Can a Combination of Hands-on Experiments and Computers Facilitate Better Learning in Mechanics?

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Abstract

Microcomputer-Based Laboratories (MBL) have been successfully used to promote conceptual growth in mechanics understanding among preservice teachers and engineering students. In MBL laboratories students do real hands-on experiments where real-time display of the experimental results facilitates conceptual growth. Thus students can immediately compare their predictions with the outcome of an experiment, and students' alternative conceptions can thus successfully be addressed. We also report from a case where only MBL-technology was implemented, but the students were not asked to make predictions. As a result "misconceptions" were not confronted and conceptual change was not achieved among "weak" students.

Introduction

Acquiring a conceptual understanding of mechanics has proven to be one of the most difficult challenges faced by students (for a good overview see McDermott 1998). Studies by many different researchers have shown that misleading conceptions of the nature of force and motion, which many students have, are extremely hard to overcome. These strong beliefs and intuitions about common physical phenomena are derived from personal experience and affect students' interpretation of the material presented in a physics course. Research has shown that traditional instruction does very little to change students' "common-sense" beliefs (see for example McDermott 1998; Hestenes et al. 1992; Hake 1997; Bernhard 2000a).

For some decades sensors attached to a computer have been used in most experimental physics research laboratories. The attachment of a sensor to a computer creates a very powerful system for the collection, analysis and display of experimental data. In this paper I report on cases where hands-on experiments have been combined with a microcomputer-based system for the collection and display of experimental data. This MBL concept has proved to be a very powerful educational tool.

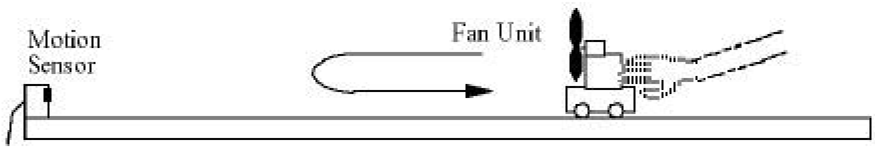

Figure 1. Typical setup of a MBL-experiment. A low-friction cart is pushed towards a motion sensor. A fan unit attached to the cart provides an approximately constant force in a direction opposite to the initial movement and the cart will thus change its direction of motion. The results are shown in Figure 2. Note that the fan unit provides a visible force.

In an MBL laboratory students do *real* experiments, not simulated ones, using different sensors (force, motion, temperature, light, sound, EKG ...) connected to a computer via an interface. One of the main educational advantages of using MBL is the real-time display of experimental results and graphs thus facilitating direct connection between the real experiment and the abstract representation. Because data are quickly taken and displayed, students can easily examine the consequences of a large number of changes in experimental conditions during a short period of time. The students spend a large portion of their laboratory time observing physical phenomena and interpreting, discussing and analysing data with their peers. The MBL context adds capacity and flexibility that, to be exploited requires the laboratory to be reconceptualised, giving students more opportunity to explore and learn through investigations (Tinker 1996; Thornton 1997b). This makes it possible to develop new types of laboratory experiments designed to facilitate better student learning and to use laboratories to address common preconceptions. *To take full advantage of MBL the educational implementation is important, not the technology! Active engagement is important!*

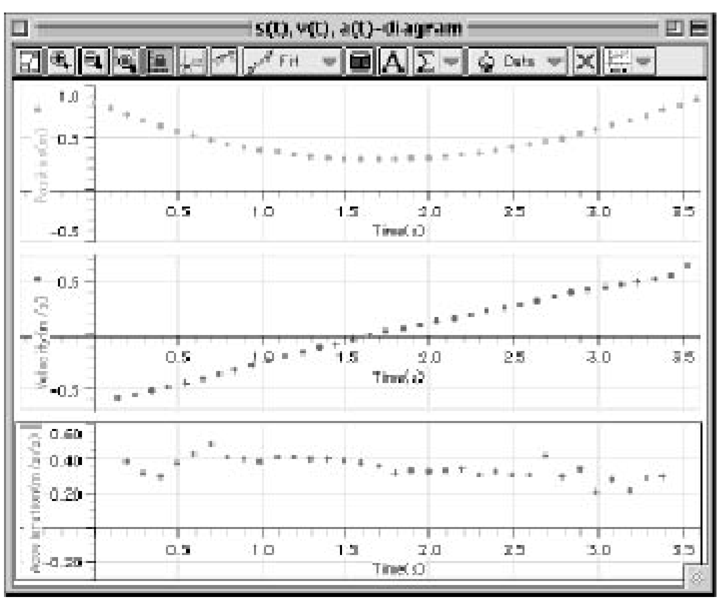

Figure 2. Results of the MBL laboratory shown in Figure 1. The position, velocity and acceleration as functions of time are displayed. A common misconception is that the cart has zero acceleration at the turning point. Another common misconception is that the

acceleration is in the direction of motion (see the poor results on the pre-test for "coin acceleration" in Figure 4). By asking the students to make a prediction and sketch the *s(t)*, *v(t)* and *a(t)* graphs *before* the experiment and by the rapid display of the experimental results these misconceptions can effectively be addressed.

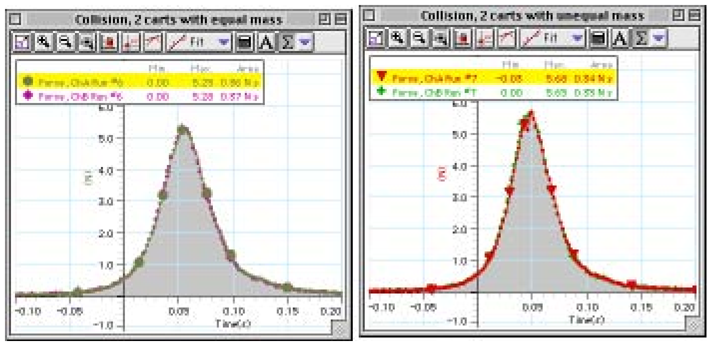

Figure 3. Results from an MBL-experiment with two colliding carts with equal and unequal masses respectively. Force sensors are mounted on top of each cart. The graphs show the forces measured by the sensors during the collision and the area below curves. Note the time scale. Most students are surprised to discover that the forces are equal when the carts have different masses (see "3rd collision" pre-test in Figure 4).

Implementation of MBL laboratories

The physics department at Högskolan Dalarna started using MBL in 1994/95. Laboratories using MBL-technology have been introduced in most physics courses. Below will be described the results of implementations of MBL in "active engagement" mode (Cases 1 and 2) and in mainly "formula verification" mode (Cases 3 and 4).

Cases 1 and 2

Case 1: An early implementation of MBL laboratories (Preservice teachers 1995/96) in a course for preservice science teachers (preparing for teaching grades 4-9 in Swedish schools). *Case 2*: A full implementation of MBL laboratories (Mechanics I 1997/98 for Engineering students) and some other reforms (see Table 1). This curricular reform also included changes to the advanced mechanics course (Mechanics II). The reformed advanced mechanics course is described elsewhere (Bernhard 1998, 1999). In both cases 1 and 2 there were about 40 students in the course.

The educational approach (Bernhard 2000b) taken in both cases was inspired by, but not identical to, the approach taken by Sokoloff et al. (1998) in *RealTime Physics* (see also Thornton 1997b, and references therein) and in case 2 also by the "New Mechanics" paper by Laws (1997). Laboratories were written in Swedish by the author.

- In both cases MBLs were used in an active engagement mode and the laboratories emphasised concepts and connections between different concepts.

- Case 1 had an early version of MBL laboratories and no laboratory on Newton's 3rd law.
- Cooperation was encouraged.
- Students preconceptions were addressed by asking the students to make predictions of the outcomes of all experiments (*elicit* [*student ideas*] - confront - resolve).
- After making predictions, the students performed the experiment and compared the outcome with the prediction (elicit - *confront* - *resolve*) and discussed the result. At this point the rapid display of the results by the computer in graphical form is of crucial educational value.
- Each laboratory group of 2-3 students was asked to submit a written report from each laboratory. This reinforces and strengthens student understanding, since they have to describe the laboratory in their own words.

Case 3: Preservice teachers 1998/99

(~ 30 students)

- MBL-technology was used in the laboratories.
- The original laboratories were transformed into formula verification laboratories and the number of laboratories was reduced for economical reasons.
- The students were not usually asked to do predictions.
- No laboratory on kinematics.

Case 4: Preservice teachers 1999/2000

(~ 25 students)

- Similar to case 3.
- The Newton's 3rd law laboratory was changed from "formula verification" to "active engagement".

Motion	This laboratory introduces kinematics concepts using MBL and also uses the tutorial software *Graphs and Tracks I & II*.
Analysis of motion using *Videopoint*	Introduces two dimensional kinematics using *Videopoint*.
Force and motion I & Force and motion II	The force and motion laboratories use MBL-equipment to study dynamics (Newton's 1st and 2nd laws). Cases with friction and friction free cases are studied.
Ballistic pendulum	A ballistic pendulum is used to determine the muzzle speed of a ball fired by a projectile launcher. This is an "open" laboratory where the students are required to deduce necessary equations

	themselves.
Impulse and collisions	This laboratory uses the new PASCO force sensor to measure forces during collisions (Newton's 3rd law) and to experimentally study the impulse - momentum law.
Moment of inertia	This laboratory uses the rotary motion sensor to study rotary motion, moments of inertia and oscillatory motion (ideal and physical pendulums). To study physical pendulums and the parallel axis theorem (Steiner's theorem) we used equipment which was designed and manufactured at Högskolan Dalarna together with the rotary motion sensor.

Table 1. Laboratories (4 hours) used in the Mechanics I course in 1997/98.

Evaluation instruments

The *Force Concept Inventory* (FCI) developed by Hestenes et al. (1992) and the *Force and Motion Conceptual Evaluation* (FMCE) developed by Thornton and Sokoloff (1998) were used as instruments for evaluating students' conceptual understanding. The data from the FMCE-test were analysed using the *Conceptual Dynamics* method developed by Thornton (1997a). Using this method, student views (for example force-follows-velocity view or physics view) can be assigned.

Results

Cases 1 and 2

As can be seen in Tables 2 and 3 and in Figures 4 and 5 the students in cases 1 and 2 have gained a much better conceptual understanding of mechanics than students in traditionally taught courses. A high fraction of the students have acquired a Newtonian view and a low fraction of students hold a force-follows-velocity view after instruction. The students in Mechanics I (case 2) performed significantly better on traditional problems in the final examination, than the students did in earlier similar courses.

In this course male and female students also had the same normalised gains.

Course	Year	Main student body	Method	Pre-test average	Post-test average	Gain (G)	Normalised gain (g)
Preservice	95/96	Preservice science teachers (grades 4-9)	early MBL	50%	71%	21%	42%

Mechanics I	97/98	Engineering	Full MBL +	51%	73%	22%	45%
Preservice	98/99	Preservice science teachers (grades 4-9)	MBL-technology Formula verification	49%	65%	16%	31%
Preservice	99/00	Preservice science teachers (grades 4-9)	MBL-technology Some MBL pedagogy	35%	67%	32%	49%
Traditional	97/98	Engineering	Traditional	50%	58%	8%	16%

Table 2. Results of pre- and post-testing using *Force Concept Inventory* (Hestenes et al. 1992) on different student groups.
Gain (G) = post-test - pre-test. Normalised gain (g) = gain / (maximum possible gain) (Hake 1997).

Course	**Year**	**Main student body**	**Method**	**Pre-test average**	**Post-test average**	**Gain (G)**	**Normalised gain (g)**
Mechanics I	97/98	Engineering	Full MBL +	29%	72%	43%	61%
Preservice	98/99	Preservice science teachers (grades 4-9)	MBL-technology Formula verification	33%	53%	20%	30%
Preservice	99/00	Preservice science teachers (grades 4-9)	MBL-technology Some MBL pedagogy	27%	62%	35%	48%

Table 3. Results of pre- and post-testing using *Force and Motion Conceptual Evaluation* (Thornton and Sokoloff 1998) on different student groups. Gain and Normalised gain defined as above.

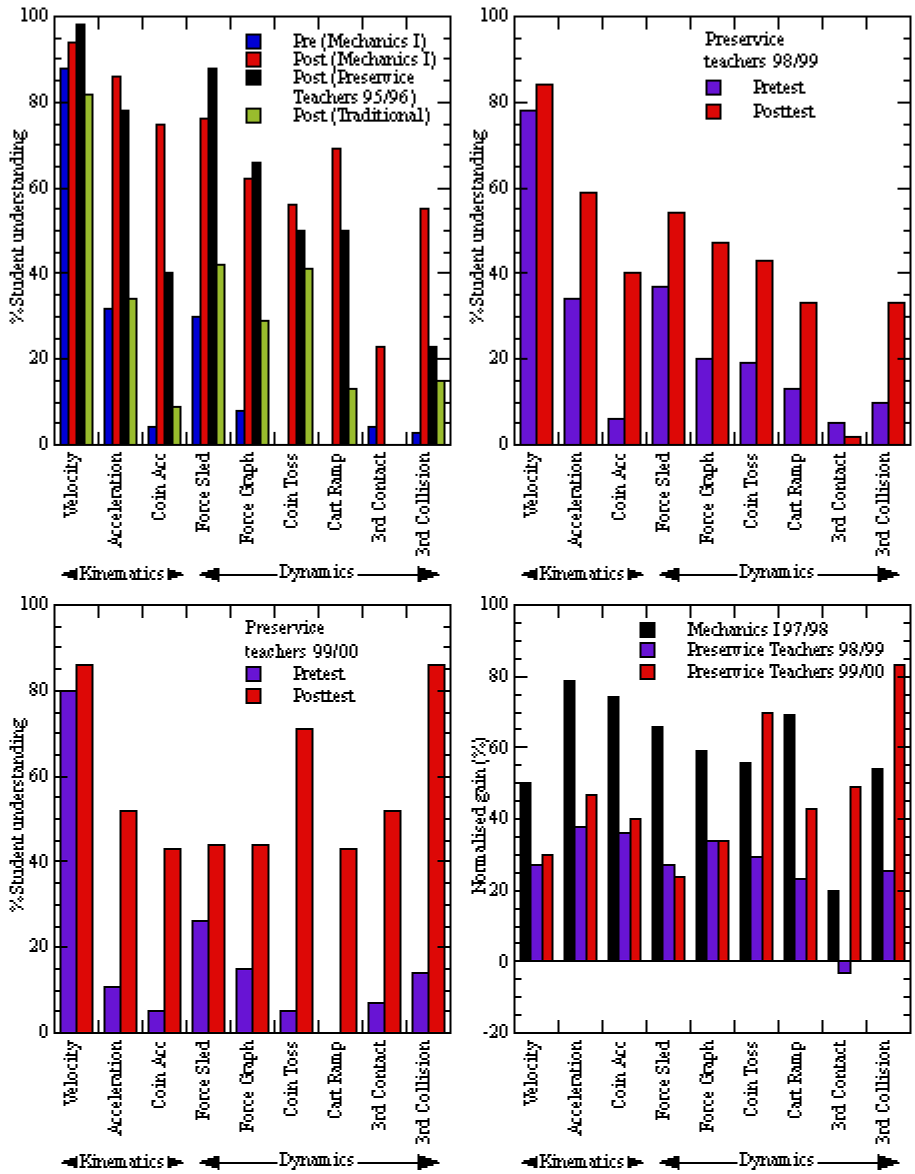

Figure 4. Conceptual understanding in mechanics as measured by the FMCE-test.

Case 3

The students in case 3 did not perform as well as in cases 1 and 2, but somewhat better than students in traditionally taught courses did. As can be seen in Figure 5 almost the same fraction of students hold the force-follows-velocity view after instruction as before instruction. By eliminating the active engagement part from the laboratories the preconceptions of the students believing in this view were not reached.

There were also large differences in gains between male (higher gain) and female (lower gain) students. A higher fraction of female students believed in a force-follows-velocity view after the course than before instruction!

Case 4

The students in case 4 performed similarly to the students in case 3, except for a much better performance in the Newton's 3rd law conceptual areas (see Figure 6 below). The difference in gains between male and female students was smaller than in case 3.

Discussion and conclusions

Microcomputer-Based Laboratories (MBL) in an active engagement approach is proven to be an effective way of fostering conceptual change in mechanics. The conceptual understanding is long-lived (Bernhard 2000c). MBL is good both for preservice teachers and engineering students. The combination of hands-on experiments and the microcomputer-based measurement system is a very powerful educational tool and according to Euler and Müller (1999) one of the few educational approaches in physics using computers which is reported to have positive effects on student learning. Students need to make use of as many senses as possible in their meaning making and thus approaches which make use of both hands-on and high-technology tools seem to be very effective (see also Otero 2000). In a well implemented MBL-approach MBL is used as a technological tool and a cognitive tool.

However the MBL-approach can be misunderstood and implemented as a technology only approach. When implemented without sound pedagogy, MBL is only marginally better than "traditional" teaching. Pedagogy is more important than technology! The personal preconceptions students hold before instruction *must* be addressed in some way during a course. Asking students to make predictions before an experiment is done is one way to both confront "misconceptions" and to reinforce scientific views.

It is also very important to focus on the teacher's pedagogical views since they can distort/destroy the implementation of an educational approach (see also for example Sassi 2000). Probably it is as difficult to change a teacher's view/conception of teaching, as it is to change a student's view/conception of the world.

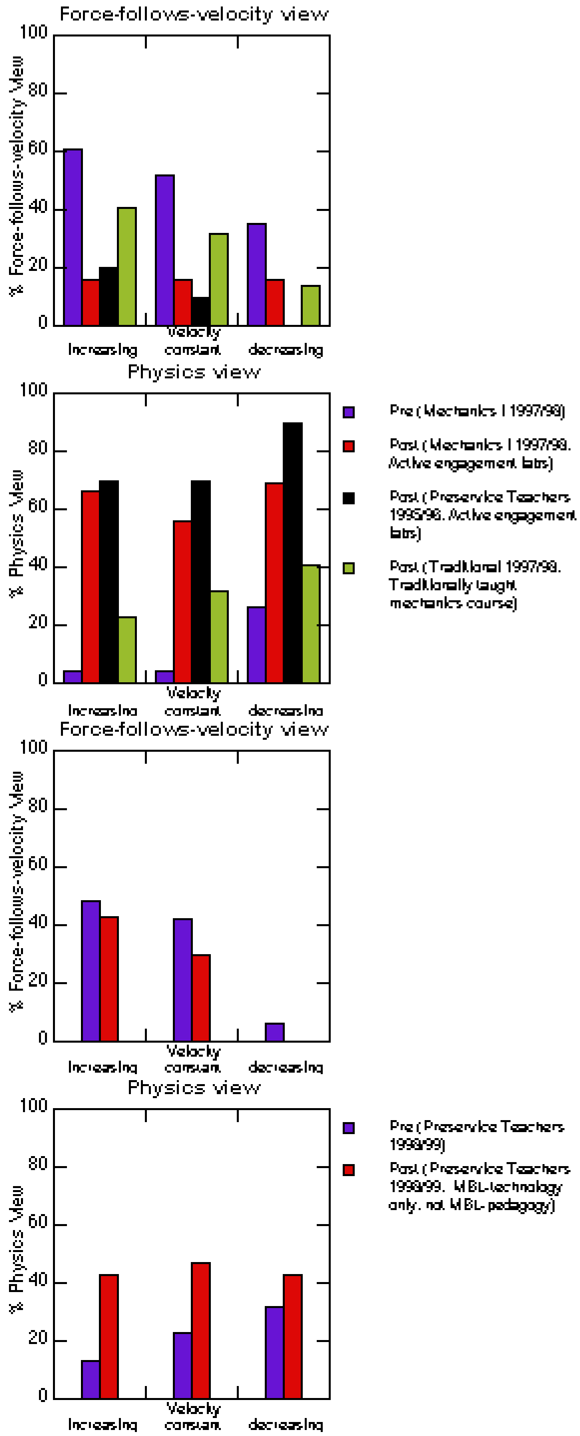

Figure 5. Fraction of students holding a "physics" and a "force-follows-velocity" view extracted from FMCE-test data using the Conceptual Dynamics Method.

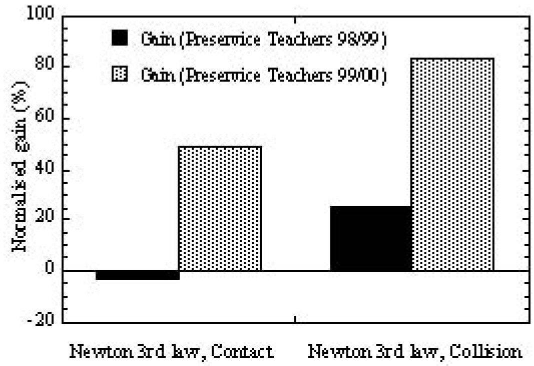

Figure 6. A comparison of Newton's 3rd law data from the FMCE-test for Preservice Teachers 98/99 and 99/00. Both groups had a laboratory dealing with Newton's 3rd law of the same length and with the same MBL-equipment. However the laboratory used by Preservice Teachers 98/99 was a formula verification laboratory and the 99/00 group "active engagement".

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