Constructivism as a Referent in the Design and Development of a Computer Program Using Interactive Digital Video to Enhance Learning in Physics

Matthew Kearney
Faculty of Education
University of Technology, Sydney. AUSTRALIA
Matthew.Kearney@uts.edu.au

David F. Treagust
Science and Maths Education Centre
Curtin University of Technology, AUSTRALIA
D.Treagust@smec.curtin.edu.au

Abstract

This paper describes the fruitful interaction between educational research on constructivism and the development and use of a multimedia computer program. The software uses interactive digital video clips to present sixteen real world demonstrations to Physics students. It is designed to be used by pairs of students to elicit their pre-instructional conceptions of Force and Motion and encourage discussion about these views. A predict-observe-explain (POE) strategy is used to structure the learners' engagement with the video clips. The choice and sequence of the video clips, as well as the multiple choice options available to students in the prediction phase of each task was informed by misconception research in physics education. All multiple choice selections and written responses made by users are recorded automatically in a text file on the computer hard drive.

Keywords

Constructivist software, Interactive multimedia, Physics learning, Digital video, Predict-observe-explain strategy, Peer learning

Background

Constructivism

The Constructivist view of learning suggests that learners construct their own knowledge, strongly influenced by what they already know. In this way, each learner builds their own individual sense of ‘reality’ (Tobin, Tippins & Gallard, 1996). Constructivism encourages educators to recognise their students’ strongly held preconceptions and to provide experiences that will help them build on their current knowledge of the world (Duit & Confrey, 1996).

Social constructivism acknowledges that learning is a social activity in which learners are involved in constructing consensual meaning through discussions and negotiations. During these discussions, students can identify and articulate their own views, exchange ideas and reflect on other students’ views, reflect critically on their own views and when necessary, reorganise their own views and negotiate shared meanings (Prawat, 1993, Solomon, 1987, McRobbie and Tobin, 1997). Although individuals construct their own understandings, it is not done in isolation but in a social context.

Probing Student Understanding

If students are to experience meaningful learning they must review and if necessary reform their strongly held personal views. Hence, the elicitation of student ideas is central to any teaching approach informed by constructivism (Driver & Scott, 1996). Student interviews, concept maps, student journals and diagnostic multiple choice tests are techniques which have been used as probes of student understanding for these purposes (Treagust, D., Duit, R. & Fraser, B., 1996). As well as identifying preconceptions, the process of eliciting students’ pre-instructional ideas can also offer an opportunity for student learning (Duit et al., 1996). From a social constructivist perspective, if students’ ideas are elicited in a social setting, they receive an opportunity to articulate and clarify their own preconceptions, reflect critically on their own and others’ ideas and co-construct reformulated ideas.

The Predict-Observe-Explain (POE) Strategy

White and Gunstone (1992) have promoted the predict-observe-explain (POE) procedure as an efficient strategy for eliciting and promoting discussion of students’ science conceptions. This strategy involves students predicting the outcome of a demonstration; committing themselves to a possible reason for their prediction; observing the demonstration; and finally explaining any discrepancies between their prediction and observation.

Whether used individually or in collaboration with other students, POE tasks can help students explore and justify their own individual ideas, especially in the prediction and reasoning stage. If the observation phase of the POE task provides some conflict with the students' earlier prediction, reconstructions and revision of initial ideas is possible (Searle & Gunstone, 1990; Tao & Gunstone, 1997).

Constructivism and Educational Software Design.

The behaviourist paradigm dominated early developments in educational software. Drill and practice and tutorial programs (and more recently, artificial intelligence developments) were designed primarily for reinforcement of concepts. However, many writers (Jonassen, 1994; Harper & Hedberg,1997; Squires, 1999) have encouraged a shift in emphasis to more constructivist software, engaging learners collaboratively in open ended, exploratory learning environments where students can construct meaningful knowledge.

Squires (1999) suggests that a recurrent theme in most guidelines for the development of constructvist software is that learning should be authentic. He suggests that constructivist software should allow for 'cognitive authenticity' by promoting opportunities for learners to express personal ideas and opinions and articulate ideas, experiment with ideas, engage in complex environments which are representative of interesting and motivating tasks and receive opportunities for intrinsic feedback. He also suggests that constructivist software should allow for 'contextual authenticity' by relating tasks to the real world, encouraging collaborative learning in which peer group discussion is prominent and encouraging the role of a teacher as a facilitator of learning.

Using video to enhance learning in physics

Early Use of Video

The use of video and films as 'visual aids' in Physics education dates back to the 1950's when the American Association of Physics teachers sponsored a set of films to bring together current film technology, the expertise of the film producer and the knowledge and experience of outstanding Physics teachers. These were followed in the 1960's by the well known Physical Science Study Committee (PSSC) series of films, parts of which survive today in the videodisc series *Physics Cinema Classics* (Fuller & Lang, 1992). However these films and many similar Physics films produced in the following years had a major limitation: the control exercised by the classroom teacher or student is limited to turning the videotape on or off. Thus an important pedagogical consideration is severely limited during such passive viewing of these films: the ability of the teacher to respond immediately and appropriately to the needs of the students (Zollman & Fuller, 1994).

Computer-controlled Digital Video in Physics Education

'Interactive video' could be defined as any video which the user has more than minimal 'on-off' control over what appears on the screen. The 'media attributes' (Salomon, Perkins & Globerson, 1991) of interactive digital video include: 'random access', allowing users to select or play a segment or individual frame (picture) with minimal search time; 'still frame', allowing any frame of the video clip to be clearly displayed for as long as the user wishes to view it; 'step frame', enabling users to display the next or previous frame, and 'slow play' enabling the user to play the video at any speed up to real time in a forward or backward direction. (NB. Videotape does not fully allow this as an individual frame degrades if displayed for a long time and random access is difficult. Alternatively, digitised video, either on a computer or a videodisc player, enables these interactive features.)

'Interactive video' makes possible the detailed study of interesting laboratory or real life events and is considered an important technology in the area of computer based learning in science (Weller, 1996). The clips can show dangerous, difficult, expensive or time consuming demonstrations not normally possible in the laboratory (Hardwood & McMahon, 1997) For example, one clip used in this study showed footage of an astronaut performing a demonstration on the moon. Such real-life scenarios can make science more relevant to the students' lives (Duit & Confrey, 1996; Jonassen & Reeves, 1996), and help students build links between their prior experiences and abstract models and principles of physics (Escalada & Zollman, 1997). Through the use of the digital video facilities, students have access to a more sophisticated way of observing events. Video clips also allow students to view accurate and reliable replications of demonstrations (Bosco, 1984).

Making Quantitative Observations using Digital Video Clips: Video-based Laboratories

Interactive video presentations can be used to make measurements and gather data about events. Computer digital video systems allow students and teachers to capture video of experiments they perform themselves by storing the video on their computer's hard drive. When connected to spreadsheets, students can then use the interactive video clips to efficiently gather data and make graphs and other representations to analyse and model their data. Many studies have shown these 'video based labs' to be motivating and authentic learning experiences for students (Beichner, 1996; Rubin, Bresnahan & Ducas, 1996; Laws & Cooney, 1996; Rodriguez et al. 1999; Gross, 1998).

Squires (1999) describes these video based labs as facilitating a constructivist learning environment. They promote open ended exploration in an authentic learning environment; particularly when the learner chooses and captures their own film clips.

Making Qualitative Observations using Digital Video Clips

An important learning outcome in most Physics courses is for students to learn to observe their own world more carefully. The use of digital video gives teachers and students sophisticated 'tools' to observe dynamic processes and physical phenomena in intricate detail. The ability to 'slow down time' (using 'slow motion' or 'frame by frame' facilities) makes the video medium most suitable for students to observe and consider 'time dependant' phenomena prevalent in many Physics episodes, particularly in the Mechanics domain.

Embedding interactive video clips into a POE sequence using a computer program

The interactive digital video computer program reported in this paper attempts to make use of digital video clips of appropriate Physics demonstrations as part of a predict-observe-explain sequence. In these sequences, students commit themselves to a prediction and reason for a particular outcome, before observing the video clip and explaining any discrepancies between their predictions and observations. Instead of observing a real life demonstration (often conducted by the lecturer in a 'whole class' setting) in the observation phase of the POE sequence, students collaborate in small groups at the computer to make detailed qualitative observations of the video clips. These observations provide the intrinsic feedback on their earlier predictions. Unlike the 'video based labs' discussed previously, no quantitative measurements take place here. Alternatively, the emphasis is on the articulation of rich, detailed, qualitative responses (both verbal and written), so important to learning in a social constructivist environment.

The computer environment permits more intimate, small group interactions with the POE tasks, giving students control of the demonstrations and allowing the teacher more time to interact with students. These collaborative small groups encourage the social interactions and personal reflections which are essential for peer learning.

Finally, the computer environment supports the sequencing and presentation of the POE tasks. For example, the program discussed in this paper does not allow the students to view the video of a demonstration (the observation phase) until their predictions and reasons are completed. (Indeed it is not possible to change these responses after viewing the video clip.) The computer program also automatically and efficiently places students' written responses into text file for further analysis.

Previous studies of POE tasks in a computer environment

The use of POE tasks within a computer environment has been reported sparingly in the literature. Many of these studies do not completely follow the full POE procedure reported by White & Gunstone (1992). For example they may use the prediction stage without the reasoning stage or 'skip' the explanation stage altogether. There were no studies reported in the literature which used digital video of real life demonstrations as part of a POE sequence; most using animations for viewing.

Program Design and Development

Purpose of the program

Cognitive Learning Outcomes for Students

The program is designed to be used by students working in collaborative pairs to elicit and promote discussion about students' pre-instructional Physics conceptions. The collaborative use of the POE computer tasks in this program should promote a student's conceptual development in the domain of Physics by one or more of the following:

a) articulation and/or justification of the student's own ideas
b) reflection on the viability of other students' ideas
c) critical reflection on the student's own ideas

d) construction and/or negotiation of new ideas

The program provides students with an opportunity to engage in ‘science talk’ (Lemke, 1990) and a means of developing science discourse skills (exploration, justification, negotiation, challenge etc.)

Affective Learning Outcomes for Students

The challenging, real world contexts presented in the program should stimulate students’ intrinsic interest and curiosity in various mechanics related events and related principles. Hence the program should create student awareness and appreciation of the integral relationship between Physics and students’ everyday lives.

Benefits for Instructor

The computer program documents the elicited views of the students in text files on the computer hard drives. These pre-instructional conceptions can be used to guide future learning episodes (Ausubel, 1968). The program should provide an opportunity for the teacher to engage in small group discussions with students as they engage in the POE tasks. (This is very much in contrast to the traditional whole class, instructor-led POE demonstration.) The program should provide a stimulus for later whole class discussions. Indeed, the instructor version of the program contains the ‘correct science views’ for each POE task.

Domain of program

The topic of motion (mainly projectile motion) was chosen as the domain for the program for three main reasons. Firstly, there was ample literature on student misconceptions in mechanics to aid construction of the POE tasks as well as for use in analyses of students’ elicited preconceptions. Secondly, motion is an essential part of all introductory physics courses. Thirdly, there are many possible demonstrations which depict various forms of motion that are quite easy to film and indeed, easy to observe on film! These scenarios often ‘lend’ themselves to close analysis using the sophisticated tools available in the video medium.

The influence of physics education research

Misconception research on mechanics (eg. Clement, 1982) informed the selection and creation of the video clips as well as the sequencing of the 16 POE tasks. Common misconceptions emerging from this literature also informed the design of the multiple-choice options offered in the prediction stage of the POE tasks.

Most video clips depicted scenarios designed to elicit different variations of pre-Newtonian alternative conceptions. Where possible, abstract situations discussed in the literature were adapted to an everyday, real world context for the video clips used in this study. This had the effect of creating highly rich contexts for the students, in line with constructivist strategies. For example, the pendulums discussed in Caramazza, McCloskey & Green (1981) and McDermott (1984) were adapted to a child on a swing (Task 8). The famous scenario of a running person dropping a ball as discussed in McCloskey (1983) was adapted to the video clip of a walking child trying to drop a small ball into a cup on the ground (Tasks 10 and 11). The canon ball discussed by McDermott (1984) was adapted to a soccer ball kicked into the air by a boy (Task 7). Speed variations (Tasks 4 and 5) and mass variations (Tasks 5 and 6) as discussed by Millar & Kragh (1994) were incorporated into some of the tasks to help elicit naïve 'impetus' views.

Some of these tasks have a rich history and have been considered by many scientists over the centuries. For example Task 12 involves the famous scenario of a ball released from the mast of a moving sailing boat. Students needed to predict where the ball would land: behind, below or in front of the mast. (Most students predict that the ball will land behind the mast rather the below it!) Galileo Galilei (1632) discussed this problem in detail in the 'Dialogue Concerning Two Chief World Systems'.

Three video clips (Tasks 1, 2 and 9) were related to vertical motion only. They were designed to elicit alternative viewpoints relating to one-dimensional motion. The remaining videos covered both half flight and full flight projectiles. Projectiles used in the video clips covered both active launches (eg. a person throwing a ball) and passive launches from 'carriers' (Millar & Kragh, 1994).

Sources of the digital video clips

A major stage in the software development was finding appropriate video clips for the program. Sixteen clips were needed to create enough POE tasks for students to engage in the program for approximately two learning sessions. A balance between vertical motion, half flight and full flight projectile motions was required as well as a balance between active and passive launches. The video demonstrations needed to contain interesting and relevant material and where appropriate, surprising outcomes suitable for inclusion in POE tasks. Commercial sources of video clips needed copyright permission.

This search for appropriate video clips proved to be a challenging one. After extensive investigations and advice from the physics education community worldwide, the following sources of video clips were found and where appropriate, permission was granted to use the clips:

- Commercial VHS tapes in physics education. These clips were digitised before inclusion in the program. (4 tasks)
- Commercial CD ROM packages (6 tasks)
- Own filming (6 tasks)

Screen sequence for each POE task

The first screen of each task includes a photo and a written description of the scenario to be considered. The photo on this screen was captured from the first ‘frame’ of the video clip (to be viewed in the observation phase of the POE sequence) . In complex situations (eg. Task 12: The Sailing Boat), a brief video ‘preview’ is offered (without showing the outcome of the demonstration) to help avoid ambiguities.

The second screen of each task (or the third in the case of tasks with a video ‘preview’), displays the same photo and a question asking the student to predict an outcome. Six of the tasks (Tasks 3 to 8) require students to draw their predictions on a piece of paper. The other ten tasks require students to make their prediction by choosing from a selection of up to four multiple choice options. The options available to students are based on known misconceptions from research in Mechanics, in the tradition of other multiple choice diagnostic tests reported in the literature (eg. Halloun & Hestenes, 1985). Some of the tasks give the students a further option to record their own predicted outcome if they disagree with the options given.

The next screen asks the students to give a reason for their prediction. This two-tiered strategy (Treagust, 1987) allows the student to articulate the reasoning behind their initial multiple choice selection. This reasoning stage can be challenging but is an important stage as many students make a correct prediction but describe incorrect reasons. Students write their responses (in full sentence form) in a ‘text input box’ shown on the screen. (There is a rather crude software ‘mechanism’ incorporated into the program whereby students need to type at least ten words or the software ‘asks’ them to ‘re-write’ their response!) All text input by the users is recorded as a text file on the hard drives.

The software does not allow students to proceed to the observation (of the video) stage unless they have fully committed themselves to their prediction and reasons. If they want to go 'backwards and forwards' and edit their prediction or reasons, they can do this, but not after proceeding to the observation stage. This ability of the multimedia program to structure these capabilities is crucial to the effectiveness of the POE strategy in the small group setting and the level of learner control of the POE tasks.

The next screen allows the students to observe the video of the event. After approximately 10 seconds, another 'text input box' shows on the screen (underneath the video clip) to allow students to describe and record their observations in detail. Students can replay and manipulate the video clip as many times as they wish before proceeding. The 'explanation' phase is the focus of the final screen for each task. This is perhaps the most difficult stage for students as they have to again describe in writing any differences between their prediction and observation.

Trial of the beta version of the program

The program was developed during 1998 using the multimedia authoring software: Macromedia Authorware. A beta version of the program was trialed by two separate groups during October 1998. The first evaluation was with a Physics class at the University of Sydney International Preparation Program. Students' written responses from each POE task were collected, verbal interactions were recorded on audiotape and students completed a 'feedback' questionnaire after their session. The second evaluation was done by an academic from Science Education and two academics from the Physics Department at Curtin University, Perth. At this stage, the program only contained ten tasks which could be selected by the students in any order. It did not contain any of the film clips made by the researcher and also contained one task which eventually was deleted from the final version of the program. The astronaut task was missing from this original version and there were no tasks requiring drawings for the prediction stage.

Students generally reacted positively to the program. Meaningful conversations were observed and data from the audio tapes indicated that students articulated their ideas and often negotiated 'shared meanings'. Feedback from the student questionnaires indicated that the students also perceived meaningful conversations taking place during their engagement with the program. Students' written responses to the tasks (recorded on the computer) revealed many pre-Newtonian conceptions. However, it was the 'reasons' for these predictions which revealed many alternative science views. This often occurred after a correct prediction. Fortunately there were no major programming ‘bugs’. However, students used the questionnaires to make valuable suggestions for improvements in the program. The lack of a 'back' button to return to responses on previous screens for editing purposes was a common criticism. (Although this would never be considered after the observation stage of the POE tasks!) The inability to edit written responses was another complaint.

The three academics from Curtin University reacted positively to the program. They used a special technique where their faces and conversations were filmed simultaneously with the contents of the computer screen. The videotape then shows the users working as an 'inserted picture' on the main computer screen. (This technique is discussed in Yeo, Loss, Zadnik, Harrison & Treagust, 1998.) They made many helpful suggestions about screen design and also the language used in the tasks. Their main criticism however was that correct ‘science views’ for each task were not given at all. Consequently a special ‘instructor’s version’ of the program was made which included answers to each task.

Changes in the program resulting from these trials

Apart from the creation of a separate instructor’s edition of the program, both of these trials did lead to other major changes in the program. Six more tasks were added (using video clips filmed by the first author). These were added to further align the program with misconception research in mechanics. For example, the ball and cup task was transformed to a ‘heavy’ ball and cup task. An additional ‘light ball and cup’ task was then created to distinguish any students who held naive impetus preconceptions relating to mass variations in objects (Millar & Kragh, 1994). In this additional task, a small child walking towards a cup was filmed dropping a ‘light’ ping pong ball in contrast to the heavy ball in the preceding task.

It was decided that a multiple choice format was not suitable for tasks involving pathway predictions. There were too many possible outcomes to be covered by multiple choice options and more detailed data could be gained from student drawings of these pathways (White & Gunstone, 1992). Hence tasks 3 to 8 were designated ‘drawing tasks’ where students’ predictions would not be recorded on the computer but instead would be recorded on paper. (A future version of this program will allow students to draw and ‘submit’ electronic drawings to be saved on the computer with the user’s text responses.)

The sequence in which students did the sixteen tasks was also changed. Guidelines for the development of constructivist software generally encourages a ‘low structure’ non-linear sequencing, and a high degree of ‘student access’ to material providing students with many navigational opportunities (Kennedy & McNaught, 1997). However this was not possible for this particular program. The observation of certain video clips could easily influence students’ responses in other subsequent tasks. Hence the tasks where students had to draw their predicted and observed pathway needed to be in the first part of the program.

The trials also resulted in many other minor but important changes to the program. The format of the text file (which recorded student responses) was made more user friendly. A compulsory tutorial (at the start of the program) was developed to help students gain familiarity with the software. The ability to ‘go back’ to written responses and edit them (a strong criticism of the beta version) was also incorporated into the final version of the program. (Although it was still not possible to change predictions and reasons after viewing the video clips!) Screen design issues were also addressed including changing the background colour back to white for ease of reading, addition of small icons on most screens, and the addition of arrows to point out important parts of graphics.

Current and Future Directions

The program is currently being used as part of a dual case study of two groups of physics students using the program. The foci of this study are the students’ learning conversations during their interaction with the computer program, the actual physics misconceptions elicited by the program and the students’ and instructors’ perceptions of various aspects of the program (eg. the compatibility of the digital video clips with the POE strategy). Preliminary findings from this study are reported elsewhere (Kearney & Treagust, 1999, 2000). The constructivist nature of the program could be enhanced by allowing students (or instructors) to film their own suitable scenarios rather than using pre-recorded clips (Squires, 1999). The possibilities of combining this strategy into predict-observe-explain tasks could be the subject of further research and software development.

Summary

There has been strong criticism of passive multimedia use in education (Madian, 1995) and more particularly in physics education (Yeo, Loss, Zadnik, Harrison & Treagust, 1998). There has also been criticism of the limited influence and impact of constructivist research findings on the practice of science education (Ben-Zvi and Hofstein, 1996). This paper attempts to provide an example of educational research relating to constructivism informing both the content and processes incorporated in an interactive multimedia program. Physics educators at all grade levels will be increasing their use of video and computer technologies in their learning environments. Hence instructors need to consider examples of using these technologies effectively to enhance learning of science (Escalada & Zollman, 1997). The thoughtful consideration of educational research in the design and use of these technologies is essential.

References

Ausubel, D. (1968). Educational psychology: a cognitive view. New York: Holt, Rinehart & Winston.

Beichner, R. (1996). The impact of video motion analysis on kinematics graph interpretation skills. AAPT Announcer, 26, 86.

Ben-Zvi, R. & Hofstein, A. (1996). Strategies for Remediating Learning Difficulties in Chemistry. In D.F. Treagust, R. Duit, & B.J. Fraser (Eds.),*Improving Teaching and Learning in Science and Mathematics.* (pp.109-119) New York and London : Teachers College Press

Bosco, J. (1984). Interactive video: educational tool or toy? Educational Technology 24(3), 13-19.

Caramazza, A., McCloskey, M. & Green, B. (1981). Naive beliefs in 'sophisticated' subjects: misconceptions about trajectories of objects. Cognition, 9, 117-123.

Clement, J. (1982). Students' preconceptions in introductory mechanics. American Journal of Physics, 50, 66-71.

Driver, R. & Scott, P. (1996). Curriculum development as research: a constructivist approach to science curriculum development and teaching. In D.F. Treagust, R. Duit, & B.J. Fraser (Eds.). Improving teaching and learning in science and mathematics. (pp.94-108). New York and London: Teachers College Press

Duit R. & Confrey J. (1996). Reorganising the curriculum and teaching to improve learning in science and mathematics. In D.F. Treagust, R. Duit, & B.J. Fraser (Eds.). Improving teaching and learning in science and mathematics. (pp.79-93). New York and London: Teachers College Press.

Escalada, L. & Zollman, D. (1997). An investigation on the effects of using interactive digital video in a physics classroom on student learning and attitudes. Journal of Research in Science Teaching, 34(5), 467-489.

Fuller,R. & Lang, C. (1992). (Eds.) Physics: cinema classics. Videodiscs produced by American Association of Physics Teachers.

Galilei, G. (1632). Dialogue concerning the two chief world systems - Ptolemaic & Copernican. Translated by Stillman Drake. University of California Press. Berkeley. 1967.

Gross, M. (1998). Analysis of human movement using digital video. Journal of Educational Multimedia and Hypermedia 7(4), 375-395.

Halloun, I. & Hestenes, D. (1985). Common sense concepts about motion. American Journal of physics, 53, 1056-1064.

Hardwood, W. & McMahon, M. (1997) Effects of integrated video media on student achievement and attitudes in high school chemistry. Journal of Research in Science Teaching, 34(6), 617-631.

Harper, B. & Hedberg, J. (1997, December). Creating motivating interactive learning environments: a constructivist view. Paper presented at the Annual Meeting of the Australasian Society for Computers in Learning in Tertiary Education. Perth.

Jonassen, D. (1994). Thinking technology: towards a constructivist design model. Educational Technology, 34(3), 34-37.

Jonassen, D. & Reeves, T. (1996). Learning with technology: using computers as cognitive tools. In D. Jonassen (Ed.). Handbook of research on educational communications and technology. (pp 693-719). New York: Simon & Shuster Macillan.

Kearney, M. & Treagust, D.F. (1999, July). Using multimedia supported predict-observe-explain tasks to probe student understanding. Paper presented at the 30th Annual Meeting of the Australasian Science Education Research Association. Rotorua, NZ.

Kearney, M. & Treagust, D.F. (2000, April). An investigation of the classroom use of prediction-observation-explanation computer tasks designed to elicit and promote discussion of students' conceptions of force and motion. Paper presented at the Annual Meeting of the National Assoc. for Research in Science Teaching. New Orleans, USA.

Kennedy, D. & McNaught, C. (1997). Design elements for interactive multimedia. Australian Journal for Educational Technology. 13(1), 1-22.

Laws, P. & Cooney, P. (1996). Constructing spreadsheet models of MBL and video data. AAPT Announcer, 25, 32.

Lemke J. (1990). Talking science: language, learning and values. Norwood, NJ: Ablex.

McCloskey, M. (1983). Intuitive physics. Scientific American, 248 (4), 114-122.

McDermott, L. (1984). Research on conceptual understanding in mechanics. Physics Today, July, 24-32.

McRobbie, C. & Tobin, K. (1997) A social constructivist perspective on learning environments. International Journal of Science Education, 19(2), 193-208.

Madian, J. (1995) Multimedia - why and why not? The Computing Teacher, 22(5), 16-18.

Millar, R. & Kragh, W. (1994). Alternative frameworks or context-specific reasoning? Children's ideas about the motion of projectiles. SSR, 75, 27-34.

Prawat, R. (1993) The value of ideas: problems versus possibilities in learning. Educational Researcher, 22(6), 5-12.

Rodrigues, S., Pearce, J. & Livett, M. (1999, July). Using video-based labs or motion sensors during practical work in first year physics. Paper presented at the 30th Annual Meeting of the Australasian Science Education Research Association. Rotorua, NZ.

Roth, W., McRobbie, C., Lucas, K. & Boutonne, S. (1997). Why may students fail to learn from demonstrations? A social practice perspective on learning in physics. Journal of Research in Science Teaching, 34(5), 509-533.

Rubin A., Bresnahan, S. & Ducas T. (1996). Cartwheeling through *CamMotion*. Communications of the ACM, 39(8), 84-85.

Salomon G., Perkins, D. & Globerson, T. (1991). Partners in cognition: extending human intelligence with intelligent technologies. Educational Researcher, 20(3), 2-9.

Searle, P. & Gunstone, R. (1990). Conceptual change and physics instruction: a longitudinal study. ERIC Document, ED 320 767.

Solomon, J. (1987). Social influences on the construction of pupils’ understanding of science. Studies in Science Education, 14, 63-82.

Squires, D. (1999). Educational software for constructivist learning environments: subversive use and volatile design. Educational Technology, 39(3), 48-54.

Tao, P. & Gunstone, R. (1997). The process of conceptual change in ‘Force and Motion’. ERIC Document, ED 407 259.

Tobin,K., Tippins, D. & Gallard, A. (1996). Research on instructional strategies for teaching science. In D. Gabel (Ed.). Handbook of research in science teaching and learning. (pp 45-93). New York: Macmillan.

Treagust, D.F. (1987) The development and use of diagnostic instruments to evaluate students’ misconceptions in science. International Journal of Science Education, 10, 159-169.

Treagust, D.F., Duit, R. & Fraser, B (Eds.). (1996). Improving teaching and learning in science and mathematics. New York: Teachers College Press.

Weller, H. (1996). Assessing the impact of computer-based learning in science. Journal of Research on Computing in Education. 28(4), 461-485.

White, R. & Gunstone, R. (1992). Probing understanding. London and New York: The Falmer Press.

Yeo, S., Loss, R., Zadnik, M., Harrison, A. & Treagust, D.F. (1998, April). What do students really learn from interactive multimedia? A physics case study. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching. San Diego.

Zollman, D. & Fuller, R. (1994). Teaching and learning physics with interactive video. Physics Today, 47, 41-47.

Acknowledgments

The guidance and advice (relating to Authorware programming issues) given by the New Technologies in Tertiary Teaching and Learning (NETTL) group at Sydney University during the development of the program during 1998 was most appreciated.