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ABSTRACT

From the theoretical reference frame of constructivism, much of the rhetoric and positive research findings in support of microprocessor based laboratory (MBL) activities facilitating science learning can be interpreted in terms of the increased opportunities for student-student interactions and peer group discussions about familiar and discrepant events in relation to ready-to-hand data. However, the rhetoric is not widely matched by practice. It is possible that teachers' failure to utilize MBL activities more widely is a result of not recognizing their capacity to transform the nature of laboratory activities to be more consistent with contemporary constructivist theories of learning. This research aimed to increase understanding of how MBL activities specifically designed to be consistent with a constructivist theory of learning support or constrain student construction of understanding. It was conducted in a Year 11 physics class, comprising 14 boys and 3 girls, taught by the first author. Seven activities relating to kinematics were prepared in predict-observe-explain format. Students worked in pairs in laboratory sessions that were part of the normal class program. Data sources included video and audio recordings of students and teacher during each laboratory session, computer records of all data sets recorded by students, students' written notes and reports, semi-structured interviews with selected students, and the teacher's reflections on each session. Analysis of students' discourse and actions revealed many instances where students' initial understanding of concepts of displacement, velocity and acceleration were challenged by the data presented on the computer screen, and their negotiation of new understanding was mediated in multiple and subtle ways by the computer display. Students invented numerous techniques for manipulating data in the service of their emerging understanding. Recommendations are made for development of appropriate pedagogical strategies incorporating MBL activities, which will likely catalyze student construction of understanding. (Contains 29 references.) (Author)

Microprocessor Based Laboratory Activities as Catalysts for Student Construction of Understanding in Physics ®

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Abstract

From the theoretical reference frame of constructivism, much of the rhetoric and positive research findings in support of microprocessor based laboratory (MBL) activities facilitating science learning can be interpreted in terms of the increased opportunities for student-student interactions and peer group discussions about familiar and discrepant events in relation to ready-to-hand data. However, the rhetoric is not widely matched by practice. It is possible that teachers' failure to utilise MBL activities more widely is a result of not recognising their capacity to transform the nature of laboratory activities to be more consistent with contemporary constructivist theories of learning. This research aimed to increase understanding of how MBL activities specifically designed to be consistent with a constructivist theory of learning support or constrain student construction of understanding. It was conducted in a Year 11 physics class, comprising 14 boys and 3 girls, taught by the first author. Seven activities relating to kinematics were prepared in predict-observe-explain format. Students worked in pairs in laboratory sessions that were part of the normal class program. Data sources included video and audio recordings of students and teacher

during each laboratory session, computer records of all data sets recorded by students, students' written notes and reports, semi-structured interviews with selected students, and the teacher's reflections on each session. Analysis of students' discourse and actions revealed many instances where students' initial understanding of concepts of displacement, velocity and acceleration were challenged by the data presented on the computer screen, and their negotiation of new understanding was mediated in multiple and subtle ways by the computer display. Students invented numerous techniques for manipulating data in the service of their emerging understanding. Recommendations are made for development of appropriate pedagogical strategies incorporating MBL activities which will likely catalyse student construction of understanding.

Two recent reviews of the use of educational technology in science education (Berger, Lu, Belzer, & Voss, 1994; Linn, 1998) make little reference to microprocessor based laboratory (MBL) activities, concentrating more on interactive videodisk, telecommunication, and hypermedia applications. This is somewhat surprising because for many years persistent claims about the potential of computers in science education have been made (Bigum, 1998; Nachmias & Linn, 1987; Thornton, 1987; Tinker, 1981; Weller, 1996) but the results of research into the effectiveness of computer based teaching strategies have been equivocal, especially in respect of science achievement (Berger et al., 1994; Dexter & Anderson, 1998; Thornton & Sokoloff, 1990). With particular reference to microprocessor based laboratory (MBL) activities, it has been claimed that their value lies in the ease with which data can be collected and stored, the ability to access data over very long or very short time intervals, and the power to process and display data rapidly, thus providing more time for students to manipulate variables, test hypotheses and explore relationships (Kelly & Crawford, 1996; Thornton, 1987; Tinker, 1981; Rogers, 1995).

Despite the rhetoric, the reality is that relatively few science teachers have adopted MBL methods. The only Australian study documenting use of MBL methods that we have identified (Russell, 1991) found that by 1989 only about 4% of science teachers in 44 Brisbane schools had used computers in laboratories. Furthermore, using on one or a few occasions does not necessarily result in a teacher incorporating computers into his/her normal teaching practice. For example, Clark and Jackson (1998) reported that time pressures and lack of computer training resulted in an enthusiastic teacher who collaborated with them in a MBL research study subsequently reverted to "his previous teaching philosophy and style." Similarly, the cooperating teacher in a study by Roth, Woszczyna and Smith (1996) found that the disadvantages in terms of learning to manage the computer software outweighed the advantages.

From the theoretical reference frame of constructivism (Appleton, 1997; Fensham, Gunstone, & White, 1994; Geelan, 1997), much of the rhetoric and positive research findings in support of MBL activities facilitating science learning can be interpreted in terms of the increased opportunities for student-student interactions and peer group discussions about familiar and discrepant events in relation to ready-to-hand data. However, there is convincing evidence that school science laboratory activities typically do not have this orientation (Woolnough, 1991; Nachmias & Linn, 1987; Tamir, 1991; Tobin, 1990; Wilkinson & Ward, 1997). It is possible that teachers' failure to utilise MBL activities more widely is a result of not recognising their capacity to transform the nature of laboratory activities to be more consistent with contemporary constructivist theories of learning. Even experienced science teachers who avow constructivism as a referent for their teaching and who are expert in computer applications may not capitalise effectively on MBL activities completed by their students in the normal course of instruction (Roth, McRobbie, Lucas, & Boutonne, 1997).

More than a decade ago, Nachmias and Linn (1987) pointed to the need for researchers to study how students construct understanding of physical phenomena in MBLs. Little progress has been made in this regard, leading Clark and Jackson (1998, p. 32) recently to re-iterate "we need to study how students make connections between MBL activities and the physical phenomena." Driver, Asoko, Leach and Scott (1995) argued "that the relationship between views of learning and pedagogy is problematic, and that no simple rules for pedagogical practice emerge from a constructivist view of learning." They conclude that one important role of the teacher is "to develop appropriate pedagogical practices which enable students to engage thoughtfully in class activities." When the activities are microprocessor based it is particularly difficult for the teacher to listen to students' conversations in order to diagnose how the computer mediated phenomena are being interpreted and then to respond appropriately. This hiatus provided the impetus for the research reported here, and also suggested the methodology adopted.

The research commences a larger study which aims to add to the fundamental understanding of how MBL activities support or constrain students' construction of understanding of physics concepts. Specifically, the aims of the research reported here were to document and interpret:

1. The patterns of interaction between experimental phenomena, computer display, collaborative student groups, individual students and their teacher;
2. The role of the computer in presenting information, engaging student collaboration, and mediating between experimental phenomena and student understanding of physics concepts.

Research design

Setting

The research was conducted in a large government high school in Brisbane, where the first author has used MBL activities in junior science and senior physics classes for about fourteen years. The school has an excellent reputation for academic, sporting and cultural achievement of students, a high proportion of senior students proceeding to tertiary studies. Ten computers equipped with MicroLab™ interfaces and supporting software are part of the normal equipment of the physics laboratory cum classroom in which the first author's Year 11 physics class was conducted. The room is relatively large and well equipped, with laboratory benches around the perimeter and desks and chairs centrally located in front of a raised demonstration bench and whiteboard. Two smaller preparation rooms are attached to the laboratory and one of these was utilised to provide a quieter location for one pair of students to carry out the MBL activities under conditions which would be conducive to audio recording.

Kinematics comprises part of the first term physics program in Year 11. The research was conducted during normal lessons. From the students' point of view, the only change from the established procedure for physics lessons was that there were two video cameras and several microphones evident and one extra person (the second author) was present in the room.

Participants

There were fourteen boys and three girls in the class, one of two Year 11 physics classes in the school. Prior to the commencement of the research, students had studied some elementary kinematics in their junior science classes, at which time they had sketched distance-time graphs and used formulae to solve simple problems involving distance and speed. They had not engaged in MBL activities relating to motion nor had they been introduced to the concepts of vectors or gradients.

Eight groups of students (seven pairs and one group of three) were engaged in the MBL activities. Donald and Martin (pseudonyms) were selected for more intense study than other students. Their selection was purposive. Although it is planned to extend the study to include more intensive study of multiple groups, in the early stage represented by the research reported here it was considered appropriate to focus on one group which was selected to be not atypical of others in the class and to comprise two students who were articulate and cooperative. Donald's grades in physics are average while Martin is a very capable physics student.

MBL activities in kinematics

The teacher had designed, constructed and progressively modified the interfaces and supporting software utilised in this research. This equipment has been used successfully in scores of schools over the past nine years. It is economical, easy to use, reliable, and features versatile data logging and graphing capability with sophisticated smoothing routines. Velocity-time and acceleration-time graphs are generated by successive differentiation of the relevant-displacement-time graph. Students can store graphs for retrieval at a later time, select segments of graphs for detailed examination, and print hardcopy or cut and paste into other applications such as a word processor.

In the first lesson, students familiarised themselves with the motion sensor, a small wheel on a handle which could be rolled back and forth along the bench to replicate various patterns of movement to be introduced in subsequent activities. They also practised collecting and displaying data generated by the sensor, displaying them as displacement-time graphs, and using the software functions to generate store and retrieve graphs of various kinds.

A series of seven laboratory tasks involving motion was prepared based on a predict-observe-explain (POE) format which is familiar to many science educators (White & Gunstone, 1992). Students were familiar with the POE strategy, having been required to use it to plan, execute and record physics activities earlier in the year. The utilisation of the POEs derived from the constructivist framework adopted by the teacher for his teaching and was consistent with the imperative, identified by Nachmias and Linn (1987), Driver et al (1995), and Clark and Jackson (1998), to understand how students construct understanding of physical phenomena in MBLs. An example of the POE activities is provided as Appendix 1.

Data sources

One video camera mounted in a corner of the laboratory provided a record of activities of students and the teacher, while a second video camera was employed in the smaller room while Donald and Martin were working there. Microphones enabled audio recordings to be made of their conversations, and of the teacher as he addressed the whole class and interacted with groups and individual students. The computer that Donald and Martin used was linked to the video recorder to provide a visual record of the screen display superimposed on the videorecording of the students engaged in the MBL activities. In addition, hard copies were made of all of the data sets generated in the MBL activities completed by Donald and Martin.

After each lesson, the teacher made notes of key events that had occurred, including issues that he thought required follow up in subsequent lessons or interviews with students. After the final lesson, photocopies were made of all students' POE notes.

Within one week of the conclusion of the series of three lessons on kinematics, the teacher conducted a semi-structured interview with Donald and Martin. Selected sections of the video and audio recordings of their MBL activities were replayed to the students who were then asked to clarify or elaborate their thoughts and actions as they collaborated to construct understanding of the concepts involved. Transcripts of the interview and the audio component of the recording of Donald and Martin were added to the substantial data base.

Data analysis

The data analysis sought to identify and interpret firstly the patterns of interaction between the students, computer display, experimental phenomena and the teacher, and secondly the role of the computer display in the processes of student collaboration and understanding of physics concepts.

Analysis initially focused on data relating to Donald and Martin. At the conclusion of each lesson, the audio recording was transcribed and each turn of speech was numbered consecutively. Annotations of students' gestures and activities were added to the transcript, as were the graphs generated during the MBL activities and saved by Donald and Martin in the computer for future reference. From these records, descriptions and tentative interpretations of students' actions during the MBLs were constructed by the researchers. These were then systematically tested by searching for confirming and disconfirming data in students' notes written during the lessons, the teacher's post lesson notes, and semi-structured interviews with Donald and Martin. The interviews also provided an opportunity to clarify aspects of students' interaction with the MBL equipment, and their joint construction of understanding of the physics involved in the MBL activities.

Finally, notes written by all students in the class during the MBL activities were examined to ascertain the extent to which there were similarities and differences between those of Donald and Martin. The video recordings from the camera located in the main laboratory provided confirmation that other groups engaged in the MBLs in similar fashion to Donald and Martin, although no audio recordings were made of other groups' activities.

Results

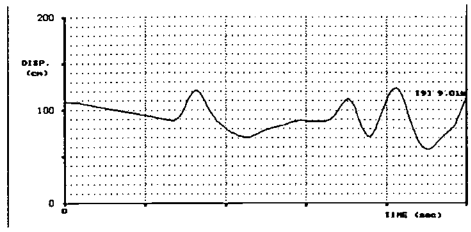
In this section a discussion of the activities of the dyad which comprised Donald and Martin are selected for closer study are presented first. The principal focus of all the findings is on this dyad. Following this some of the major findings are then elaborated in relation to the rest of the class.

Donald and Martin began each data collection task by reading carefully the POE motion problem. This they translated into a movement of the wheel, which they practised, while discussing the predicted graphical outcome. After collecting data, their observations, analysis and explanations centred around the monitor display. These patterns of interaction are illustrated in Figure 1.

INSERT FIGURE 1 HERE

To simplify the diagram both students are represented by the single term 'dyad'; however Donald and Martin acted both individually and in concert when referring to their task sheets, the keyboard, the hand-held wheel, and the monitor display. Donald initiated most conversations, while Martin's contributions were more considered and insightful. The teacher joined them periodically between sharing his time with other groups.

During the first of the three laboratory sessions both students developed what was to become a wide variety of techniques to help interpret and understand the computer generated graphs. For their first experiment with wheel sensor and graphic analysis, they recorded a random movement of the wheel back and forth on the bench over ten seconds. They visually divided the graph into smaller segments, and then replicated each section in turn with controlled, describable motion.



Martin: So we'll start analysing the first 2 seconds. Yeh it was moving slowly that way (pointing to graph). Moving slowly in a negative direction.

Donald: For 2 1/2 2 1/4 seconds (he writes "the first 2.3 seconds the wheel was moving slowly in a negative direction").

Between them they recreated each section, Martin using the technique of superimposing each new graph on the original. During this task both students continually gestured towards and touched the screen, estimated values and slopes, and related forward and backward motion of the wheel on the bench to positive (up) and negative (down) directions on the graph's displacement axis. The teacher joined them and showed an interest in what they had learned thus far.

Teacher: What happens when it goes FAST forward?

Martin: You get a sharp slope like that (showing part of the graph on the screen) . . . it would be a much steeper angle.

Both students were able to explain to the teacher and write a lucid description of the graph in their POE notes in terms of fast and slow, positive and negative displacements.

The second task required they predict the displacement graph: "A person walks at steady speed down the road for 4 seconds, stops for 4 seconds, then returns back to the start in 2 seconds."

Martin: You'll want to start there (touching screen at lower left hand corner as origin).

Donald: Yeah it'll be a slow even up (hand rising in a slant) and then a pretty much dead down (hand drops vertically sharply).

Here Donald confused the "stops for 4 seconds", which should be a horizontal displacement line, with velocity dropping to zero. As with future occasions, Martin reserved his opinion on Donald's answer, and practised moving the wheel before generating the required graph. Both students viewed the graph silently for some time. Donald sketched the graph in his POE notes and wrote "Slow increase for 4, stop for 4, medium decrease for 2", contrasting with his initial response. His later written notes and descriptions of graphs showed progressively a more canonical use of scientific terms; by the third day he wrote of another graph: "the relevant section of the graph shows a constant increasing gradient (parabola)."

The next task generated a lengthy discussion: "A cricket batsman hits the ball and scores two runs. Study the motion of the batsman." Martin initially drew a 'double hump' displacement graph, which would have in fact described four runs. He appeared to be influenced by Donald, who traced his hand up and down against the blank screen to predict the graph for the first run, "and then we'll have to do it again" for the second run. (The students had actually traced out a speed-time graph). Martin voiced second thoughts. The transcript reads:

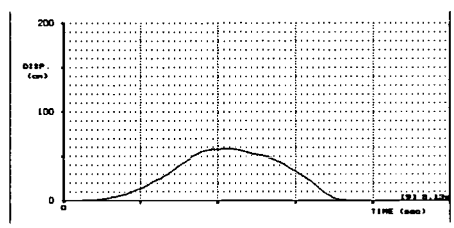
Donald: Yeah but he does two runs (they check their POE sheets). (The two students think, mumbling for about 8 seconds, looking at the blank screen graph. Martin describes what to expect by tracing out ONE 'hump' corresponding to two runs. Donald seems to accept the point).

At this juncture the teacher joined the discussion, directing it to associating curved displacement graphs with acceleration and deceleration. He suggested they break their predictive 'double hump' graph into segments and analyse each section. After he left, both students applied these ideas to their prediction.

Donald: Well we'll only need that bit (pointing to the first 'hump' in the displacement graph).

Martin: And we'll just (?) that again (pointing to the second hump).

Donald: Yeah but that's all . . . because see that's one run (Martin: = Oh yeh) two runs. I didn't realise that till afterwards. Otherwise we do it like (he draws a single hump graph on own POE sheet and shows Martin).



Martin crossed out the second hump on his POE notes (as shown in the freehand sketch above), while Donald created a screen graph using the wheel.

During the second lesson the dyad returned to the same graph for a velocity-time analysis (shown at turn 370 below). Beneath the original displacement graph is the corresponding velocity-time graph, with some letters added to assist the analysis. The turns of speech are numbered as in the original transcription.

369 Martin: Is that the batsman?

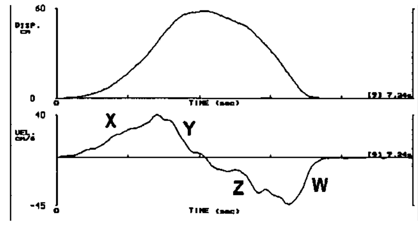
370 Donald: Yep. That's about right because it should be full speed to there, then it should slow down quicker . .

371 Martin: (touching the screen **v-t** graph) Accelerating **[x]** . . decelerating **[y]** .

372 Donald: Accelerating again **[z]**

373 Martin: Still decelerating **[z]** . . . (Donald disagrees with Martin's claim that section **z** is decelerating)

374 Donald: Well I guess you could also go like that (he flips his hand over at the mid-point of the **v-t** graph) . . . I don't know if I'm making it any easier. Because the batsman actually turns around so it would be accelerating

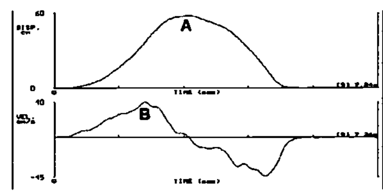


Donald immediately identified the display (turn of speech 370) not from the displacement graph (which differed in scale from the original graph), but from the previously unseen velocity graph, stating that the features at **x** and **y** matched the first run of the batsman. Martin (turn 371) correctly described these two motions as accelerating and decelerating. Donald (turn 372) ignored the sign convention and described section **z** as 'accelerating again', which he later defended (turn 374) by saying "because the batsman actually turns around so it would be accelerating." Martin (turn 373) more precisely said the section **z** "is still decelerating." Then Donald (turn 374) held his hand against the screen at the midpoint to fold the right half over the left hand half to explain his viewpoint. Martin (turn 375) demonstrated with his hand on the screen how to 'flip' the **z-w** section about the horizontal axis, showing the return run mimics the **x-y** section from the first run.

Donald continued to misread graph features as he alternated between reading the screen and writing his POE notes.

377 Martin: Yep (both write notes) Maximum displacement . . .

378 Donald: (checking screen) Would be at 3 and . . . (he looked at the wrong graph [**B** on the velocity graph], and was corrected by Martin).



379 Martin: Maximum displacement is furthest from the origin . . . so it'll be here [at] (touching the peak of displacement graph).

380 Donald: Yeah . . . Yeah that's about right, about 4 (writes notes).

Donald not only misread velocity for displacement, he confused the gradient (representing acceleration and deceleration) with the maximum value on the velocity graph.

381 Martin: Maximum velocity would be . . .

382 Donald: (turning to screen) Between 3 and 4 [**y**], and . . . ah . . . 6 1/2 to 7 1/2 [**w**].

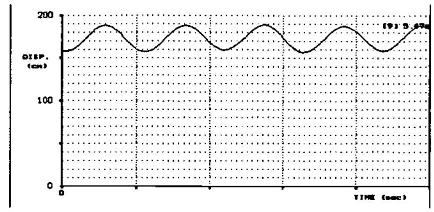
383 Martin: You'd be at 3 [between **x** and **y**] for maximum velocity (touching screen).

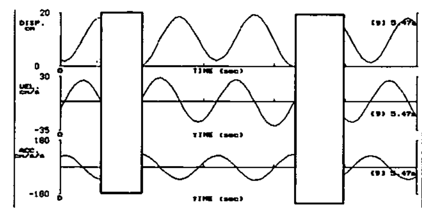
384 Donald: Yeah, but you still have that maximum velocity for (his hand moves down section **y**)

385 Martin: No that's decelerating (tracing over same section **y**).

396 Donald: Oh yeah. 3 and 6 I think we have . (writes notes)

New insights and adjustments in understanding were mediated frequently by students' recourse to the monitor display, using a variety of techniques. On one occasion Michael held his pencil horizontally alongside the graph to contrast with Donald's slanted pencil in clarifying a point. As the students examined a precise acceleration graph on day 3, Martin recalled a misleading conclusion from a less accurate graph on day 2. Sections of some graphs were cut and enlarged, such as the portion of a graph representing pendulum motion that had been generated by attaching a physical pendulum to a sensor wheel. The students were searching for an example of a body (a) stationary yet accelerating, and (b) accelerating in a direction opposite to its motion. They switched to a screen which displayed displacement, velocity and acceleration curves. Immediately Martin held a vertical sheet of paper against the screen to compare values at the same time.





Donald: Yep. (He also holds up a sheet of paper and does the same, checking four vertical alignments). Again . . and again . . OK. (Both turn to make notes). Well that proves that one then.

That proves BOTH.

Martin:

Donald: Does it?

Martin: Yep. (both holding up POE sheets). Zero velocity, acceleration (both turn to screen again).

The transcripts revealed how students used numerical techniques such as calculating areas under curves and averages, estimating and approximating. They made allowance for human error in generating data, looked for trends in the shape of curves, and learned to judge how closely the computer generated graphs measured up to the written description of motion found in the tasks.

The video recording showed that both students wrote their POE notes independently, as they interchanged comments and made frequent references to the monitor. During the first lesson their observations and explanations were remarkably similar, although Donald tended to describe the graphs as they appeared on the monitor (as a "series of sharp ascent/sharp descent"), whereas Martin described the graphs in terms of the wheel's motion on the bench (a "fast series of positive and negative displacements"). By the third lesson Donald and Martin were writing POE notes that quite differed in presentation, yet agreed in interpretation. In contrast with Donald's earlier word choice, his later notes reflected a more formal use of kinematics terminology.

The POE notes were consistent with the transcripts taken from the video and audio recordings. For example their referring to a less-than-constant velocity graph in Task 3 as "subject to experimental error" was reflected in their written notes (Donald: "we took the average line or line of best fit"; Martin: "ours went up and down (human error), but would average out at around the right amount").

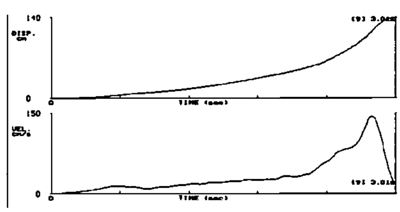
The POE notes both supported and extended the understanding of the transcripts. During Task 5 both students had some difficulty in moving the wheel so as to create the shape of graph they expected based on their prediction. On the third attempt they succeeded, as shown on the right. One essential feature of this graph was that the gradients on either side of the peak should be equal in magnitude. Martin's POE notes reflected one criterion by which he was judging the screen-generated graph: namely, that the angles (as shown in his notes) should be equal. As he later said to Donald, "Both of these angles should be the same."

The dialogue between Donald and Martin suggested that they both developed an agreed canonical interpretation and understanding of motion graphs. The analysis is well summarised thus:

- the MBL provided opportunities for student-student interactions, and supported student construction of understanding of kinematics graphs and concepts;
- the dyad used a variety of techniques to make meaning of the graphs, such as
- using feedback from a graph to repeat experiments and generate new graphs,
- pointing to, gesturing, touching, and writing on the monitor screen,
- enlarging, superimposing, and comparing multiple graphs, and
- applying quantitative analysis and approximations;
- the students' initial understanding of kinematics concepts was often challenged by data presented on the screen, and their negotiation of new meaning was mediated in a variety of ways by the computer display:
- the visual patterns conveyed meanings (positive/negative values, rising/falling curves, fast/slow motion, increasing/decreasing values),
- the sequence of lessons developed concepts progressively (from displacement through velocity to acceleration), often presenting the same ideas from multiple perspectives,
- the display helped draw out and reveal students' thoughts, facilitated their thinking, and structured their conversation,
- the display effectively directed and corrected students by reason of its visual and textual messages,
- the monitor made the phenomenal (physical motion of the wheel) concrete (in the form of an electronic display), a reality, an unquestioned authority to which reference and appeal was made,
- the display provided a memory aid, a constant reminder, of the 'frozen' results of an earlier experiment.

The semi-structured interview of Donald and Martin one week after the final MBL activity supported a number of these conclusions, as they expressed their perspectives of MBL activities and how their concepts of kinematics developed.

Both students' initial understanding of acceleration graphs underwent a number of changes during the three lessons, as had been observed by the teacher. During the second lesson the students had tried to generate a displacement curve (the upper graph on the right) showing constant acceleration.



Teacher: On one occasion you had a displacement-time graph that was curved upwards like that [right, top], and when you did your velocity graph [right, lower] it was also curved upwards. . . How would you interpret those two now?

Donald: It was an irregular acceleration.

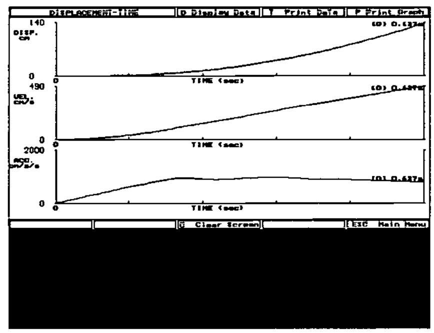
Teacher: You come you know that?

Donald: Because if the velocity is constantly increasing . . . uhm . . . sorry - if the velocity-time graph is a curve it means the acceleration is changing.

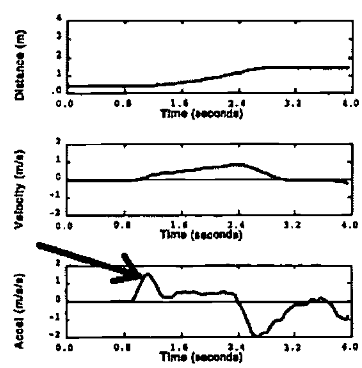
Teacher: Yes right. So looking at this velocity graph [the lower graph], which part was probably fairyl constant acceleration?

Donald This part of the curve from there to there [he points to the first two-thirds of the lower graph, a **v-t** graph).

Donald explained his present understanding, which had been clarified during the third lesson after he and Martin created a more accurate graph (shown right).



The teacher then showed the students a similar graph (from Kelly and Crawford, 1997, p.546) created by students studying the motion of a trolley accelerating down a ramp. The arrow (added for this discussion) pointed to an unexplained irregularity in the acceleration graph, a feature which had provoked considerable interest in the original study as to its cause. Donald and Martin were asked what they thought could have caused the irregularity.



Donald: . . . It's just . . . the initial start

Martin: Umm . . I think someone could have . . given it a little bit of a push or something . . . when it initially it took off it took of it started with a jerk like it accelerated really fast for a split second . . .

At the start of the first lesson following the interview Martin approached the teacher and suggested a second possibility, that the trolley's back wheel had been 'chocked' with a piece of wood. When pulled over the chock, the trolley had a larger initial acceleration, which would explain the bump. Martin's explanation reflected considerable insight into the meaning of the graph, and a singular cognitive engagement with the earlier MBL activities.

The student interview confirmed that MBL methods and the monitor display promoted student engagement with the tasks and "prevented boredom." Some of their comments were: "It helped us to understand how the graphs were connected . . . the relationships between them"; "the motions come up instantly . . instead of having to go back and draw it, and it converts the graphs easier - one to the other, like displacement times the velocity times the acceleration"; "you don't have to draw 50 000 graphs by hand . . it keeps the flow of the experiment going so you don't get distracted."

Teacher: After the third lesson I did a brief summary in class [of the displacement, velocity and acceleration graphs]. Before I went over those how much understanding of that would you have gleaned from the first day?

Donald: We'd made all the connections between the graphs.

Teacher: How about the acceleration one?

Donald: Ah . . . it took us a bit longer to get those but we did end up getting them out.

The teacher's observation notes recorded that the students had minimal difficulties using the MBL equipment to conduct experiments. Their management of the software was unproblematic. Not all of the tasks involved kinesthetic actions (moving the wheel), or real-time graphing (creating displacement graphs), features previously associated with the instructional benefits of MBL methods (Brasell, 1987; Beichner, 1990). Many tasks involved recalling previous data for display. Nevertheless during these tasks the level of social and intellectual involvement appeared to be equally engaging.

An analysis of the POE notes from the other seven dyads in the main classroom showed that four of the dyads created and recorded experimental data after the same manner as Donald and Martin. Their initial predictions and observations were couched in similar phrasing, showing direct collusion in writing notes. As the tasks became more complex, individual students showed more divergent written commentary. The confusion of graph features made by Donald appeared also in many other POE notes. In the case of the remaining three dyads their POE notes were less complete, and fewer complex tasks were attempted. All of these students were placed in the lower half of class achievement in the weeks following this research. The purposive selection of Donald and Martin was based on a judgment that they were not atypical, and the similarity in POE notes from other groups supported this assumption. However, the finding that those groups which produced the least complete POE notes, with evidence of numerous errors, were comprised of lower achieving students suggests the need for further research.

Discussion

The research reported here set out to address a perceived need to know more about how students relate MBL activities to physical phenomena with a view to eventual provision of what Driver et al. (1995) termed "simple rules for pedagogical practice" consistent with a constructivist view of learning. Central to the research was the application of the POE strategies, an approach different in some important respects from the teacher centred, confirmatory and, in relation to MBL technology, tentative approach of the chemistry teacher described by McRobbie and Thomas (1998). The teacher and students involved in the present study had moved beyond concern about the implementation of MBL technology. Furthermore, the teacher's justification for using MBL activities was not to confirm what the students had already learnt in class, but rather to challenge students' existing conceptions of kinematics and provide opportunities for them to build scientifically acceptable understandings collaboratively, based on empirical data.

Although essentially limited to a study of two students within a fairly typical senior physics class, this research provides encouragement for teachers who wish to realise some of the frequently promoted benefits of MBLs. It suggests that linking the familiar strategy of Predict-Observe-Explain with the technological capacity of sensors and computers enables students to address their own understandings in effective ways. It needs to be emphasised that this outcome has not always been reported when science teachers utilise MBL activities. What may have made the difference in this study is the teacher's adoption of a constructivist theory of learning as a frame of reference for his teaching which was given expression in a series of appropriate POE activities. The research provides some insight into the ways in which students engaged with these activities and the data they yielded to construct and reconstruct personal and shared understanding.

Figure 1 describes three stages characteristic of Donald and Martin's involvement in the MBL activities. In the first, Understanding the Task, the POE task focused the students' attention on the relationship between the physical system (sensor wheel in various configurations) and their conceptual understanding. In the second stage, Collecting Data, the students' focus moved to the monitor and the data displayed as the experimental apparatus was manipulated. It is important to note that the students' actions in stage 2 were purposeful in that they were directed to testing their prior predictions based on current understanding. Thus, the data collection went through multiple cycles until the students were satisfied that the display bore a clear relationship with the physical data.

The third stage, Analysing and Explaining, was typified by a three-way interaction between the two students and the computer monitor, similar to the mediated collaboration and reflective collaboration interactions described by Lidstone and Lucas (1998) in relation to students' engagement with a multimedia program.

There remain many questions to be answered concerning the optimal uses of MBLs in science classrooms. However, this research suggests that an effective way of catalysing student construction of understanding may be to link the power and flexibility MBL technology with established teaching strategies based on constructivist theories of learning.

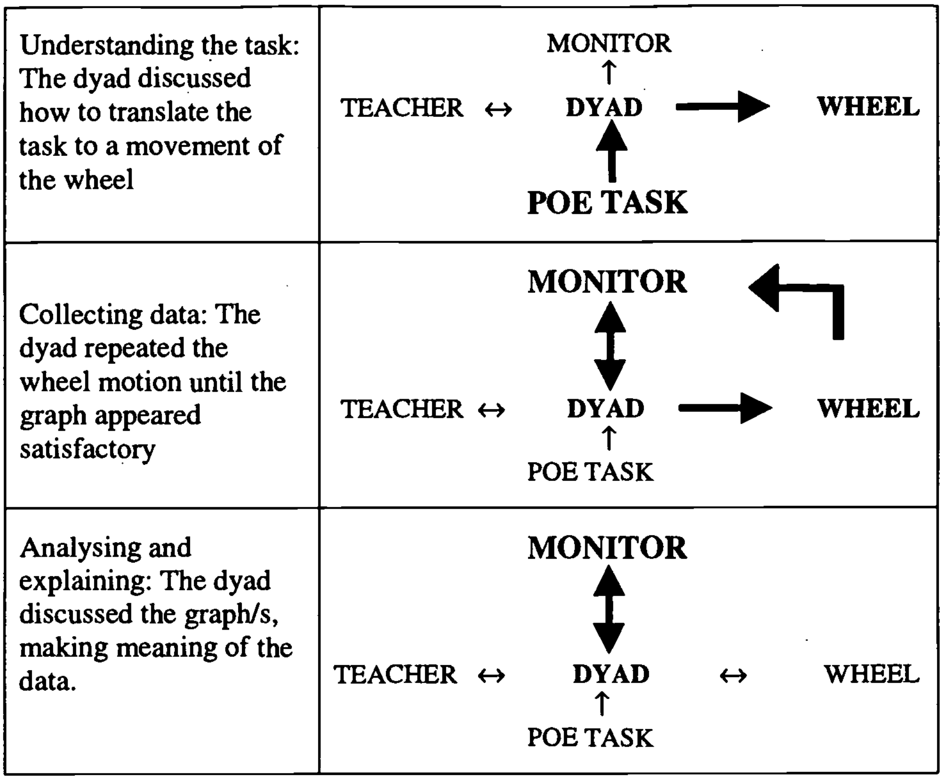


Figure 1: As each task proceeded, the patterns and emphasis of interactions changed, as shown by the intensity of typeface and arrow. The dominant interactions involved the triad of Donald, Martin, and the monitor display.

Appendix 1. One of the POE tasks used in the MBL activities

Name:

REMEMBER, please

1. Work together and take time to discuss your views
2. Meticulously write down your Predictions, Observations, and Explanations. For each experiment, complete the sequence

   Prediction: .....

   Observation: ....

   Explanation: .....

3. Sketch graphs of your predictions and observations to support your written words
4. Use correct scientific terms where possible in both speech and writing
5. Use extra sheets of A4, and number the pages.

MOTION AND DISPLACEMENT GRAPHS

TASK 2

You can move the wheel by hand to imitate the following actions, treating each as a straight line (linear) motion.

In every case **Predict** the displacement graph you would expect, move the wheel to imitate the motion and record your **Observation**. Then **Explain** the outcome.

1. A person walks at steady speed down the road for four seconds, stops for four seconds, then returns back to the start in two seconds.
2. A cricket batsman hits the ball and scores two runs. Study the motion of the batsman.
3. A car is stationary. It then starts when the light turns green and accelerates to the speed limit. It slows when approaching a red light, then stops.
4. A cyclist starts from rest and cycles up a steep hill. He pauses for breath, then coasts down the other side of the hill.
5. Describe a motion story of your own.

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