AC 2011-923: INVESTIGATING STUDENT LEARNING IN TWO ACTIVE LEARNING LABS - NOT ALL "ACTIVE" LEARNING LABORATORIES RESULT IN CONCEPTUAL UNDERSTANDING

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1. Introduction

An important aim in engineering education is to ensure that students not only *learn* to understand theories and models, and their *relation* to objects and events, but also *learn* to *use* and *apply* these models and theories. Especially during lab-work, students are expected to link observed data to both theoretical models and the objects and events they are exploring[1, 2]. However, according to a large body of research, establishing relevant connections between concepts, representations, theories/models and observable objects and events is a very difficult task for students[3, 4].

Mechanics, first experienced by engineering students in introductory physics courses, encompasses an important set of foundational concepts for success in engineering. However, although it has been well-known for some time that acquiring a conceptual understanding of mechanics is one of the most difficult challenges faced by students, very few successful attempts to engender conceptual learning have been described in the literature. On the contrary, research has shown that most students participating in *university level* courses, selected for detailed examination in for example the US and Sweden, had not acquired a Newtonian understanding of mechanics at the end of their respective courses[4-9].

To promote students' learning it is important to ensure that the learning environment enables them to focus on the object of learning and discern its critical features. Recently, I described 10 years of experiences of designing and using conceptual labs in engineering education that have successfully fostered insightful learning[9]. A conceptual lab is described as "one that helps students to develop fruitful ways of linking concepts and models to objects and events[8]. Furthermore, it is a place of inquiry, where students' 'ways of seeing or experiencing … the world [are developed]'; i.e. the lab is an arena for further learning rather than simply for confirmation theories and formulas that have already been taught in lectures"[9]. A common feature of such labs is that they exploit technology called probe-ware or Microcomputer-Based Labs (MBL).

Probe-ware systems were introduced into physics teaching almost three decades ago and are good examples of the use of interactive technology in physics education[10]. They consist of a sensor or probe connected to a computer, which analyses data collected by the probe, and transforms experimental data directly into a graph displayed on the computer screen. When using probe-ware, students can perform experiments using a range of sensors to gather data on variables such as force, motion, temperature, light or sound. The *simultaneous* collection, analysis and display of *experimental* data is sometimes referred to as *real-time* graphing. The immediacy of this technology allows the design of labs that foster a functional understanding of physics most effectively[5, 10-12]. It has been proposed[13, 14] that the following characteristics of learning environments using probe-ware are primarily responsible for the reported learning achievements: "1. Students focus on the physical world. 2. Immediate feedback is available. 3. Collaboration is encouraged. 4. Powerful tools reduce unnecessary drudgery. 5. Students understand the specific and familiar before moving to the more general and abstract. 6. Students are actively engaged in exploring and constructing their own understanding." However in an earlier paper[8] I have demonstrated that not all labs in which probe-ware is used lead to high post-course achievements in mechanics conceptual tests.

Prior research has suggested that a common attribute of successful physics laboratory activities is, as Trumper states in a review[15], "that they are learner-centred. They induce students to become active participants in a scientific process in which they explore the physical world, analyze the data [and] draw conclusions". However Lindwall[16] has analyzed several learning environments and argues that many other environments fulfill conditions 1-6 described above, without achieving good results in conceptual tests. Results of my earlier studies show that the students achieve better results (using concept tests such as FCI[17] and FMCE[18] to measure success) if lab-instructions are created that apply teaching strategies in line with variation theory than if the teacher adopts a non-conceptual approach[8, 9].

This led to the following questions:
i) What differences in learning could be observed between engineering students taking the same introductory physics course except for mechanics lab sessions; one group participating in regular sessions, while another participated in conceptual, variation theory-based sessions.
ii) What aspects of the learning environment direct the students towards the intended object of learning?
iii) How can we further develop these aspects?

This paper shows that changing 16 h of labs could result in large difference in students' achievements in concept tests, with normalized gains of $g \approx 48\%$ and effect size $d \approx 1.1$. The possibility of fostering insightful learning in student laboratories by using carefully designed activities based on education research and theoretically informed development is demonstrated. Below, I describe the theoretical framework and object of study (§ 2), the methodology for evaluating the learning process (§ 3), learning results and an analysis of students' activities (§ 4) in conceptual and non-conceptual labs. Finally in section 5, a short discussion, conclusion and implications of the results are presented.

2. Theoretical framework and object of study

2.1 Variation theory

As described briefly in the introduction, most students do not change their conceptions of mechanics concepts, i.e. they do not change their ways of seeing the world using force and motion concepts from a naive to Newtonian understanding, even after one or more university level course(s) in mechanics. Hence, teaching and learning in mechanics need to be developed to engender "conceptual change" in order to heighten students' "ways of seeing" (and understanding) physical phenomena. Learning is seen as developing students' ways of experiencing the world to develop capabilities to handle novel situations in powerful ways[19, 20]. My view is close to the view about conceptual change described by F. Marton and M.-F. Pang[21]: "Perception is seen as discernment (and not construction, for instance), and our concern is primarily the differences between different 'ways of seeing' Above all, our answer to the question 'What changes in conceptual change?' is different from the answers suggested by other theorists. In our view it is the world experienced, the world seen, the world lived that changes. (p. 542)"

Variation theory, developed by Marton and co-workers[22-28], provides an explanatory framework describing the conditions required for learning. Central to this theory is the notion that we learn

through experiencing differences, rather than recognizing similarities. Central concepts in variation theory are *discernment*, *simultaneity* and *variation*. Learning is seen as the process of developing certain capabilities and values that enable the learner to handle novel situations effectively. Powerful ways of acting emerge from powerful ways of seeing. Thus, aspects that can be discerned by the observer determine how something is seen in a particular way. People discern certain aspects of their environment by experiencing variation. When one aspect of a phenomenon or an event varies, while one or more aspects remain the same, the one that changes is the one that will be discerned. One of the main themes of variation theory is that the pattern of variation inherent in the learning situation is fundamental to the development of certain capabilities. It should be noted that 'discerning' is not the same as being 'being told'.

Experiencing variation amounts to experiencing different instances simultaneously. This simultaneity can be either *diachronic* (experiencing, *at the same time*, instances that we have encountered at different points in time) or *synchronic* (experiencing different co-existing aspects of the same thing at the same time).

2.2 Mediating tools

According to variation theory an important condition for learning is that students are able to focus on the object of learning and discern its critical features. An essential part of a lab is the use of appropriate kinds of instrumentation to study an experimental set-up or natural phenomenon. Thus, a human experience in the laboratory is a mediated experience[29-31] and the relationship can schematically be expressed as[32, 33]:

Human ⇔ Instrument ⇔ World.

In science, instruments do not merely "mirror reality", but mutually constitute the reality investigated. This technology can be used to place some aspects of reality in the foreground, others in the background, and to make certain aspects readily visible that would otherwise be invisible or difficult to perceive[32-34]. Technology can thus be used in conceptual labs to frame our experience or give shape to the figure-background relationship[31, 35, 36] and hence bring critical features into the focal awareness of students and highlight any relevant variation.

2.3 Setting and object of study

As part of a larger study[9], the students taking the mechanics part of an introductory physics course for engineering students were offered, in the academic year 2002 – 2003, the option to take an alternative "conceptual" lab-course (details of the labs are described below). The alternative "conceptual" lab-course, and as well as the regular "non-conceptual" lab-course, consisted of four 4-hour lab-sessions, i.e. a total of 16 hours of labs. However, it should be noted that all students attended the same set of 20 hours lectures (with all students in a lecture hall) in mechanics and participated in similar sets of 12 hours problem-solving sessions (with groups of approximately 30 students led by a doctoral student). Thus, the only difference between the groups, in terms of teaching, was the 16 hours of labs. The features of the alternatives are summarized in table 1.

Group	No. Students	Lectures	Problem-solving	Non-conceptual labs	Conceptual labs	Pre-test %	Post-test %	Norm Gain %	Effect size
Regular labs non-conceptual	86	20 h (all)	12 h (groups of approximately 30 students)	16 h (groups of 2–3 students)		29.3 (16.4)	42.3 (22.9)	18.4	0 (by definition)
Alternative labs conceptual	25				16 h (groups of 2–4 students)	34.3 (23.1)	65.8 (21.8)	47.9	1.08

Table 1. Organization of the mechanics part of the physics course for engineering students described in this paper, and results from the pre- and posttests using the FMCE[18] as described in section 3 (means with standard deviations in parenthesis), calculated normalized gains[12] and calculated effect size (Cohen's *d*)[37].

The students participating in the alternative conceptual labs were volunteers, since for legal reasons students could not be randomly assigned to groups. As can be seen in figure 1a, the pre-course conceptual understanding of mechanics of the two groups was very similar, with close to negligible differences.

The approach used in our development of conceptual labs was, as mentioned above, originally inspired by the pedagogical approaches applied in RealTime Physics [38, 39] and research in physics education [7]. According to this research, certain concepts and topics are difficult to learn, or are misconceived, by most students (See Figure 7a). Hence, in the selection and design of tasks special attention should be given to critical features of the subject matter to be learned, as is done, for example, in RealTime Physics. The pedagogical principles behind RealTime Physics are only briefly described in the literature and are commonly described in terms such as "[incorporating] a learning cycle consisting of prediction, observation, comparison, analysis and quantitative experimentation"[39]. However, I claim[40] that the design of many tasks in RealTime Physics can be understood in terms of the principles proposed by *Variation theory*[41].

The labs in the alternative conceptual lab course were a subset (4×4 h) of conceptual labs used in an earlier conceptual lab-course (7×4 h) utilizing probe-ware technology and instructions in line with active learning[42, 43].

Motion: This lab introduces kinematics concepts, using probe-ware, and the tutorial software Graphs and Tracks I & II.
Force and motion I: The aim of this lab is to foster a conceptual understanding of the relationships between position, velocity, acceleration and force with "friction-less" motion using probe-ware technology.
Force and motion II: This lab continues the study of dynamics (Newton's first and second laws). Cases with friction are also studied.
Impulse and collisions: This lab uses force sensors to measure forces during collisions (Newton's third law) and to experimentally study the impulse-momentum law.

The regular labs were so-called Richards' labs[44], in which students explore the relationships between physical variables pertinent to a given physical set-up, e.g. a bifilar pendulum. These labs are not typical "cookbook labs" and students are free to choose their own procedures; hence the labs could be categorized as inquiry type labs. According to, for example, Trumper[15] a common attribute of successful physics laboratory activities "is that they are learner-centered. They induce students to become active participants in a scientific process in which they explore the physical world, analyze the data [and] draw conclusions". Hence, the regular Richards' labs in this course could be expected, on theoretical grounds, to foster students' conceptual learning.

3. Methodology

In this study quantitative as qualitative methods to study students' learning have been employed[45]. Conceptual test enables a quantitative comparison of post-course understanding between the treatment groups and also facilitate a comparison between learning environments at different universities even in different countries. Quantitative analysis of conceptual tests can give *some* answer to the question "did it work?" However, in a discussion about "scientific culture" and "scientific rigor" in educational research Erickson and Gutierrez[46] reminds us that "a logically and empirically prior question to 'Did it work?' is 'What was the 'it'?'" and that such a "question [is] best answered by qualitative research". To investigate to the process of learning and what students actually *do* students' courses of action in labs have been recorded using digital camcorders in this study.

For studying students' conceptual understanding in mechanics the two most commonly used research-based "inventories" or "concept tests" in physics education research are the *Force Concept Inventory* (FCI)[17] first published in 1972 and the *Force and Motion Conceptual Evaluation* (FMCE)[18] first published 1998. Both concepts tests cover one-dimensional kinematics and Newton's laws. Additionally, for example, two-dimensional motion with constant acceleration, vector sums and cancellation of forces are included in the FCI. The FMCE on the other hand probes student understanding of one-dimensional kinematics and dynamics in more depth. Both tests utilize several representational formats. The FCI largely uses a combination of verbal and pictorial representations, while the FMCE relies on verbal and graphical representations. Both test use multiple-choice questions (FCI: 30 questions; FMCE: 43 questions) to assess students' conceptual understanding of mechanics. The distractors (wrong answers) in both test are carefully chosen by research to correspond with common-sense beliefs (misconceptions) as shown in the research literature on misconceptions. The multiple-choice format of the test makes it feasible to conduct controlled, large-scale educational studies and especially to compare and contrast learning environments. The FMCE has been shown, by its developers, to provide reliable and valid measures of students' conceptual understanding of basic Newtonian mechanics[18]. Thornton et al.[47] have presented an empirical comparison between the tests. The FCI is designed to have results analyzed as a single-number score while FMCE is designed to have it's result reported and analyzed in conceptual clusters as is shown in Figure 1.

Since FCI and FMCE are widely used and well established instruments in physics education research[12, 47-50] I have originally used the FCI as an operational measure of conceptual understanding when first starting to develop conceptual labs in the late 1990:s[42, 43, 51] and later switching to the FMCE rather than to develop and validate tests on my own. The change to use the FMCE was based on the fact that this test enabled a more fine grained analysis of student

understanding due to its design to present results in conceptual clusters and hence were a better tool for evaluating learning environment design and support further development.

In this study the FMCE-test was taken by the students both during one of the first lectures, as a pre-test, and after the course as a post-test.

In Figure 1a pre-test data are presented as 'absolute' values for different conceptual clusters, while in Figure 1b the data are presented using a measure called *normalized gain*[12], defined as $g =$ *Actual gain*/[*Gain(max possible)*] where *Actual gain* is the difference between group averages on the pre- and post-test. Normalized gain provides a measure that is useful in comparing courses in terms of their enhancement of test achievements since it is a measure that is rather independent of pre-test values[52]. This gain parameter was independently employed by Hovland et al. in 1949[53] calling it *effectiveness index*, Gery in 1972[54] calling it the *gap-closing parameter*, Hake in 1998[12] calling it *normalized gain*, and by Cohen et al. in 1999[55] calling it *POMP* (Percentage of Maximum Possible). Following the practice in physics education research I use the term *normalized gain*.

A measure that is common in education literature is *effect size* (Cohen's d[37] and similar measures) defined as $d = (M_E - M_C)/S_p$; there M_E is the experiment group average, M_C is the control group average and S_p is the pooled standard deviation.

For the qualitative analysis students' courses of action in the conceptual labs as well as in the non-conceptual labs were recorded using digital camcorders, then the acquired data were used to detect typical interaction patterns and find evidence supporting, or refuting, hypotheses regarding the generality of these patterns[56]. Students' talk recorded on video by the camcorders has been transcribed verbatim and selected parts have been translated into English. In the transcription standard conventions used in conversation analysis have been used[57]:

[A *single left bracket* indicates the point there overlapping speech start.
=   *Equal sign*, indicate that there is no gap between two turns.
(0.0)   *Numbers in parentheses*, indicate elapsed time in silence in seconds, so (7.4) is a pause of 7 seconds and four-tenth of a second.
(·)   *A dot in parentheses* indicates a tiny "gap" within or between utterances.
word   *Underscoring* indicates some form of stress.
::   *Colons* indicate prolongation of the immediately prior sound. Multiple colons indicate a more prolonged sound.
°   Utterances or utterance-parts bracketed by *degree signs* are relatively quieter than the surrounding talk.
(word) *Parenthesized words* are especially dubious hearings or speaker identifications.
(( ))   *Double parentheses* contain transcriber's descriptions or comments.

In translating transcriptions from Swedish to English the focus have been on conveying the meaning of students' talk, rather than to present a "true" word-by-word translation. Intonations have not been included in the transcripts due to differences in the meaning they convey.

In the analysis presented below I focus on central characteristics of learning environments to explore what the students do and the resources they use, see for example the thesis of Oskar

Lindwall[16] for a review and more details of the methodology used. Hitherto only recordings from the conceptual labs have been transcribed an analyzed in detail. The recordings from the non-conceptual labs have not yet been transcribed, but some preliminary analysis have been made and will be presented below.

4. Results

4.1 Results from Force and Motion Conceptual Evaluation (FMCE)

The FMCE pre-test results are presented in Figure 1a. Although students could not be randomly assigned to the groups, the between-group differences in pre-course conceptual understanding of mechanics were very small, almost negligible (the difference between the groups' pre-test average values is trivial; $t = 0.58$, $p = 0.36$). In Table 2 the normalized gains of the students taking each of the lab-courses are summarized (and compared with those taking other courses) and in Figure 1b the data are presented for different conceptual domains. In Table 1 some numerical data for students achievements in the pre- and post-tests are presented.
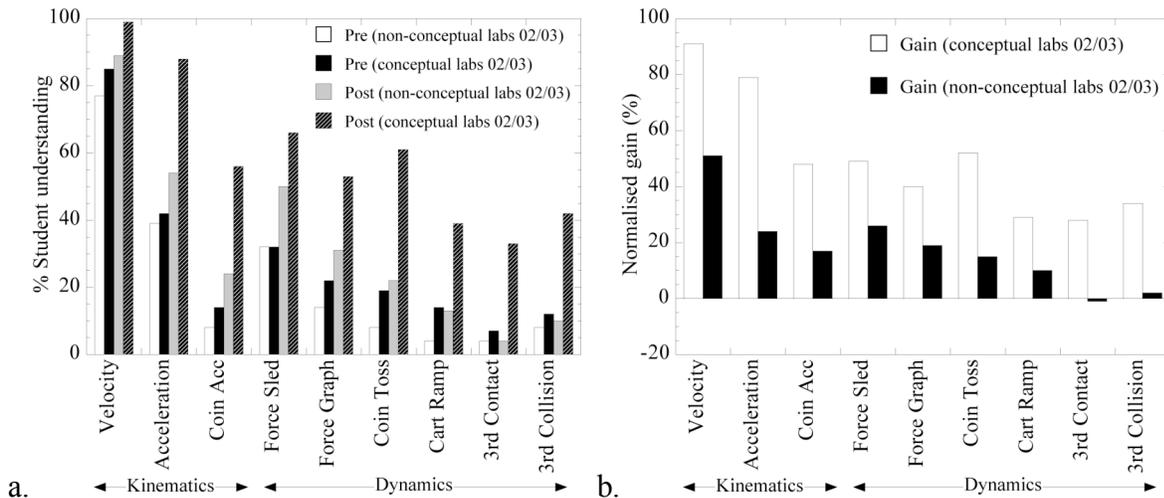

Figure 1. a) Absolute pre- and post-course FMCE-test results for students participating in the conceptual and non-conceptual lab-courses. b) Comparison of the achievements of the two groups of students, using normalized gain.

The differences in results between the regular (non-conceptual) and the alternative (conceptual) labs are striking. The students participating in the conceptual labs achieved a normalized gain of 48%, compared to just 18% for the students participating in the non-conceptual labs. This difference is strongly statistically significant ($t = 2.93$, $p = 0.0003$). The effect size (Cohen's d) calculated from the post-test averages is $d = 1.08$. An effect size $d > 0.8$ is regarded as a large one[37]. In Figure 1b it can be seen that there is a large difference in normalized gain for all conceptual clusters in the FMCE-test, especially for the element related to Newton's 3rd law (contact forces and forces in collisions).

4.2 Analysis of task structure and results from analysis of video recordings

An analysis of video recordings from the conceptual labs showed that students' courses of action are framed[58] by encounters with the instructions, the technology, the teacher, and other students. When using the technology, students receive immediate feedback. In the process of constructing graphs they can see when they make mistakes. Students intertwine different interpretative resources as well as different experiential domains, such as graphical shapes, with narrative accounts of past actions. Learners must focus on the central aspect of the graphs and, in order to complete the assignments, they have to make certain conceptual distinctions. The instructions for the task specify the process and the variance and invariance in the learning space. In order to solve the tasks successfully, the students have to deal with certain concepts in certain ways. In addition to designing the learning environment, choosing the technology and writing the instructions, teachers support students' activities in the lab, including encouraging students to shift their attention to central features of the graphs while down-playing less important aspects. Students have a common perspective on the graph and negotiate their different interpretations of the graphical representation, experiment, and subject matter. Discussions are made an important component of the process of completing the tasks and solving presented problems; students share perceptions of the graphs and negotiate interpretations of the graphical representations, experiments, and subject matter. Two examples are discussed in more detail below, including an analysis of task structure and transcripts of discussions during students' courses of action.
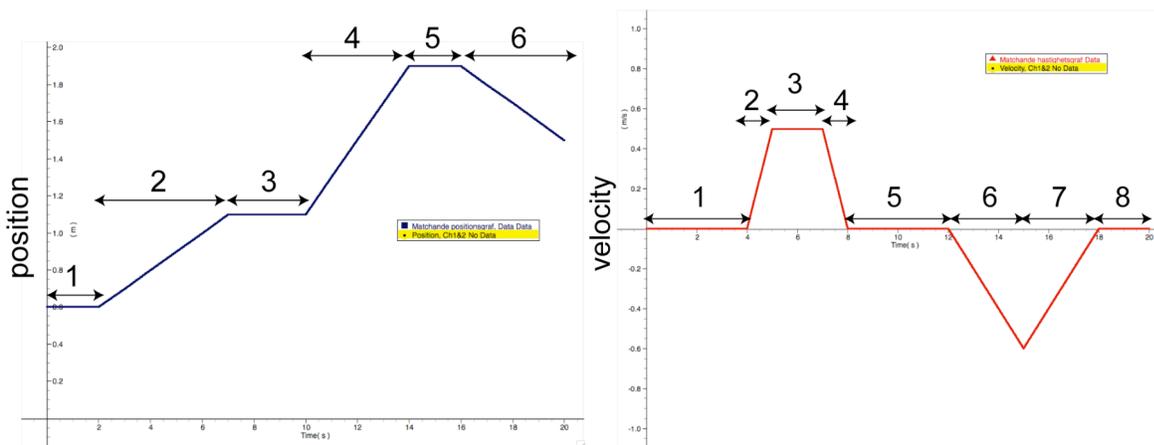

Figure 2. Examples of a *position-time* (left) and *velocity-time*-graph (right), that students are asked to recreate in the motion (kinematics)-lab, by their own motion in front of a motion sensor. The different parts of the graphs are not numbered in the task, but numbered in this paper to facilitate an analysis.

Matching a velocity-time-graph with your own motion. This example is one of the earlier tasks in a typical conceptual-lab in mechanics. Students are first asked to walk along different trajectories that should match given position-time graphs and then a given velocity-time graph. While moving, the participant and the other learners can see the experimental graphs as they are produced in *real-time*. Figures 2a and 2b present two of the graphs they are asked to match, which bring position and velocity to the fore, respectively. Other features of the situation, physical and non-physical, are not highlighted by the technology, i.e. some discernment has already occurred. It is also important for position and velocity to be established as having

relationships with objects and events in the real world. In order to complete the assignment, students have to understand this; they must also make important conceptual distinctions.

The transcripts (translated from Swedish) below present excerpts from discussions among three female engineering students (Anna, Beata and Cecilia; not their real names) regarding their courses of action. In excerpt 1 the students start to analyze the task to match the velocity-time-graph.

Excerpt 1

```
1.    Beata      but wait (.) it is divided into a positive and a negative
2.    Anna       yes, but the velocity is counted as a negative when you
                 walk towards it
```

We would re-arrange and amend this paragraph, as follows, 'When walking, the students face the computer screen in order to see the graph displaying their motion in real-time, and the system records motion away from and towards the sensor as negative and positive, respectively. In turn 1 Beata realizes that she has to understand the difference between positive and negative velocities and in turn 2 Anna expands the interpretation by explaining the measurement set up and the directions that count as positive and negative. At this point the students already have to make the conceptual distinction between positive and negative velocities. In excerpt 2 the students continue to analyze how they should walk to match the velocity-time-graph.

Excerpt 2

```
1.    Beata      one should stand still
2.    Anna       stand still
3.    Beata      and when one must
4.    Anna       move yourself a little
5.    Beata      yes (.) backwards a little
6.    Anna       backwards a little then
7.    Cecilia    this is so hard
8.    Beata      then it's constant
9.    Anna       then it's constant velocity
10.   Beata      then I change direction
11.   Anna       then (.) then (.) no:: then you stop
12.   Anna       here you stand still ((points at the screen))
13.   Beata      yes (.) yes I do
14.   Anna       here you stand still and then (.) you walk back ((signs
                 with her hand))
15.   Beata      and then
16.   Anna       oh:: yes
17.   Cecilia    I don't really grasp this ((Cecilia has been drinking some
                 juice and have been thinking during Anna's and Beata's
                 discussion in previous turns))
18.   Beata      the last one then
19.   Cecilia    first you stand still
20.   Beata      m::
21.   Cecilia    then you walk
22.   Anna       and then you walk constantly
23.   Cecilia    one tries to do it
24.   Cecilia    ((points to the screen)) and then walk constantly (.) then
                 decrease
25.   Beata      yes
26.   Cecilia    then stand still (.) then walk forward again
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27.   Beata     forward?
28.   Anna      yes forward
29.   Cecilia   speed up (.) slow down
30.   Beata     yes
31.   Cecilia   stand still
32.   Anna      °yes precisely speed up (slow down)°
33.   Cecilia   this will really be a brain exercise
34.             (7.4) ((Anna and Beata prepare for measurement))
35.   Cecilia   this will really be cool
```

In excerpt 2 it can be seen that the students try to interpret, and narrate, the motion they should perform. In turn 9 Anna adds to Beata's interpretation, by pointing out that segment 3 of the velocity-time graph indicates constant velocity, *not* constant position. In turn 10 Beata interprets the point between segments 3 and 4 as indicating an immediate change of direction, but in turns 11-14 Anna corrects this interpretation and points to segment 5, indicating a need to stand still. In turn 17 Cecilia re-enters the discussion and the students once more go through the motions required to perform the task successfully. Segment 1 is described in turns 19–20, segment 3 in turns 21–25, segment 5 in turn 26 and finally segments 6–7 in turns 26–32. In this excerpt it can easily be seen how the students negotiate the meaning of the different parts of the graph and how they correct each other. When performing the actual experiment all students try walk and match the graph, and again they need to discuss and interpret their results and make conceptual distinctions. Space does not permit the presentation of multiple examples and extensive transcripts. However, one example will be discussed in some detail below, accompanied by an analysis of the task structure and some transcripts from students' courses of action.

Acceleration with zero velocity. In this activity students monitor the motion of a cart propelled by a fan that provides almost constant acceleration (see Figure 3a). The students give the cart an initial push in the opposite direction to that in which the force of the fan is acting, so that the cart will slow down and reverse its direction of motion. They do this after studying the motion of the cart without reversing its direction, but with acceleration in different directions. Students are first asked to observe the motion of the cart (without measuring it) and then to sketch their predictions of how the motion will be represented by position-time, velocity-time and acceleration-time graphs. After they have made their predictions the motion of the cart is once more observed and this time the probe-ware equipment is used to measure the motion, and simultaneously display it as a graph (a typical graph is shown in Figure 3b). To make accurate predictions, not only do the differences between position, velocity and acceleration have to be discerned, but also the relationships between these concepts. Velocity and position vary, but students have to recognize that the acceleration is constant, and that a zero velocity does not imply that the acceleration is zero – as is commonly believed. Asking the students to make predictions before the experiment is performed facilitates comparisons between their thinking and reality, i.e. a variation in the space of thinking models. Students thus have the opportunity to discriminate between different "models" and see which is the most powerful. In excerpt 3, below, students discuss what the acceleration should be when the velocity is zero at the cart's turning point, and what the acceleration-time graph should look like around this point.
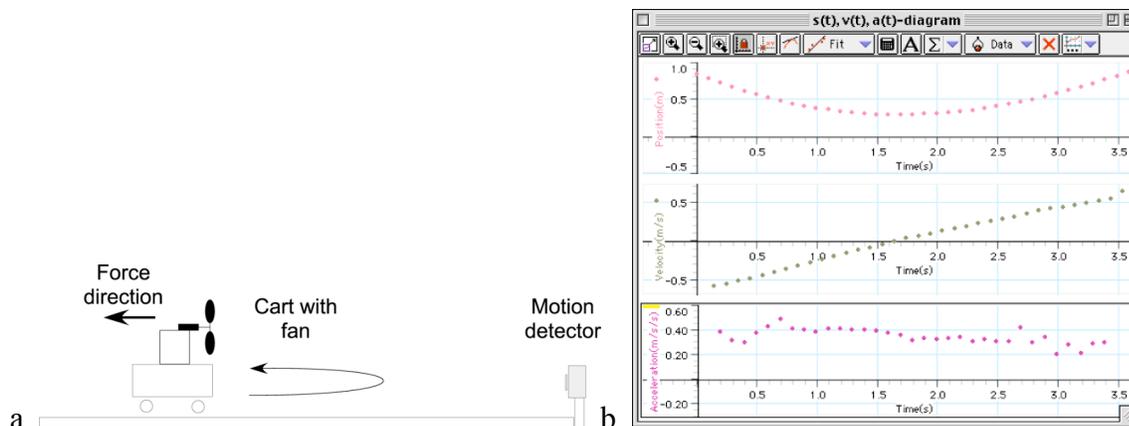
Figure 3. A typical setup in a probeware-experiment. A low-friction cart is pushed towards a motion sensor. A fan unit attached to the cart provides an approximately constant force in the opposite direction to the initial movement and, thus, the cart's direction of motion. The results (which show that acceleration is not zero at the turning point) are presented to the right.

Excerpt 3
```
1.    Beata     here I don't think the acceleration will be constant
2.    Cecilia   no for it will only [increase then
3.    Beata                         [it will
4.    Cecilia   =then stop
                ((a few turns are missing here due to a change of tape))
5.    Beata     something like that increases
                ((makes a sketch))
6.    Cecilia   then it becomes zero
7.    Beata     =for a little while when it turns
```

The students suggest that the acceleration "becomes zero for a little while when it turns". However, after performing the actual experiment Cecilia finds that "the acceleration turns out strange"; contrary to their prediction it is not zero, as shown in Figure 3b. After discovering that their prediction was not correct, and the acceleration was not in fact zero, the students discuss the results for a long time and finally in excerpt 4 they decide to ask the instructor.

Excerpt 4
```
1.    Beata     it is so [strange
2.    Cecilia            [acceleration in this case
3.    Cecilia   the acceleration can't be constant (.) since it stops and
                when it starts again
4.    Cecilia   can it be constant?
5.    JONTE     yes
6.    Cecilia   because it feels weird
```

After some discussion between the students' and instructor the issue is resolved in excerpt 5.

Excerpt 5
```
1.    JONTE    there you have zero (.) but if you look at delta v:: even at
               this point
2.    Cecilia =you mean that the velocity doesn't change much
3.    JONTE    no but you [you have
4.    Beata               [no
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 5.  JONTE   the whole time a constant [change in velocity
 6.  Cecilia                          [okay
 7.  JONTE   =per unit time
 8.  Cecilia yes
 9.  Beata   if you have a straight line (.) you will have the same slope on
             it (.) then you will have the same acceleration the whole way
             (3.7)
10.  Cecilia °m::°
11.  Beata   because acceleration is
12.  Cecilia [it's because
13.  Beata   [the derivative of velocity
```

As can be seen in the excerpt above, it took several turns before the students realized in the final turns why acceleration is not zero when the velocity is zero at the turning point.

These excerpts illustrate how the students' courses of action were framed by their encounters with the instructions, the technology, the teacher and other students, and the importance of their negotiations for linking observed data to theoretical concepts and the objects and events they explored in the conceptual labs[1, 2]. In contrast, students in the Richards' labs made little use of physical concepts in the completion of their assignments.

5. Discussion, conclusion and implications

As pointed out in the introduction, a necessary condition for learning is that students are able to focus on the object of learning and discern its critical features. A way to establish this, according to the theory of variation developed by Marton and co-workers, is *through the experience of difference (variation)*, rather than through the recognition of similarity[24]. In a lab, an experiential *human–instrument–world* relationship is established[33]. The technology used places some aspects of reality in the foreground, others in the background, and makes certain aspects visible that would otherwise be invisible. In labs, this can be used to bring critical features of the object of learning into the focal awareness of students and to afford variation.

To solve the tasks in the conceptual labs students have to make conceptual distinctions between different concepts of motion such as position, velocity and acceleration, i.e. develop from an undifferentiated notion of "motion" to a differentiated conceptual understanding, such as that presented in the acceleration example, when the cart's velocity (but not acceleration) is momentarily zero. One may be surprised that students did not learn this in high-school physics courses. However, a large body of research shows that the data presented in Figure 1 are not atypical for either high-school or university level students[4-9]. In the example, the students would probably not have discovered the falsity of their belief that zero velocity implies that acceleration is also zero, or that acceleration is in the direction of motion, without the combined guidance of probe-ware technology and instructions. In other tasks the velocity is placed in the foreground by the probe-ware technology and the instructions, so students are more or less forced to realize the differences between constant position and constant non-zero velocity, and between negative and positive velocity. In still other tasks the masses of colliding cars are varied and students' are led to the conclusion that the force sensors on the carts show the same forces, regardless of the mass and speed of the different carts. The task presented in the example, and the tasks in some other labs, could seem to be almost too simple for a university level course. However, as pointed out by Laws[6], a thorough understanding of kinematics is essential for the understanding of dynamics.

Teaching Method/Course	Norm. Gain (FMCE)	Reference
Physics 02/03 (Sweden) Conceptual labs	48%	This study
Physics 02/03 (Sweden) Non-conceptual labs	18%	This study
Traditional (USA)	16%	Saul and Redish[49]
Workshop physics (USA)	65%	Saul and Redish[49]
RealTime physics (secondary implementation, USA)	42%	Wittman[50]
Conceptual labs 1997/98 (Sweden)	61%	Bernhard[43]

Table 2. Learning gains for different courses in mechanics as measured by the FMCE-test[18].

As displayed in table 2, the learning gains are much higher for the conceptual labs than for the regular courses, and much higher than for traditionally taught courses. The course compares very well, in terms of gains, with secondary implementations of RealTime Physics. However, the normalized gain from the conceptual lab-course considered here is slightly lower than the gain obtained from an earlier conceptual lab-course (1997/98), since it included fewer lab sessions and.

Probe-ware technology is not, in itself, sufficient for the effective learning of mechanics. In a previous study[8], I showed that labs using probe-ware can be effective for learning mechanics, but that this technology can also be implemented in ways that lead to low achievements. According to my analysis, the necessary patterns of variation were not included in the design. The design of instructions, and hence task structure, seems to influence student learning strongly, in accordance with *variation theory*. In other studies I have shown that this theory can be used to design learning environments for interactive lecture demonstrations and learning electric circuit theory[9, 59, 60]. Hence, I argue that my results corroborate variation theory and show that it can be used as a 'tool' for designing labs to promote conceptual understanding[61, 62]..

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