Physics Learning and Microcomputer Based Laboratory (MBL) — Learning effects of using MBL as a technological and as a cognitive tool[*]

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Physics Learning and Microcomputer Based Laboratory (MBL) — Learning effects of using MBL as a technological and as a cognitive tool[*]

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Different cases of physics instructor's implementations of Microcomputer Based Laboratory (MBL) in physics teaching have been studied. When implemented as a technological tool only poor learning results were observed while when MBL were used as both a technological and cognitive tool good learning results were observed. New technology thus does not necessarily lead to better learning. When developing and implementing computer aided learning we must focus as much on the cognitive aspects as on the technological aspects. Also we must focus on instructor's conceptions of teaching and learning since this affects their understanding of curricular reforms and lead to transformations of original developers educational intentions.

1. Background, Aims and Framework

Microcomputer Based Laboratory (MBL) was introduced into physics teaching more than one decade ago (Tinker 1996). An attachment of a sensor to a computer creates a very powerful system for collection, analysis and display of experimental data. Today several systems, specially developed for schools and undergraduate courses, are commercially available for different computer platforms. In a Microcomputer Based Laboratory (MBL-lab) students do *real* experiments, not simulated ones, using different sensors (force, motion, temperature, light, sound, EKG…) connected to a computer via an interface.

According to several studies (for example Tinker 1996, Thornton 1987, 1989 and 1997a, Thornton and Sokoloff 1998, Hake 1997, Laws 1997, Bernhard 2000a and 2000b, Hamne and Bernhard 2001) MBL is very effective in fostering a good functional understanding among different groups of students. According to a presentation by Euler and Müller (1999) at the ESERA-conference in Kiel 1999 MBL is the only method in physics teaching using computers with a proven positive learning effect. Bernhard (2001) has proven that MBL can give long-lived conceptual understanding. 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. This make it possible to develop new types of lab experiments designed to facilitate better student learning and to use labs to foster a better conceptual understanding. Because data are quickly taken and displayed a predict – observe – explain cycle (POE) is easily implemented.

The question thus arises: Is the reported good learning effects of MBL due to inherent properties of the MBL-technology or is the educational implementation crucial?

2. Methods and Samples

In this study different implementations of MBL-labs in introductory university level physics (mechanics) courses at a smaller Swedish university (Högskolan Dalarna) were studied. The main student body in the courses were either engineering students (Case II) or pre-service teachers (Case I, III, IV and V) preparing to be certified for mathematics and science teaching in Swedish grade 4 – 9. Between 20 – 40

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students were registered in the courses. Different instructors had different educational “views” which led to different ways of implementing the MBL-labs. The cases are summarised in table 1.

Case I and II: In Case I (Pre-service Teachers 95/96) and in Case II (Engineering students, Mechanics I) MBL-labs were implemented as “conceptual” labs. The educational approach taken in both cases were inspired by, but not identical to, the approach used in *RealTime Physics* (Sokoloff *et al* 1998, Thornton 1997a and references therein) and in Case II also by the “New Mechanics” paper by Laws (1997). The approach is described in some detail in Bernhard (2000a) and in more detail in a forthcoming paper (Bernhard, to be published).

- In both cases MBL were used as conceptual labs and among other things the labs emphasised concepts and connections between different concepts and the active engagement of students.
- Co-operation among students was encouraged.
- Students’ preconceptions were addressed by using a POE-cycle (Predict – Observe – Explain). In implementing this cycle the rapid display of the results by the computer in graphical form is thought of being of crucial value.
- Each lab-group of 2-3 students was asked to submit a written report from each lab. This reinforces and strengthens student understanding, since they have to describe the lab in their own words.
- The instructions for the labs in both Case I and II were written in Swedish by the author.
- MBL was used both as a technological tool (measurement, processing and display of experimental data) and as a cognitive tool (sense making).

Case III: Pre-service Teachers 98/99.

- MBL-technology was used in the labs.
- The original labs were transformed into formula verification labs with instructions written by instructor E (se table 1).
- No POE-cycle was used.
- MBL was mainly used as a technological tool.

Case IV and V: Pre-service Teachers 99/00 and 00/01.

- MBL-technology was used in the labs.
- The “impulse and collision” lab from Case III was changed back into a conceptual lab using a further improved instruction written by the author.
- The labs dealing with Newton’s 1st and 2nd laws were not changed from Case III (formula verification) but the students were orally asked by the instructor to do a POE-cycle.
- MBL was used as a technological tool and partly as a cognitive tool.

The conceptual tests Force Concept Inventory (FCI, Hestenes *et al* 1992) and Force and Motion Conceptual Evaluation (FMCE, Thornton and Sokoloff 1998) were used as evaluation instruments (pre- and post-test). The results of testing using the FMCE-tests are displayed in figure 1–6. Between 80 – 90 % of total number of registered students participated in the conceptual tests.

3. Results

When implemented (Case I and II) as conceptual labs MBL achieves good learning results as displayed in figure 1 and 2. In Case II both male and female students also achieved the same normalised gain [Normalised gain (Hake 1997) is defined as gain divided by the maximum possible gain] measured by the FCI-test.

However figure 3 show that when MBL were used for formula verification labs (Case III) significantly poorer learning results were obtained compared to Case II. The difference between the conceptual lab approach and the formula verification approach is very apparent when Cases III, IV and V are investigated in more detail. In Case III all labs were formula verification but in Cases IV and V the lab dealing with Newton 3rd law were conceptual. In figure 4 the conceptual understanding of the students in the areas where formula verification labs were used are presented and compared to Case II which used conceptual labs. As can be seen the results for the cases using a non-conceptual approach are quite similar except for “coin toss” and “cart ramp”. However for Newton 3rd law understanding, as measured by the FMCE-test, there is a significant difference between Case III and Cases IV and V. In Cases III, IV and V identical lab-equipment using MBL-technology were used in both versions of collision lab. However the educational approach chosen was different. Cases IV and V used a conceptual active engagement approach and Case III a non-conceptual formula verification approach. As can be seen in figure 5 there is a large learning difference. The formula verification approach even led to negative learning in the case of contact forces.

A detailed analysis of data has shown that the formula verification approach has been especially disadvantageous for female and for poorly prepared students. Figure 6 shows for example that for Case III that the fraction of students believing in a force-follows-velocity view didn’t change very much as a result of teaching.

4. Discussion, Conclusions and Implications

This study shows that there is a significant difference in learning when MBL is used for implementing conceptual labs (MBL used as a technological and a cognitive tool) and for implementing formula verification labs (MBL used as a technological tool). Could however the effects reported be due to either different student backgrounds or different lab instructors? Data suggests that the answer is no to this question. In figure 1 and 2 one can se that engineering and pre-service teachers obtained very similar learning results. Instructor B was the lab-instructor both in Case I and in Cases IV and V with different learning results for kinematics and Newton 1st and 2nd law. The same instructor also taught both the labs in Cases IV and V using non-conceptual and conceptual approaches. Instructor E participated in the teaching of Cases II and III. Thus the results correlates to the educational approach but not to the teacher or to the type of student body. The results are also in line with a large body of literature (se for example Hake 1977 and McDermott 1977) that the active engagement of students is essential in obtaining a good functional understanding.

It should be noted that instructor E, when he rewrote the lab-instructions for Case III, thought he improved the labs. Case III is not invented as a control group by a person who didn’t actually believe in the approach chosen. Thus the question arises what constitutes a “good” lab. In short I would propose that according to a “formula verification lab view" a "good" lab proves the "theory" with a good accuracy or measures a physical quantity like *g* with a good accuracy. Better accuracy – better lab. If a law is proven with a high accuracy it's tacitly assumed that the students now must accept the law and in incorporate it in their understanding. However in a "conceptual lab view" a "good" lab is a lab which help students in their meaning making and helps them to build concepts and understand concepts and connections between them. Better "understanding" – better lab.

The result of this study shows that MBL doesn't automatically give good learning results. MBL-technology, and other forms of computer aided learning, can not be implemented as only a technology. The educational implementation is of crucial importance and hence there is no definite answer to the common question if computers help to achieve "better" learning. Another conclusion is that we, when developing new curricula, must be as aware of instructor's conceptions of teaching and learning as we in teaching and curriculum design must be aware of student's preconceptions. Physics instructors perceive the intentions of a curricular reform or the advantages of an educational tool through their own understanding and conceptions ("misconceptions"?) of teaching and learning. In active engagement curricula using MBL-tools these tools are intended to be used as booth a technological and a cognitive tool. However, many instructors, perceive the MBL-tools as only a technological tool [see also similar results by Sassi (2001)]. Tinker (1996, page 3) points out: "*It is not usually advantageous to simply replace a traditional lab with an equivalent one using MBL. This kind of 'substitution' policy is easiest for schools to implement, but the result of such a substitution is often a simple lab made more difficult and expensive by the inclusion of computers with no educational gain. The MBL context adds capacity and flexibility that, to be exploited requires the lab to be reconceptualized, giving students more opportunity to explore and learn through investigations. This, in turn, often requires a change in teaching style that takes time and institutional commitment*".

To achieve positive learning effects, when using computer aided learning, we must focus as much on the cognitive aspects as on the technological aspects.

Bibliography

Bernhard J, 2000a, *Teaching engineering mechanics courses using active engagement methods*, Proc. of PTEE2000, Budapest, June, 2000.

Bernhard J, 2000b, *Improving engineering physics teaching - learning from physics education research*, Proc. of PTEE 2000, Budapest, June, 2000.

Bernhard J, 2001, *Does active engagement curricula give long-lived conceptual understanding?* In Pinto R and Surinach S (eds), Physics Teacher Education Beyond 2000, Elsevier, Paris, pp 749 – 752.

Euler M and Müller A, 1999, *Physics learning and the computer: A review, with a taste of meta-analysis* in Komorek *et al* Proceedings Second International Conference of the European Science Education Research Association.

Hake R R, 1997, *Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses*. Am J Physics, **66**, 64–74.

Hamne P and Bernhard J, 2001, *Educating pre-service teachers using hands-on and microcomputer based labs as tools for concept substitution*. In Pinto R and Surinach S (eds), Physics Teacher Education Beyond 2000, Elsevier, Paris, pp 663 – 666.

Hestenes D, Wells M and Swackhamer G, 1992, *Force Concept Inventory*. The Phys Teacher, **30**, 141–158. Translated into Swedish by J Bernhard, 1997.

Laws P L, 1997, *A New order for Mechanics*, in Wilson J (ed.), Proc. Conf. on Intro Physics Course, Wiley, New York, pp. 125–136.

McDermott L C, 1997, *How research can guide us in improving the introductory course*, in Wilson J(ed.), Proc. Conf. on Intro Physics Course, Wiley, New York, pp 33–45.

Sassi E, 2001, *Lab-work in physics education and informatic tools: advantages and problems*, In Pinto R and Surinach S (eds), Physics Teacher Education Beyond 2000, Elsevier, Paris, pp 57 – 64.

Sokoloff D R, Thornton R K and Laws P W, 1998, *RealTime Physics*, Wiley, New York.

Thornton R K, 1987, *Tools for scientific thinking - microcomputer-based laboratories for teaching physics*. Phys Ed, **22**, 230–238.

Thornton R K, 1989, *Tools for scientific thinking, Learning physical concepts with real-time laboratory measurements tools*, in Redish (ed.) Proc Conf Computers in Physics Instruction, Addison Wesley, Reading, pp 177-189.

Thornton R K, 1997a, *Learning Physics Concepts in the Introductory Course: Microcomputer-based Labs and Interactive Lecture Demonstrations*, in Wilson J (ed.) Proc Conf on Intro Physics Course, Wiley, New York, pp. 69–86.

Thornton R K, 1997b, *Conceptual Dynamics: Following Changing Student Views of Force and Motion*, in Redish and Rigden (eds), AIP Conference Proceedings, **399**, pp 913 – 934. New York, American Institute of Physics.

Thornton R K and Sokoloff D R, 1998, *Assessing student learning of Newton's laws, The Force and Motion Conceptual Evaluation and the evaluation of active learning laboratory and lecture curricula*, Am J Physics, **66**, 338–352. Translated into Swedish by J Bernhard, 1998.

Tinker R F (ed.), 1996, *Microcomputer-Based Labs: Educational Research and Standards*. NATO ASI Series F vol **156**, 1996, Springer, Berlin.

Case	Course	Year	Registered # of students	Main student body	Approach in labs		Instructors	
					Kinematics, Newton 1st and 2nd laws	Impulse, collision, Newton 3rd law	Lect-ure	Lab
I	Pre-service	95/96	40	Pre-service Science Teachers (grade 4-9)	MBL – conceptual	No lab	A	B
II	Mechanics I	97/98	40	Engineering	MBL – conceptual	MBL – conceptual	C	C, D, E
III	Pre-service	98/99	31	Pre-service Science Teachers (grade 4-9)	MBL- formula verification	MBL- formula verification	B	E
IV	Pre-service	99/00	25	Pre-service Science Teachers (grade 4-9)	MBL- formula verification	MBL – conceptual	B	B
V	Pre-service	00/01	20	Pre-service Science Teachers (grade 4-9)	MBL- formula verification	MBL – conceptual	B	B

Table 1. The student body, approaches and instructors of the different cases discussed in this paper. The instructors A – E were either senior lecturers or experienced lecturers. Instructor C is the author of this paper.

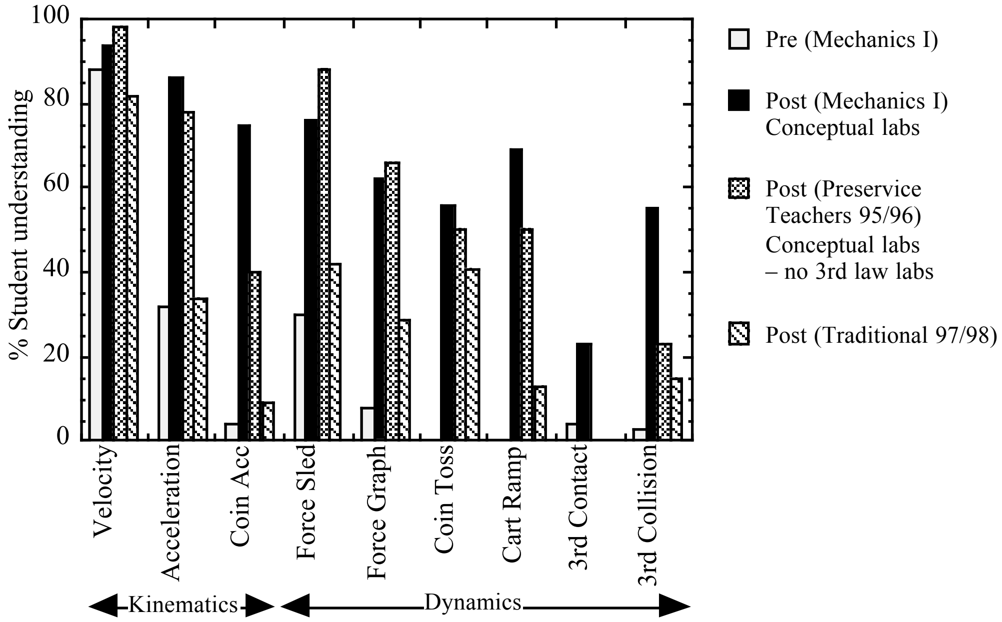

Fig 1. Student understanding in different conceptual areas of mechanics after having studied at a university level course in mechanics as measured by the FMCE-test (Thornton and Sokoloff 1998). The pre-instructional understanding of the students in the Mechanics I course and the post-instructional understanding of students in a traditionally taught course in mechanics (engineering students) is included as a comparison.

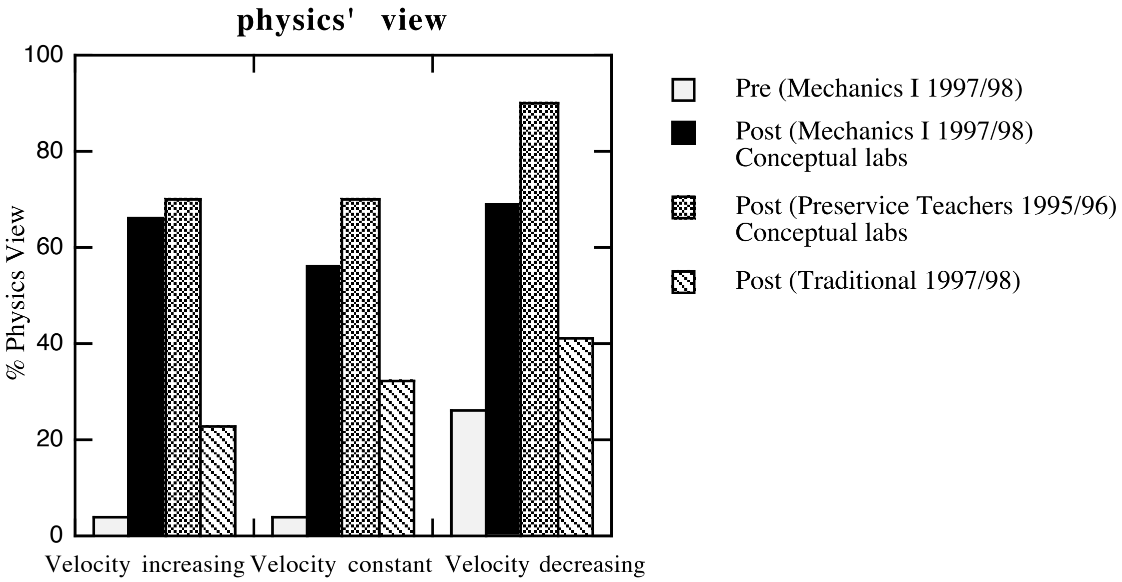

Fig 2. Fraction of students holding a ”Physics’ view”. Student’s views are assigned from FMCE-data using a method developed by R Thornton (1997b). Pre = pre-test = testing done prior to instruction. Post = post-test = testing done after instruction.

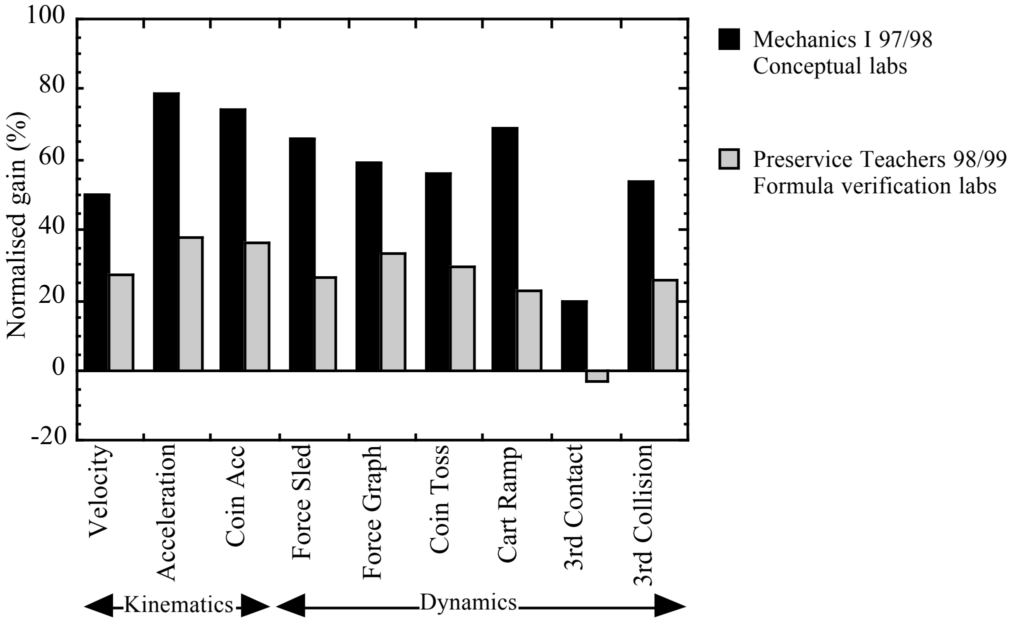

Fig 3. Comparison of normalised gains (Hake 1997) of two courses using the same MBL-technology in labs but different educational approaches. Note the negative learning gain for Newton 3^{rd} law contact forces.

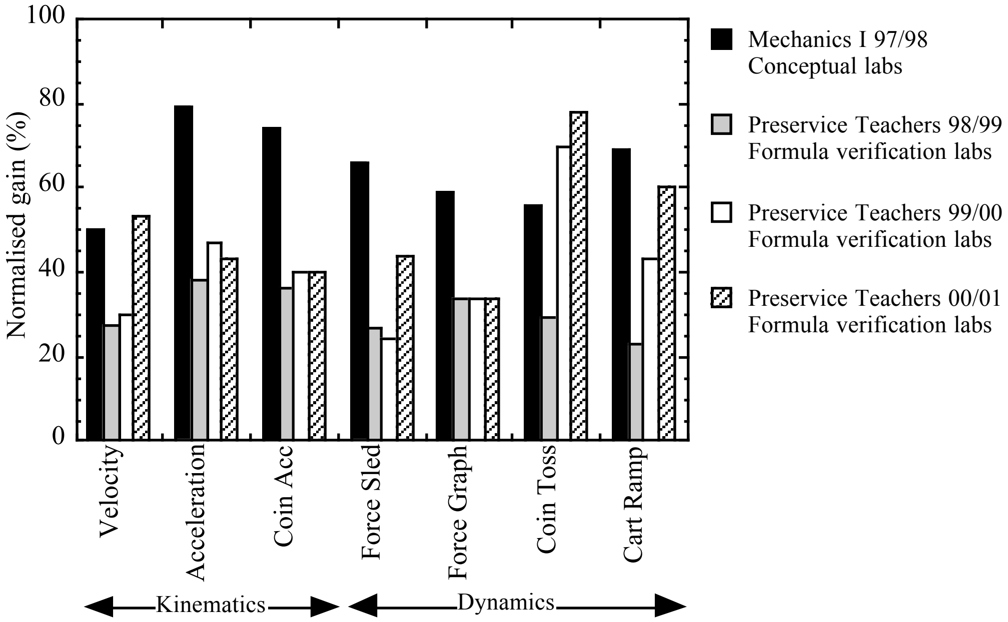

Fig 4. Comparison of normalised gains in the area of kinematics and Newton 1st and 2nd laws for four different courses using the same MBL-technology in labs but different educational approaches. Note that both the Pre-service teachers 99/00 and 00/01 display some understanding of the forces involved in a coin toss but not the corresponding acceleration.

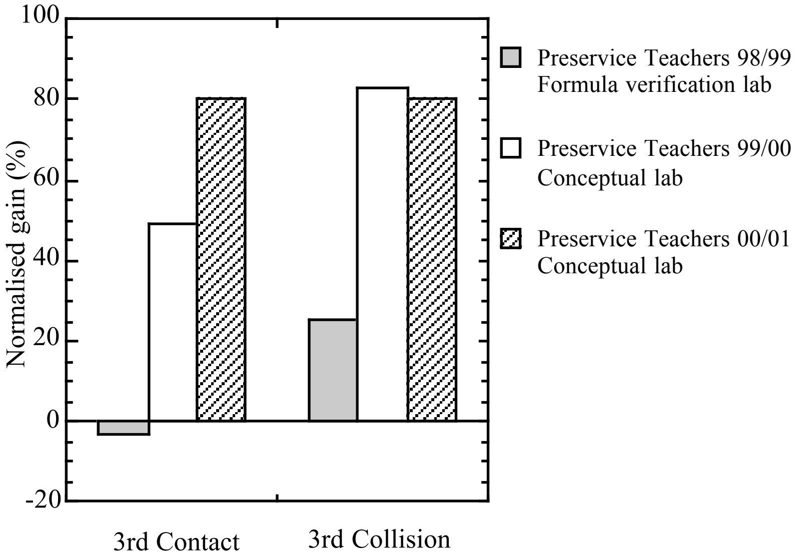

Fig 5. Comparison of learning in the domain of Newton's 3rd as measured by the FMCE-test.

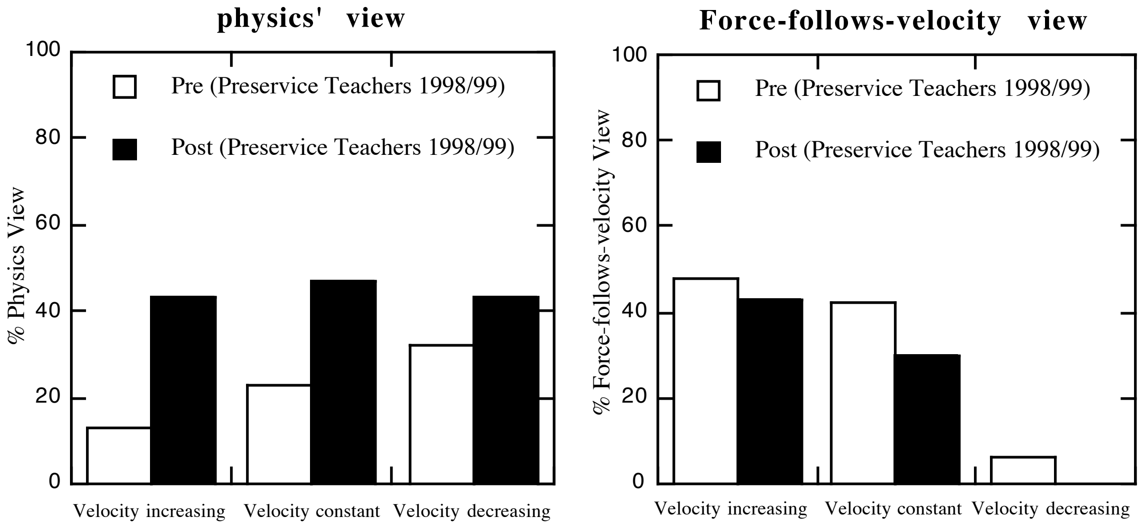

Fig 6. Fraction of students holding a ”Physics’ view” and a “Force-follows-velocity view” for Case III. Student’s views are assigned from FMCE-data using a method developed by R Thornton (1997b).