning, gender, spatial reasoning, and specific prior knowledge. *Journal of Research in Science Teaching,* ***30,*** 883.

30. Kenealy, P. (1987). A syntactic source of a common "misconception" about acceleration. In: *Proceedings of Second International Seminar: Misconceptions and Educational Strategies in Science and Mathematics III,* pp. 278-292. Ithaca, New York: Cornell University.

31. Kleinman, R., H. Griffin, and N. K. Kerner. (1987). Images in chemistry. *Journal of Chemical Education,* ***64,*** 766-770.

32. Knight, Randall D. (1997). *Physics: A Contemporary Perspective; Student Workbook,* preliminary edition. Reading, Massachusetts, Addison-Wesley.

33. Kozma, Robert B. (2000). The use of multiple representations and the social construction of understanding in chemistry. In: *Innovations in Science and Mathematics Education*, edited by Michael J. Jacobson and Robert B. Kozma, Mahwah, New Jersey, L. Erlbaum Associates.

34. Kozma, Robert B. and Joel Russell. (1997). Multimedia and understanding: Expert and novice responses to different representations of chemical phenomena. *Journal of Research in Science Teaching,* ***34***, 949-968.

35. Kozma, Robert, Elaine Chin, Joel Russell, and Nancy Marx (2000). The roles of representations and tools in the chemistry laboratory and their implications for chemistry learning. *Journal of the Learning Sciences* ***9***, 105-143.

36. Larkin, Jill H. (1983). The role of problem representation in physics. In: *Mental Models*, edited by Dedre Gentner and Albert L. Stevens, Hillsdale, New Jersey, L. Erlbaum Associates, pp. 75-98.

37. Laws, Priscilla W. (1993). New approaches to undergraduate teaching: Introductory courses. In: *Physics Departments in the 1990s*, edited by Gerald M. Crawley and Bernard V. Khoury. College Park, Maryland, American Association of Physics Teachers and American Physical Society.

38. Legg, M.J., Legg, J.C., and Greenbowe, T.J. Analysis of success in general chemistry based on diagnostic testing using logistic regression. *Journal of Chemical Education (in press).*

39. Lesh, Richard, Tom Post, and Merlyn Behr. (1987). Representations and translations among representations in mathematics learning and problem solving. In: *Problems of*

Representation in the Teaching and Learning of Mathematics, edited by Claude Janvier. Hillsdale, New Jersey, L. Erlbaum Associates, pp. 33-40.

40. Maloney, David P. (1993). Research on problem solving: Physics. In: *Handbook of Research on Science Teaching and Learning,* edited by Dorothy L. Gabel. New York, Macmillan Publishing Company, pp. 327-354.

41. Mazur, Eric. (1997). *Peer Instruction: A User's Manual.* Upper Saddle River, New Jersey; Prentice-Hall.

42. McDermott, Lillian C. (1990). A view from physics. In: *Toward a Scientific Practice of Science Education*, edited by M. Gardner, J. G. Greeno, F. Reif, A. H. Schoenfeld, A. diSessa, and E. Stage, pp. 3-30. Hillsdale, New Jersey, Lawrence Elbaum.

43. McDermott, Lillian C. (1991). Millikan Lecture 1990: What we teach and what is learned – Closing the gap. *American Journal of Physics, **59,*** 301.

44. McDermott, Lillian C. (1993). Guest comment: How we teach and how students learn – A mismatch? *American Journal of Physics, **59,*** 301.

45. McDermott, Lillian C. (1997). Bridging the gap between teaching and learning: The role of research. In: *Proceedings of the International Conference on Undergraduate Physics Education,* edited by E. F. Redish and J. S. Rigden. Part One: pp. 139-165. American Institute of Physics, Woodbury, New York.

46. McDermott, Lillian C., Mark L. Rosenquist, and Emily H. Van Zee. (1987). Student difficulties in connecting graphs and physics: Examples from kinematics. *American Journal of Physics, **55,*** 503.

47. McDermott, Lillian C. and Peter S. Shaffer. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigation of student understanding. *American Journal of Physics, **60,*** 994.

48. McDermott, Lillian and the Physics Education Group. (1996). *Physics by Inquiry.* New York, John Wiley.

49. McDermott, Lillian C., Peter S. Shaffer and the Physics Education Group. (1998). *Tutorials in Introductory Physics. [Tutorials; Homework; Pretests & Exam Questions.]* Upper Saddle River, New Jersey; Prentice-Hall.

50. Meltzer, David E. (1996). Comparative effectiveness of conceptual learning with various representational modes. *AAPT Announcer, **26(4),*** 46.

51. Meltzer, David E. (1998). Effectiveness of instruction on force and motion in an elementary physics course based on guided inquiry. *AAPT Announcer, **28(2),*** 125.

52. Meltzer, David E. and Kandiah Manivannan. (1996). Promoting interactivity in physics lecture classes. *The Physics Teacher,* ***34,*** 72.

53. Meltzer, David E. and Kandiah Manivannan. (1998). Interactive methods for large classes: Workshop W36. *AAPT Announcer* ***28(2),*** 66. [Workshop at the summer meeting of the AAPT.]

54. Mokros, Janice R. and Robert F. Tinker (1987). The impact of microcomputer-based labs on children's ability to interpret graphs. *Journal of Research in Science Teaching,* ***24,*** 369.

55. Novak, Gregor M., Evelyn T. Patterson, Andrew D. Gavrin, and Wolfgang Christian. (1999). *Just-In-Time Teaching: Blending Active Learning with Web Technology*. Upper Saddle River, New Jersey: Prentice-Hall.

56. Paivio, A. (1971). *Imagery and verbal processes.* New York, Holt, Rinehart and Winston.

57. Plötzner, Rolf. (1994). *The Integrative Use of Qualitative and Quantitative Knowledge in Physics Problem Solving.* Frankfurt am Main, Peter Lang, pp. 33-46.

58. Ramadas, J. (1982). Use of ray diagrams in optics. *School Science,* ***10,*** 1-8.

59. Redish, E. F. and R. N. Steinberg. (1999). Teaching physics: figuring out what works. *Physics Today*, ***52(1),*** 24.

60. Reif, Frederick. (1995). Millikan Lecture 1994: Understanding and teaching important scientific thought processes. *American Journal of Physics,* **63,** 17.

61. Sanger, Michael J. and Thomas J. Greenbowe. (1997). Common student misconceptions in electrochemistry: Galvanic, electrolytic, and concentration cells. *Journal of Research in Science Teaching,* ***34,*** 377-398.

62. Sanger, Michael J. and Thomas J. Greenbowe. (2000.). "Addressing Student Misconceptions Concerning Electron Flow in Electrolyte Solutions Using Computer Animations and the Conceptual Change Approach." *International Journal of Science Education*, ***22,*** 521-537.

63. Shaffer, Peter S. and Lillian C. McDermott (1992). Research as a guide for curriculum development: An example from introductory electricity. Part II: Design of instructional strategies. *American Journal of Physics,* ***60,*** 1003.

64. Sherin, Bruce L. (2000). How students invent representations of motion: A genetic account. *(Under review.)*

65. Thornton, Ronald K. and David R. Sokoloff. (1990). Learning motion concepts using real-time microcomputer-based laboratory tools. *American Journal of Physics*, ***58,*** 858.

66. Thornton, Ronald K. and David R. Sokoloff. (1998). Assessing student learning of Newton's laws: the Force and Motion Conceptual Evaluation and the evaluation of active learning laboratory and lecture curricula. *American Journal of Physics*, ***66,*** 338.

67. Törnkvist, S., K.-A. Pettersson, and G. Tranströmer. (1993). Confusion by representation: On student's comprehension of the electric field concept. *American Journal of Physics, **61,*** 335.

68. Touger, Jerold S. (1991). When words fail us. *The Physics Teacher, **29,*** 90-95.

69. Van Heuvelen, Alan. (1990a). *ALPS Kit: Active Learning Problem Sheets [Mechanics]*. Plymouth, Michigan: Hayden-McNeil.

70. Van Heuvelen, Alan. (1990b). *ALPS Kit: Active Learning Problem Sheets, Electricity and Magnetism.* Plymouth, Michigan: Hayden-McNeil.

71. Van Heuvelen, Alan. (1991a). Learning to think like a physicist: A review of research-based instructional strategies. *American Journal of Physics, **59,*** 891.

72. Van Heuvelen, Alan. (1991b). Overview, Case Study Physics. *American Journal of Physics, **59,*** 898.

73. Wandersee, James H., Joel J. Mintzes, and Joseph D. Novak. (1994). Research on alternative conceptions in science. In: *Handbook of Research on Science Teaching and Learning*, edited by Dorothy L. Gabel, pp. 177-210. New York: Simon and Schuster Macmillan.

74. Whalen, Leah M., Patrick D. Noonan, and Michael T. Hayes. (1996). *Impact of NSF-funded Projects in Science for Elementary Teacher Preparation*, report submitted to WPI and to the Division of Undergraduate Education of the National Science Foundation.

75. Williams, H. Thomas. (1999). Semantics in teaching introductory physics. *American Journal of Physics **67,*** 670-680.

76. Witkin, H.A., P. K. Oltman, E. Raskin, and S. A. Karp. (1971). *A Manual for the Embedded Figures Test.* Consulting Psychologists Press, Palo Alto, CA.

77. Wu, Hsin-kai, Joseph S. Krajcik, and Elliot Soloway. (2000). Promoting conceptual understanding of chemical representations: Students' use of a visualization tool in the classroom. *Paper presented at the annual meeting of the National Association of Research in Science Teaching,* April 28-May 1, 2000, New Orleans, LA.

78. Yang, E-M., Greenbowe, T. J., and T. Andre (*in press)*. Spatial ability and the impact of visualization/animation on learning electrochemistry. *International Journal of Science Education*.

79. Yarroch, W. (1985). Student understanding of chemical equation balancing. *Journal of Research in Science Teaching **22***, 449-459.

80. Zacks, Jeff and Barbara Tversky. (1999). Bars and lines: A study of graphic communication. *Memory and Cognition **27,*** 1073-1079.

81. Ainsworth, Shaaron. (1999). The functions of multiple representations. *Computers and Education **33,*** 131-152.

82. Boulton-Lewis, Gillian M. (1998). Children's strategy use and interpretations of mathematical representations. *Journal of Mathematical Behavior **17,*** 219-237.

83. Cheng, Peter C.-H. (1999). Unlocking conceptual learning in mathematics and science with effective representational systems. *Computers and Education **33***, 109-130.

84. Cifarelli, Victor V. (1998). The development of mental representations as a problem solving activity. *Journal of Mathematical Behavior **17,*** 239-264.

85. diSessa, Andrea A. and Bruce L. Sherin. (2000). Meta-representation: an introduction. *Journal of Mathematical Behavior **19,*** 385-398.

86. Even, Ruhama. (1998). Factors involved in linking representations of functions. *Journal of Mathematical Behavior **17,*** 105-121.

87. Goldin, Gerald A. (1998). Representational systems, learning, and problem solving in mathematics. *Journal of Mathematical Behavior **17,*** 137-165.

88. Goldin, Gerald A. and Claude Janvier. (1998). Representations and the Psychology of Mathematics Education. *Journal of Mathematical Behavior **17,*** 1-4.

89. Hitt, Fernando. (1998). Difficulties in the articulation of different representations linked to the concept of function. *Journal of Mathematical Behavior **17,*** 123-134.

90. Kaput, James J. (1998). Representations, inscriptions, descriptions and learning: A kaleidoscope of windows. *Journal of Mathematical Behavior **17,*** 265-281.

91. Pape, Stephen J. and Mourat A. Tchoshanov. (2001). The role of representation(s) in developing mathematical understanding. *Theory into Practice **40,*** 118-127.

92. Vergnaud, Gérard. (1998). A comprehensive theory of representation for mathematics education. *Journal of Mathematical Behavior **17,*** 167-181.