What matters for learning in labs? – Experiences from designing for insightful learning in labs based on a symbiosis of American and European thinking

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Abstract—**This Paper describes how, based on a symbiosis of American and European thinking, "conceptual" labs for engineering courses have been developed in a series of design-based research projects that started in 1995. Researchers working in engineering education have been encouraged to "look for opportunities to translate research questions, theories, methods, and findings… across national and institutional boundaries", and urged to "think globally about the development of engineering education as a research field". Nevertheless, engineering education has been criticized for being insufficiently global in its practices. The aim of this paper is to meet these challenges. At first the design of labs was inspired by "interactive engagement" curricula such as "RealTime Physics" and "Workshop Physics" developed in the US, after they had been adapted to the Swedish setting and traditions. Variation theory, pragmatic and (post-)phenomenological theories of the philosophy of technology, and activity theory influenced later development. Labs for advanced mechanics, and for introductory and advanced courses in electric circuit theory, were later developed using similar ideas. The labs utilized probeware and real-time computer-based measurement technologies as a mediating technology, and tasks were designed according to variation theory.**

Students' learning in several designs of these labs has been studied by recording students' activities and interactions by video, and using concept inventories such as the Force and Motion Conceptual Evaluation (FMCE). Some designs resulted in high achievement (normalized gains of 50-60%) on the conceptual tests, well in line with the results from the US. Furthermore, in the labs that led to high achievement, the technology was used help students to focus on important relationships and concepts, i.e. the technology functioned as a "cognitive tool". However, the implementation of probeware technology could also result poor achievement. This is explained by differences in how the tasks are designed and structured in the labs – the necessary patterns of variance and invariance in line with variation theory were missing. These results that identify important factors in students' learning in labs differ to some extent from earlier proposals put forward to explain the success of interactive engagement curricula. The results also question some of the assumptions behind "active learning". The analysis presented in this paper was brought forth and facilitated by achieving synergies between American and European thinking.

Keywords — design-based research, conceptual labs, experiential learning, variation theory, mediating tools.

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I. INTRODUCTION

In 1994, the author was given the task of designing a new physics undergraduate laboratory at Dalarna University, a small Swedish university college which was reforming and expanding its engineering education. As a consequence, physics teaching was expanding, and there was an urgent need for better facilities for student lab work that addressed students' conceptual learning difficulties. The author was transferred from the electronics department to lead the development of physics teaching. In search of inspiration to shape the design of the new laboratory, several research-based "interactive engagement" [1] curricula were examined. RealTime Physics (RTP) [2, 3], Tools for Scientific Thinking [4], and Workshop Physics [5, 6], all developed in the US, contained interesting ideas, and led to improved student learning [7-11].

The development of labs inspired by these curricula led to a series of design-based educational research projects [12-18] of which the first was named "Experientially based physics instruction - using hands-on experiments and computers" [19, 20]. As will be described in more detail below, the term "experientially" was deliberately chosen to reflect that the project built on the concept of intentionality defined by Brentano [21]; the pragmatic theories of experience proposed by James [22], Peirce [23], and Dewey [24]; phenomenology [25, 26], phenomenography and variation theory [27, 28]; and cultural-historic activity theory [29].

Researchers working in engineering education have been encouraged to "look for opportunities to translate research questions, theories, methods, and findings so they are readable and relevant across national and institutional boundaries", and urged to "think globally about the development of engineering education as a research field" [30]. Nevertheless, engineering education has been criticized for being insufficiently global in its practices [31, 32].

This paper describes how experiences and theories from both sides of the Atlantic have been used to benefit the design for insightful learning in labs, and how these theories led to deeper insights into what matters for learning in labs. The main focus will be on the development of introductory mechanics labs, although labs for advanced mechanics and labs for introductory and advanced electric circuit theory will also be discussed.

The research and development described in this paper were driven by two rather general research questions:

1. Could the US-based lab curricula presented in RealTime Physics be adapted to and implemented in a Swedish

introductory mechanics courses with good learning results?

2. What matters for achieving good conceptual learning in the laboratory?

The paper starts by presenting the literature related to interactive engagement labs and the theories relevant for this paper in the *Background* section. The subsequent *Methodology* section presents the methodologies used to study students' learning in the labs. The *Findings* section elaborates the results and analysis from four cases. Finally, a brief *Discussion and Conclusion*.

Background theories and methodologies have developed significantly during the two decades over which the series of design-based research projects described here spans. The theoretical framework of the study has thus been developing in parallel with the findings. Thus, some of the findings are prior to some of the items presented in the background and methodology sections, such as video analysis. Such items were not used from the beginning.

II. Background

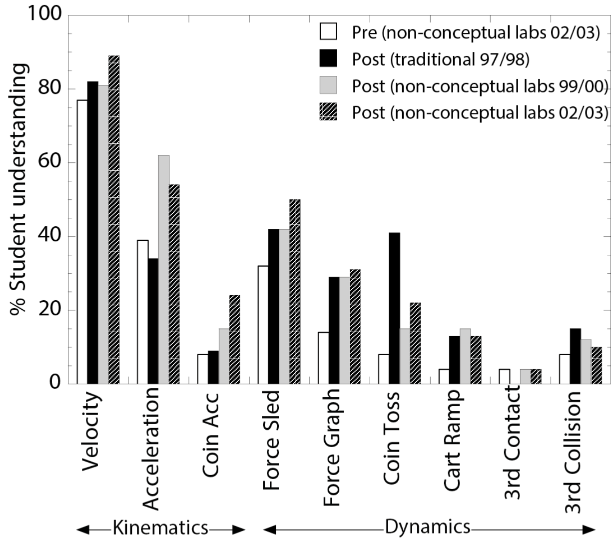

Fig. 1. Students' conceptual understanding of mechanics, according to results based on the FMCE test [33], immediately after non-conceptual university-level courses (post). Conceptual understanding when entering courses, i.e. after upper secondary school, have been used as a pre-test. To avoid overloading the figure, only results from one of the pre-tests are included.

A. Interactive engagement labs

In engineering education, one important aim is to enhance engineering students' capabilities to *apply* and to *use models and* theories. Students are expected to link theoretical models to measurements and observations, i.e. to the objects and events they explore during lab work [34, 35]. However, it is a very difficult task for students to establish relevant links between representations, concepts, theories/models, and observable events and objects [36, 37]. It is well-known that it is a difficult challenge for students to conceptually understand mechanics. As is demonstrated in Fig. 1, most students has not developed a Newtonian understanding of mechanics after participating in a university level course [1, 10, 37-41]. For most students to understand Newton's third law have proven to be very difficult; after studying university level mechanics with conventional instruction only five to ten percent of students could answer conceptual questions correctly (Fig. 1). The literature only describe a few successful approaches to learn mechanics in a conceptual way.

Since the late 1980s, many attempts have been made to create learning environments that through *guided discovery* [42, 43] or *interactive engagement* [1], direct students' focus towards relevant phenomena and concepts. An inquiry-driven learning is fostered by labs adopting these processes. Through carefully designed instructions, technology, and teacher support students are guided in their inquiry. Workshop Physics [5, 6], RealTime Physics [2, 3], and Tools for Scientific Thinking [4] are examples of such research based curricula. A common characteristics of these curricula is that they make insightful use of "probeware"-technology, also known as MBL (microcomputer-based labs).

The introduction of probeware systems in physics and engineering courses more than three decades ago is an excellent example of the use of interactive technology in education [44]. Probeware system consists of a probe or a sensor connected to a computer. Experimental data measured by the probe are analyzed by the computer and directly visualized on the computer screen. By using, for example, motion, force, sound, light, and temperature sensors, a multitude of different lab experiments can rather easily be performed.

The collection, analysis and display of *measured* data (i.e. not simulated data) is done *simultaneously* with the measurement and for this reason it is often alluded to as *real-time* graphing. The immediacy of these measurements enables that labs that constructively and efficiently promote a conceptual and functional understanding of physics can be designed [1, 10, 38, 44]. Secondary implementations (i.e. outside the original site) of Workshop Physics [45] and RealTime Physics [46] have also achieved good learning results, although not as good as those obtained at the sites where these curricula were developed. This may be the result of problems related to implementation. The following characteristics have been proposed to explain the excellent learning achievements reported by learning environments using probeware [8, 47]: "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."

B. Active learning

Active learning is an approach to education that has received considerable attention. It is, for example, one of the CDIO standards [48], and has been the topic of two special issues of the *European Journal of Engineering Education* [49, 50]. Active learning is generally believed to lead to deeper learning, a better understanding of key concepts, and a greater ability to apply knowledge in new and unfamiliar settings [51, 52].

Despite the widespread interest in active learning, the term is often only vaguely defined; indeed, a surprisingly large number of studies do not define the term at all. The authors rely instead on an intuitive – and therefore unsatisfactory – understanding of its meaning. The most commonly used definition is that given by Bonwell and Eison [53]: "instructional activities involving students in doing things and thinking about what they are doing". In a similar vein, Prince

[52] suggested that "active learning requires students to do meaningful learning activities and think about what they are doing". Trumper [54] argued that an usual feature of successful learning activities in the laboratory "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".

The interactive-constructive-active-passive (ICAP) framework proposed by Chi [55] offers somewhat more precise definitions and differentiated distinctions. In this framework, *overt* learning activities are classified as passive, active, constructive, or interactive. In *active* activities a student does something physically; in *constructive* activities a student also generates an output that extends beyond the presented materials; while in *interactive* activities two or more students cooperate on the same topic and have a substantive dialogue that does not ignore and exclude each other's contributions. Chi suggested that student learning is better when interactive activities are undertaken, rather than constructive activities. The latter are better than active activities, which are better than passive learning.

C. Variation theory

Experimentation is regarded by Dewey [56] as an "indispensable instrument of modern scientific knowing". By experiencing differences we learn, and he suggests that "subject-matters which would not otherwise have *been noted*" (emphasis added) may be discovered in experiments by intentionally altering and controlling conditions.

Marton and co-workers have further elaborated Dewey's recognition in *variation theory* [e.g. 57, 58]. This theory propose that to foster successful and insightful learning it is important to design a learning environment that enables students' to discern the critical features of the object of learning. A fundamental idea in variation theory is that we, rather than by recognizing similarities, discern certain aspects of an environment by experiencing variation. Important concepts are therefore *discernment*, *simultaneity*, and *variation*. If one, or more, aspect of an event or a phenomenon can remain the same, while one aspect changes, the latter aspect will be discerned. One of the main topics of variation theory is that For the development of certain capabilities, a main thesis of variation theory is that the pattern of variation intrinsic to the circumstances of learning is essential for this formation. By simultaneously experiencing nonidentical instances of the object of learning the learner is experiencing variation. This simultaneity can be either *synchronic* (the same time experience of coexisting, nonidentical, facets of the same thing), or *diachronic* (*the same time* experience of facets of something that we have come across at different times).

Learning in a particular classroom situation was related by Marton [58, 59] to what students can *possibly* experience in the situation, stating that "the critical aspects that it is *possible* [for a student] to discern…make up the *enacted* object of learning". The difference between the *intended* object of learning (the knowledge, skills. and values the teacher or curriculum designer wants the students to learn) and the *lived* object of learning (what the student learns in the end, i.e. the critical aspects the student *actually discerns*) are other important distinctions.

D. Mediating tools

Intentionality, as defined by Brentano [21], is an important concept in several educational philosophies and theoretical frameworks (such as phenomenography, phenomenology, pragmatism, and activity theory). The idea is that meaning emerges as an individual directs his or her awareness to an object: "There is no learning without something learned, there is no thinking without something thought, there is no experiencing without something experienced" [60]. Thus experience, learning, and thinking cannot be studied without taking content into consideration. The wholeness of our experiences is awareness, but it is differentiated in such a way that some facets are brought to the fore, i.e. focal awareness, while other facets are marginalized and constitute the background [61]. Hence, learning is seen as "a qualitative change in the *relation* between the learner and that which is learned" (Booth 2004, emphasis added).

Dewey [62] put forward that artefacts can be used as "tools of knowing", i.e. as mediating tools. He pointed out that "appliances of a technology [such as] the lens, pendulum, magnetic needle, [and] level were [deliberately adopted in inquiry] as *tools of knowing*". This implies that, in science and engineering, the technology is embodied in the empirical production of knowledge and perception is co-determined by technology. This idea has been taken further by Don Ihde, a philosopher of technology. He synthesized non-foundational phenomenology with Dewey's pragmatism in an approach dubbed "post-phenomenology" [63]. Don Ihde claims that perception is co-determined by technology. Thus instruments, in science and engineering, do not merely "mirror reality", but mutually constitute the reality investigated. Most importantly: the *technology used* places some facets of the physical world in the *foreground*, others in the *background*, and makes *certain facets visible* that would otherwise be *invisible* [26, 64-66].

Learning is promoted by ensuring that students can discern the critical features of the object of learning and focus on them [57]. Thus, the critical aspects will be foregrounded in the learning environment and accordingly come into the learners' focal awareness, making it possible to learn these critical aspects.

III. Methodology

A. Design-based research

The projects described in this paper can be seen as being based on approaches coined "design experiment" or "design-based research" [e.g. 12, 14]. The "benefits of design experiments are that we will be able to contribute to theory development, and improve practice at the same time", according to Lo *et al.* [67]. These ideas, with a more substantial insistence on teacher participation in a study, have been extended further by Ference Marton: he defines a learning study as "a systematic attempt to achieve an educational objective and learn from that attempt".

In cycles of design, the enactment, analysis, and re-design of educational activities have been investigated. The different implementations could then serve as "natural experiments". Cobb *et al*. [13, p. 9] noted that the systematic iterations in design experiments are similar to the systematic variations performed in experimental sciences.

B. Conceptual tests

To conduct an inquiry into students' conceptual understanding of mechanics the *Force and Motion Conceptual Evaluation* (FMCE) [33] has been used to investigate student understanding of one-dimensional kinematics and dynamics in depth. FMCE is a research-based conceptual test that is widely used and well-established instrument. To assess students' conceptual understanding, the test consist of multiple-choice questions utilizing verbal and graphical representations. Common-sense beliefs (misconceptions) make up the carefully designed distractors (i.e. the wrong answers). The test provides a valid and reliable measures of the understanding of basic Newtonian mechanics concepts [33]. As students' achievements on the FMCE test are categorized into various conceptual clusters, the results have been used to guide the refinement of lab designs.

To guide the development of labs in this study, the FMCE was delivered as a pre-test and post-test in all cases. Figs. 1 and 6 present the pre-test and post-test data as "absolute" values for various categories. As pre-test results were rather similar in all cases, pre-test results from only one of the cases is presented in Figs. 1 and 6, thus avoiding overload of the figures. Figs. 7 and 8 and Table II, in contrast, present the data using a measure known as the "normalized gain" (g) [1], defined as g = *Gain*/[*Gain(max possible)*] where *Gain* is the difference between pre-test and post-test values. The normalized gain is commonly used in, for example, physics education research, and enables curriculum designs to be compared taking into account differences in pre-test results between settings.

C. *Video analysis*

To guide the analysis of students' learning in labs their actions and interactions have been recorded by digital video cameras. The aim has been to find patterns of interactions that are typical [68]. The analysis of video data [69] has been inspired by *conversation analysis* [69] and *ethnomethodology* [70, 71], i.e. the focus has been on students' practical, contingent and embodied inquiry during the labs. Selected segments of the video data have been transcribed in Swedish [72]. Only a few, translated, excerpts from the transcripts are presented in this paper due to limited space.

IV. FINDINGS

This section presents the design, analysis of designs and analysis of students' learning in four cases. Subsection A analyzes and discusses Cases I and II, which were inspired by RTP. Subsection B presents and analyzes case III, which used the same probeware as in cases I and II with another educational design. Finally, subsection C compares labs that are considered to be "active learning" (Case IV) with the labs in Case II.

The presentation of the findings build on empirical material for which preliminary analysis have been presented, and discussed, earlier at conferences [73-75]. In this paper, the analysis presented at these conferences are extended. The focus is on the beneficial symbiosis between American and European ways of thinking when designing labs and understanding what matters for learning in labs.

A. *Regular "conceptual lab" design (Cases I & II)*

The design of lab activities for the introductory mechanics course started in 1995 [19, 40, 41], and was heavily inspired by RTP. The mechanics module for RTP consists of 12 two-hour labs using probeware. By tradition, lab sessions in Sweden are four-hour sessions. Furthermore, RTP uses homework assignments extensively, as is customary in the US. Following Swedish traditions for university-level education, homework assignments were not given. At Dalarna University, selected parts from RTP were made into a series of four four-hour labs that used probeware. The first lab, however, used probeware only partially, as students spent about half of the time with the Graphs and Tracks simulation software. In addition, a fifth probeware lab investigating moments of inertia was developed.

The three examples below illustrate the tasks performed by the Swedish students when using RTP. Transcripts [73] from students' courses of actions when completing the tasks have been included for the first two tasks.

Example 1*: Matching a velocity-time graph with students' own movements*. This is an example of an early task in a typical lab-sequence for conceptual mechanics labs. Students are first requested to walk in such a way that their bodily motion would first match different position-time graphs and then different velocity-time graphs. Their motion is detected by a sensor and experimental graphs *that can be seen by the students* are produced in *real time*. Two of the graphs that students are asked to match are presented in Figures 3a and 3b. They bring position and velocity to the fore, respectively.

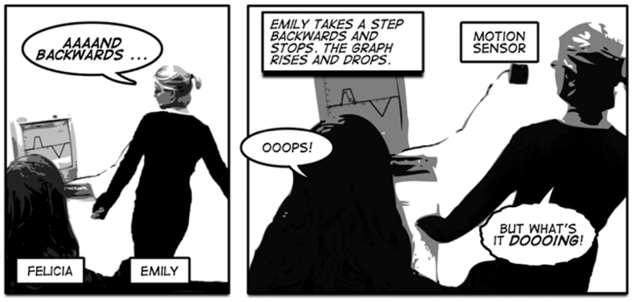

Fig. 2. Two students interacting with the motion sensor and the interface, trying to match the graph in Fig. 3 [41].

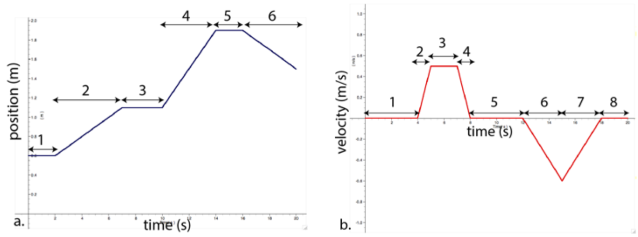

Fig. 3. Illustration of a *position-time* (a) and *velocity-time*-graph (b), that students are requested to match by their own movements in front of a motion sensor (Fig. 2). To facilitate analysis the different sections of the graphs are numbered. However, they are not numbered in the task students' participate in.

Excerpt 1 (Discussing the curve in Fig. 3b)

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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
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Several conceptual distinctions must be made by students to perform these tasks succesfully. Excerpt 1 illustrates the first distinction for the velocity task in Fig. 3b. Turn 1, illustrates the insight by Beata that she must be aware of the distinction between positive and negative velocities. The interpretation is expanded by Anna in Turn 2 by explaining the conventions for positive and negative directions in the measurement setup. The conceptual distinction between positive and negative velocities is something that has been made important for the students at this point.

Excerpt 2 (Trying to match the curve in Fig. 3b)

1. Emily: backwards (0.3) aaand ((takes a step backwards and stops, the graph rises and drops))
2. Felicia: *oops*
3. Emily: but what's it doing?* (0.7) yeah but it [is
4. Felicia: [yea:h
5. Emily: ='cause you stand still here
6. Felicia: no::
7. Emily: then it [goes down to zero
8. Felicia: [yes you shouldn't stand still
9. Emily: =no
10. Felicia: =no it's the velocity that should be [constant
11. Emily: [cons – yea:h

Excerpt 2 illustrates some more conceptual distinctions that the students must make. For example, they must realize that holding a constant position, i.e. standing still, is not the same as at constant velocity movement (as in Fig. 3b Section 3). Emily tries to match the graph in Fig. 3b, in excerpt 2 above. She stops when she get to Part 3 in the graph. However, she and her fellow student Felicia immediately recognize the drop to zero of the velocity graph. They rather quickly realize "that it is the velocity that should be constant".

a.

b.

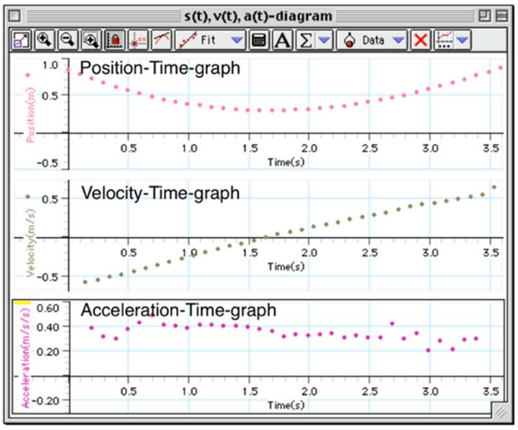

Fig. 4. a) A typical arrangement in a probeware lab. A fan unit is mounted on a low friction cart. The cart is pushed towards the motion sensor and as the fan exert a force in the direction opposite to the cart's initial direction of motion the cart will slow down and reverse its motion. b) The results presented on the computer screen by the probeware (it can be seen that at the turning point acceleration is not zero).

***Example 2**: Acceleration when the velocity is zero.* Students observe the movements of a cart propelled by a fan in this activity. The fan gives the cart an almost constant acceleration (Fig. 3a). Initially the cart is given a push in the opposite direction to the force of the fan, so that the cart will eventually slow down and the direction of movement is reversed. Before making the measurement, students are requested to first observe the cart's movement and sketch predictions of how the movement will be drawn in position, velocity, and acceleration versus time graphs. After making predictions, the cart is again set in motion and the movement is measured by the probeware equipment. Graphs are simultaneously displayed in real time (typical graphs are shown in Fig. 4b). It is necessary for students to understand position, velocity and acceleration concepts, to make accurate predictions. Students must perceive that the acceleration is constant, but that position and velocity vary (velocity even changing sign). Moreover, they need to understand, contrary to what is commonly believed, that a zero velocity is not necessarily associated with a zero acceleration. The request to make predictions is an essential component of the task and is included to encourage students to compare and contrast their thinking with reality. This gives them the opportunity to see which is the most vigorous model. In Excerpt 3, below, students discuss what the what the acceleration-time graph should look like at the instant when the cart is reversing and it has zero velocity.

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

It is suggested by the students that the acceleration "becomes zero for a little while when it turns". However, Cecilia finds that "the acceleration turns out strange" after performing the actual experiment – contrary to their prediction acceleration is not zero, as demonstrated in Fig. 4b. The students debate the results for some time after finding that their prediction was not correct, and finally they choose to discuss it with the teacher.

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. Teacher yes
6. Cecilia because it feels weird

After some discussion between the instructor and the students, the issue is settled in excerpt 5.

Excerpt 5

1. Teacher <u>there</u> 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. Teacher no but you [you have
4. Beata [no
5. Teacher the whole time a constant [change in velocity
6. Cecilia [okay
7. Teacher =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

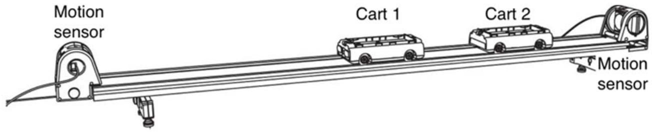

Fig. 5. Experimental setup for the impulse and collision lab

Example 3: *Impulse and collision lab (Newton's third law).* Fig. 5 illustrates the experimental setup in this case. Two carts are put on a low-friction track. On each cart force sesnsors are mounted. Extra weights can be added to the carts. At each end of the track motion sensors are mounted. To undergo an elastic collision (due to magnetic bumpers) one or both of the carts is given a thrust towards the other cart. Forces and the accelerations are measured during the experiment and can be observed by students in real time. A predict-observe-explain cycle is used and students are requested to predict, before each experiment, the forces and the accelerations for the two carts. Table I summarizes the task structure related to this experiment.

TABLE I. TASK STRUCTURE FOR THE IMPULSE AND COLLISION LAB IN CASES I AND II

Task	Cart 1		Cart 2		Measure-ments
	motion	mass	motion	mass	
1	moving	0.5 kg	still	0.5 kg	a_1, a_2, F_1, F_2
2	moving	0.5 kg	moving	0.5 kg	a_1, a_2, F_1, F_2
3	moving	1.5 kg	still	0.5 kg	a_1, a_2, F_1, F_2
4	still	1.5 kg	moving	0.5 kg	a_1, a_2, F_1, F_2
5	The heavy cart ("truck") is pushed by the light cart ("car")				F_1, F_2

A common misconception is that only an object in motion exerts a force when it collides with an object at rest. To confront this misconception experiments are carried out with one of the carts in motion and the other one standing still (tasks 1, 3 and 4). Another experiment (task 2) is carried out with both carts in motion. Extra weight is put onto one of the carts in tasks 3 and 4. The aim of these tasks is to address the conception that a heavier object exerts a larger force than a less heavy object. The final task (no. 5) confront the conception that a force is only exerted by the cart that is pushing another object.

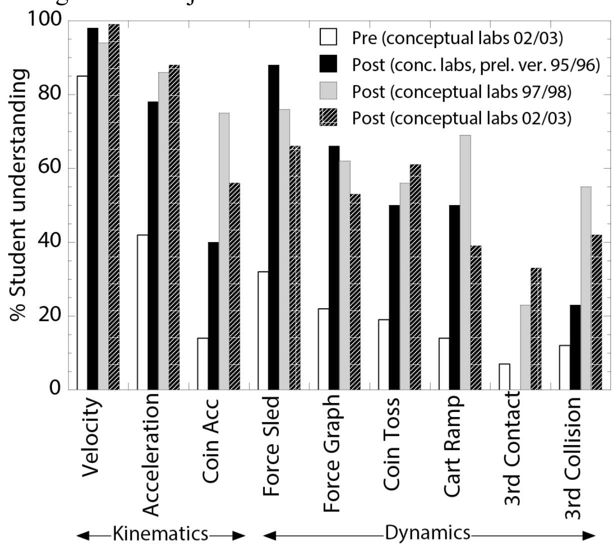

Fig. 6. Students' conceptual understanding of mechanics, according to results based on the FMCE test [33], immediately after upper secondary school (pre) after conceptual university-level courses (post).

After this description of some of the tasks, let us to return to the first research question: can the RTP curricula be successfully integrated and implemented into, and adapted to, Swedish settings? Comparing Fig. 1 with Fig. 6 shows that the implementations have achieved substantial learning gains, as measured by a conceptual test.

Table II shows the findings expressed as normalized gains. It can be seen that the 61% gain in case I and the 48% gain in case II match those obtained using the reformed curricula in the US very well.

The lab tasks described above were modified in order to seek an answer to the second research question: how should the mechanism behind the learning gains be understood?

TABLE II. LEARNING GAINS FOR MECHANICS COURSES

Curricula	Norm. Gain (FMCE)	No. of students	Ref.
Workshop Physics (USA)	65%		[45]
Traditional (USA)	16%		[45]
RealTime Physics (secondary implementation, USA)	42%		[46]
Case I – Conceptual labs 1997/98 (Sweden)	61%	40	[41]
Case II – Conceptual labs: Physics 02/03 (Sweden)	48%	25	[41]
Case III – Non-conceptual labs: Physics 98/99 (Sweden)	30%	31	[41]
Case IV – Non-conceptual labs: Physics 02/03 (Sweden)	18%	86	[41]

B. *Same probeware technology, but different pedagogical design (task structure) (Case III)*

During the author's sabbatical in 1999, the probeware labs were re-formulated to some extent to emphasize an approach designed to verify formulae. Case III is a revamped version of the *impulse and collision* lab, summarized in Table III. There are important differences, although initially it appears very alike structure of the tasks used in cases I and II. In case III, only velocities are measured during the collisions, forces are never measured. Moreover, students are not requested to make predictions for the force graphs but are only requested to make predictions for the velocity graphs. From the measured velocities v_1 and v_2 the students are instructed to compute the kinetic energy ($K=mv^2/2$) and the momentum ($p=mv$). In the next step they are request to compute the forces by computing the time derivative of the momentum, ($F=dp/dt$) and to *verify* the validity Newton's third in this way. However, forces are never measured directly during collisions. (It can be noted that the task structure illustrated in Table II is similar to the task structure that would be possible using an air-track with gliders, where photogates are used to measure velocities before and after a collision.)

TABLE III. TASK STRUCTURE FOR THE IMPULSE AND COLLISION LAB IN CASE III

Task	Cart 1		Cart 2		Measure-ments
	motion	mass	motion	mass	
1	moving	0.5 kg	still	0.5 kg	v_1, v_2
2	moving	0.5 kg	moving	0.5 kg	v_1, v_2
3	moving	1.5 kg	still	0.5 kg	v_1, v_2
4	still	1.5 kg	moving	0.5 kg	v_1, v_2

On first sight the structures of the tasks in the conceptual (Cases I and II) and non-conceptual (Case III) impulse and collision labs can be seen as quite similar. They are, indeed, similar in terms of *variation* in the movements of the carts colliding and the masses of the carts. However, in regard of *simultaneity* and *discernment* there are critical differences. In the conceptual labs, accelerations and forces are measured and presented as graphs in real time. Students are requested to predict these before each experiment. In contrast, forces are not measured in case III, only velocities, and students are not requested to predict the forces. Students are instead requested to *verify* Newton's third law after the experiment have been done. However, this requires a computation in two-steps. As the forces are not directly discerned during the experiments in case III, i.e. a lack of simultaneity, it is valid to describe it as a "non-conceptual" lab.

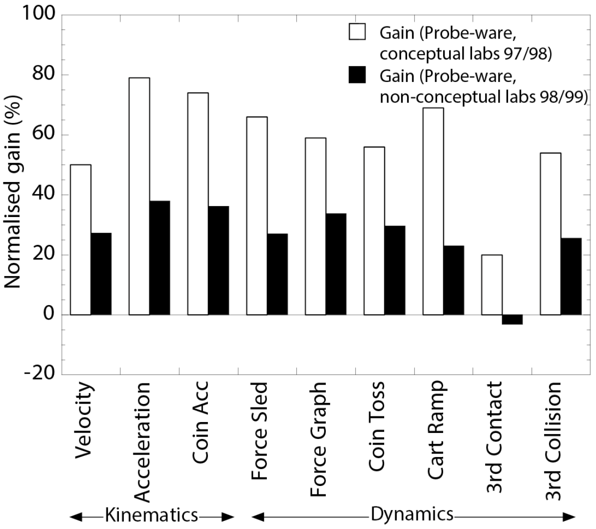

Fig. 7. Comparison of normalized gains between case I and case III measured by the FMCE test [33]

Case III differs from Cases I and II in other ways. However, space does not permit a discussion in further detail.

The results displayed in Fig. 7 reveal a substantial difference between the gains obtained by students in this case and those obtained in case I. However, the normalized gain of 30% seen in Table II shows that this case has achieved better learning than traditional labs.

C. Two active learning labs (Case II and Case IV)

In the 2002-2003 academic year it became possible at Linköping University (Campus Norrköping) to offer two different sets of labs in the introductory physics course for engineering students at. As part of an experiment, the students could choose to participate in a set of labs (case II) that used a smaller set of the probeware labs developed for case I (as discussed in Section A in Chapter IV). Indeed, the transcripts presented in that section are from case II.

The regular set of labs within the course comprised experimental problem-solving (EPS) labs ("Richards" labs [76]). Both sets were made up of four four-hour lab sessions, i.e. a total of 16 hours of lab work. All students attended the same 20 hours of lectures (in a lecture theater), and they took part in similar sets of 12 hours of problem-solving sessions (around 30 students tutored by a doctoral teaching assistant). Thus, in terms of teaching, the only difference between the groups was which version of the 16 hours of lab work that they attended.

Video was used to record students' actions and activities in both sets of labs. Analysis of the recordings revealed that in terms of Chi's [55] ICAP framework, the students' activities in both sets of labs could be seen as interactive, which implies that they were also active and constructive. The criteria for active learning proposed by Bonwell and Eison [53] and by Prince [52] were also fulfilled.

However, the analysis of the video makes it apparent that the students' activities differed significantly. The design of the probeware labs framed students to construct a conceptual understanding, while the EPS labs led students to construct experiments and mathematical models. The content of the students' interactions with each other clearly reflected these differences.

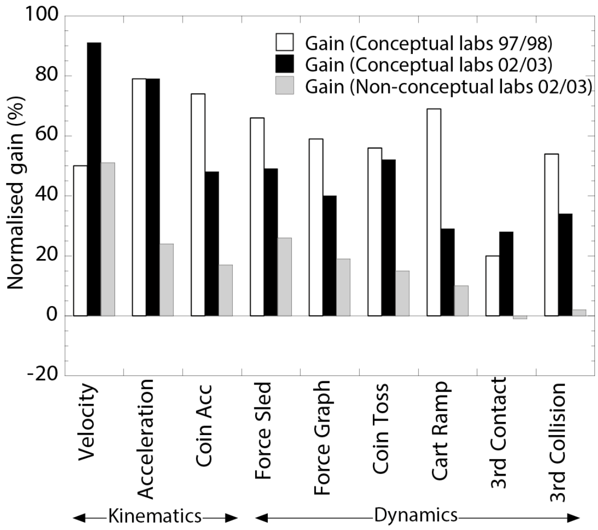

Fig. 8. Comparison of normalized gains between cases I and II and case IV measured by the FMCE test [33]

In both labs, students displayed misconceptions related to important physical concepts. The probeware labs were designed to develop conceptual understanding and to challenge such misconceptions. The EPS labs, on the other hand, did not explicitly challenge these misconceptions, and this means that it is possible for students to arrive at an adequate mathematical model of a physical system whilst having an inadequate understanding of the underlying physical concepts. However, a closer analysis of the activities of the students in the EPS labs suggests that the inadequate conceptual understanding was indeed detrimental for them in their modeling process, and that they might have arrived at an adequate model faster and with a better and deeper understanding if they had arrived at a better conceptual understanding.

The EPS labs constitute an active learning environment, and it has been suggested that such environments lead to better learning. The results shown in Table II and in Fig. 8, however, reveal that the EPS labs in case IV led to no better conceptual understanding among students than traditional labs.

V. Discussion and Conclusion

As mentioned previously, RealTime Physics (RTP) has inspired the development of the labs in cases I and II. At the sites in the USA, where RTP labs were originally developed this curriculum have had considerable success in enhancing students' learning. However, when transferred to secondary implementation sites RTP have often been less successful (yet, still greater results compared to traditionally instructed courses [46]). Many of the tasks designed by me for the Swedish introductory mechanics courses were analogous to corresponding tasks in RTP-labs. However, they were not a straightforward translation of RTP-labs into Swedish. On the contrary, tasks have been selected, adapted and adjusted to suit a context with another culture and tradition and a different course structure. In addition, labs for engineering electric circuit theory [18, 77-79] and for advanced mechanics [80] were not available in RTP. In such cases, tasks were designed "from scratch", but inspired by RTP. Moreover, the design of tasks were also theoretically informed by variation theory and insights from pragmatism, phenomenology and activity theory regarding the value and role of mediating tools in human perception. Thus, a symbiosis of American and European thinking has afforded deeper understanding and better designs than had been obtained if only sources from one side of the Atlantic had been consulted.

Table II shows that the designs presented fare well in comparison with US research-based curricula, such as RTP and Workshop Physics. This success results from basing the designs and re-designs on a theory of learning, variation theory, rather than using an *ad hoc* approach.

This work offers a slightly different explanation than that offered in the literature for the success of RTP (and related curricula). Most importantly, the results highlight that the design of tasks in line with variation theory seem to be essential. Furthermore, pedagogically sound use of probeware technology can help students to focus on the object of learning and discern its critical features [cf. 81]. Finally, the results demonstrate that it is not sufficient that students are "active": in order to successfully perform tasks, the students must deal with relevant concepts in insightful and fruitful ways.

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