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Abstract

Previous research has established probeware as an effective tool in science instruction. Less is known, however, about the reasons for its success. In this study, we investigate this issue further by contrasting the use of probeware with the use of a simulation called Graphs & Tracks. By carrying out an in-depth analysis of pre-service teachers' interaction, we want to demonstrate that the two environments – despite many structural similarities – afforded different contexts for learning. When working with probeware, the students had to make distinctions between different graphs and different concepts in kinematics to accomplish the task. When the students used Graphs & Tracks, their actions and interactions occasionally related to concepts of kinematics but more often implied a trial-and-error approach. We claim that the results show why the use of probeware, in contrast to many other interactive learning environments, often improve students' performance on conceptual tests. At a more general level, the results point to the importance of designing activities where students are forced to focus on relevant aspects of the subject matter in order to complete the task; in this case, activities where students make the relation between representation and the represented a central part of their interaction.

What makes the subject matter matter? Contrasting probeware with Graphs & Tracks

Instructional technologies seldom have any clear-cut effects on educational practices, or learning for that matter. One technological innovation, however, that somewhat contradicts this general characterisation is *probeware*. For over two decades, this technology has attracted the attention of science educators and researchers, as it is suggested that it offers a possible remedy to students' conceptual difficulties in mechanics as well as in other areas of science (e.g. Beichner, 1990; Bernhard, 2003; Thornton & Sokoloff, 1990; Tinker, 1996). Euler and Müller (1999) even claim that probeware is the only computer-based learning environment in physics education that has a proven general positive learning effect.

Although many share the view that this technology can be a helpful tool, the 'mechanisms governing success' of probeware (Linn, Layman, & Nachamias, 1987, p. 252) have been, and still are, contested. In an early and influential study, Mokros and Tinker (1987) suggested four possible reasons for the effectiveness of probeware: the use of multiple modalities, the real-time pairing of events and their representations, the genuine scientific experiences made available and the elimination of the drudgery of graph production. These suggestions have been supported, opposed, and expanded in the continuing dialogue on probeware (cf. Beichner, 1990; Brasell, 1987; Thornton & Sokoloff, 1990), and during the last decade several studies point to the importance of using probeware in carefully designed activities in order to achieve positive results (e.g. Bernhard, 2003; Nakhleh, 1994; Newton & Rogers, 2001)

Today, after twenty years of research in this area, there is still a lack of convincing evidence as to why the use of probeware regularly leads to better scores on conceptual tests than other similar activities. Some see this lack of results mainly as a consequence of the pretest/posttest procedures that are used in many studies (e.g. Berger, Lu, Belzer, & Voss, 1994). Some years ago, Roth, Woszczyna, and Smith (1996) called for a change in educational research: from treating the technological intervention as an external factor towards an approach where students' interaction with technology is investigated. In the last few years, there has been such a change and, as Russell, Lucas, and McRobbie (2003) point out, an increasing number of researchers in the field of science education are now turning to qualitatively oriented methods. Several studies have focused on the investigation of students' *work* with instructional technologies (Choi-Koh, 2003; Kelly & Crawford, 1996; Nemirovsky & Noble, 1997; Roth, 1999; Russell et al., 2003). For example, by shifting focus from representations as an external influence to the practice of graphing (Cobb, 2002; Roth & McGinn, 1997; Roth & McGinn, 1998)

One possible drawback of this second approach is the usual lack of contrasting material offered in the analysis. The use of contrasts is an important principle in various experimental designs, but it is less commonly found in studies focusing on technologies and social interaction. In this latter kind of studies, it becomes necessary to extract the benefits of, for instance, probeware without having something immediate to compare potential findings with, which can make it hard to single out critical differences between different but similar learning environments.

In this study, we will combine a detailed interaction analysis with the advantages of using contrasting materials (cf. Silverman, 2001). We will do this by observing a course in mechanics, where the students participated in two different learning environments, *probeware* and *Graphs & Tracks*, designed for the learning of kinematics. The aim is to explore some critical differences in how students *do* kinematics in the two learning environments. Thus, we want to contrast two learning environments in order to find critical differences between these learning environments, and, in doing this, highlight aspects of the interaction with probeware that, we argue, are central for the success of this particular learning environment.

Probeware and Graphs & Tracks

Probeware, also referred to as *computerised data-logging* or *microcomputer-based labs*, consists of a computer connected to probes that can measure and log different scientific phenomena. The software visualises the measured data in the form of digital meters, oscilloscopes, graphs or tables. For instance, in a kinematics lab students can be instructed to replicate a position-time graph by moving in front of a motion detector (see figure 1). Probeware can be used to carry out traditional recipe or verification labs, where the students are supposed to show the correctness of some formulae or principles (see Bernhard, 2003, for a critical discussion of this use). The alleged potential of probeware, however, is often connected to the possibility of collecting and presenting data in real-time, making it possible for students to immediately interpret a graph in relation to an observed or enacted phenomenon in an exploratory way (e.g. Beichner, 1990; Brasell, 1987).

Insert Figure 1 here

In contrast to probeware, Graphs & Tracks is a purely virtual environment that does not involve 'physical reality'. The simulated world of Graphs & Tracks is idealized and therefore free from friction and other sources of noise. The program involves the motion of a ball rolling on a stylized set of tracks, which can be configured in different ways. For each problem, the computer presents a position versus time graph, a diagram of a ball on a set of tracks and a number of initial conditions (see Figure 2). The students can also choose to observe the corresponding velocity-time and acceleration-time graphs. Six posts support the five segments of the track and the user can alter the height of these posts. The simulation starts when *roll* is pressed at which time the ball rolls down the track and the resulting graph is generated. The general task is to arrange the track and the initial conditions in a way that makes the motion of the ball correspond to the predefined graph. The evaluation is automated, and the computer displays a message when the correct solution is reached.

Insert Figure 2 here

Our comparison between the use of probeware and Graphs & Tracks is *not* based on the assumption that these two environments are comparable in terms of to any *essential* similarities. As is clear from the descriptions given above, the two learning environments have somewhat different characteristics, and they have been designed in different ways. In our view, however, there are sufficient connections between them to make a comparison both reasonable and interesting. Both environments, in the case we examine, are used to reach the *same goal* and to cover the *same subject matter*, that is, to promote understanding of a motion and its representations. Furthermore, the strengths and characteristics of these two environments are described in similar terms: they are claimed to promote student-directed exploration, to provide a link between a phenomenon and its representation, and to support collaboration (cf. McDermott, 1990; Thornton & Sokoloff, 1990). Thus, the two environments are similar enough to make a comparison – which highlights critical differences – interesting.

Methodology and research design

The approach taken here, of video-based studies of technologies and social interaction, can, in line with Jordan and Henderson (1995), be called *interaction analysis*. In the analysis, we have been guided by research that shares an interest in the situated nature of human conduct, such as *ethnomethodology* (e.g. Garfinkel, 1967; Heritage, 1984; Hester & Francis, 2000; Suchman, 1987), analyses of *interaction in the professions* (e.g. Goodwin, 1997; Heath & Luff, 2000; Sarangi & Roberts, 2000), and *situative approaches* to learning and cognition (e.g. Brown, Collins, & Duguid, 1989; Greeno, 1997; Lave & Wenger, 1991). We have also been influenced by studies that use the *constant comparative method* (Silverman, 2001), where provisional hypotheses are tested by using a contrasting case (e.g. Silverman, 1981, 1997). Even more importantly, however, we build on an emerging research tradition that focuses on interaction in science and mathematics education (e.g. Greeno & Goldman, 1998; Lampert & Blunk, 1998; Nemirovsky, Cornelia, & Wright, 1998; Roth, 1999; Säljö & Wyndhamn, 1990).

. Because our primary goal is to examine differences in how the students do kinematics in the two learning environments, we have been using methods for analysing interaction rather than theories of learning. Thus, it could be argued that we are investigating central characteristics of *learning environments* rather than *learning per se*. Instead of trying to find out if the students learn a particular subject matter, we have explored what the students do and which resources they use in their interpretation of tasks. In other words, the students' interactions in the lab are scrutinised as *practical achievements,* and our analytic attention is directed at the methods and resources on which the students rely in order to produce actions and to make sense of the situation.

Students and learning context

The data used in this study are primarily taken from an introductory course in physics at one of the larger universities in Sweden. The 22 pre-service teachers participating in the study were all attending a thematic education course. Most of them had a background in social science and in the humanities, which meant that they had little previous experience of natural science. In the course, the students participated in four labs, each lasting about four hours. The students worked in eight groups of two, three or four. The instructor had considerable experience of working with probeware; he had also written a number of texts on how to use probeware as a "cognitive" rather than "technological" tool (e.g. Bernhard, 2003). In the papers, Bernhard argues that activities involving probeware should be designed as interactive-engagement activities – where carefully written instructions guide students through an inquiry focusing on conceptual issues – rather than as cookbook activities, where students are instructed to verify some textbook equation by following a step-by-step recipe. In this course, many tasks could be characterised with the predict-observe-explain (POE) procedure (Kearney, Treagust, Yeo, & Zadnik, 2001; Linn & Songer, 1991; White & Gunstone, 1992). In these tasks, the students should state a hypothesis, then observe the results and afterwards discuss discrepancies between the hypothesis and the outcome.

The analysis builds on the first two labs, in which the students worked with kinematics. During the first lab, the students were instructed to use probeware to construct graphs of position, velocity and acceleration with the help of probes. One week later, in the second lab, they were asked to investigate the relationship between graphs by using Graphs & Tracks. According to the instructions, the goal of the labs – and the purpose of the use of both probeware and Graphs & Tracks – was 'to give a basic understanding of the representation of motion in the form of a position/time, velocity/time and acceleration/time graph and give an understanding of the relationship between position, time and acceleration'. One additional goal, as regards the work with probeware, was to 'introduce computerised data logging'. The instructions were written by the teacher, who also continuously highlighted the goals for the students.

Data analysis

The main data source consists of videotaped interaction complemented with participant observation and discussions with the teacher. One stationary camera per group was used and all the groups were videotaped during the four labs, resulting in approximately 130 hours of recorded interaction. The entire video material has been surveyed, but in order to explore the issue of how the students worked with kinematics in two different technological environments, we have delimited the analysis to cover only the first two labs, since these two labs dealt with the subject of kinematics.

In the first stage of data processing, all interaction in the two labs were jointly viewed by both authors. During the analysis of these 60 hours of video, a number of recurrent differences in the ways the students handled the tasks in the two learning environments could be observed. A number of preliminary sequences were selected and later examined in data sessions with eight to ten members of our research team with the aim of acquiring a basic understanding of the ways the students acted in the two consecutive labs.

In the second stage of analysing the data, we selected the material that will be used in this study. We wanted to make a cross-section, unaffected by our initial understanding of the differences between the groups. To achieve this, it was decided to pick out *one task* from each lab and to analyse how *all eight groups* solved the tasks on the two occasions. This selection (about three hours in all) was transcribed using the conventions of conversation analysis

(Hutchby & Wooffitt, 1998). The following analysis was performed collaboratively and individually in turns, thereby corroborating our observations. After the iterative procedure of viewing and analysing the videotapes and transcripts, a number of different ways of acting in the environments had been identified. The analysis below will focus on the most salient courses of actions the students took in the two labs. We will, however, also account for other ways of completing the labs.

Results

Below, we will first discuss what conceptual distinctions and ways of conduct that became prominent during the students' interaction when using probeware. Then, we will turn to the second lab and perform the equivalent analysis of the students' use of Graphs & Tracks. Although the individual descriptions may be interesting in their details, they also point to a more general pattern. Unless explicitly pointed out, the excerpts illustrate representative courses of action, which frequently occurred during the two labs.

The first lab: Probeware

Students' actions in the first lab will be exemplified by a task where they were instructed to walk in front of a motion detector in such a way that a graph similar to a velocity-time graph specified by their tutor would appear on the screen (see Figure 3). The computer program calculated the velocity by registering the students' distance from the detector over time. The graphs, which the students created by moving in front of the detector, were plotted on top of the pre-defined graph. This made it possible for the students to see discrepancies between the two graphs while they moved. When the students were satisfied with a constructed graph, they were asked to print it out and give it to the tutor.

Insert Figure 3 here

The matching tasks in this material were often carried out in three phases, which we call *prediction*, *performance* and *evaluation*[1]. In the prediction phase, the students tried to reach an agreement in terms of how they were going to move in front of the detector to replicate the graph given by the teacher. To do this, they used their previous experience of graph interpretation and graph production. The pre-defined graph, i.e. the graph that they were going to match, was translated into verbal descriptions, movements, and gestures. One such verbal description, which gives a detailed account of a movement that corresponds to the graph presented in Figure 3, can be found in Excerpt 1.

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Excerpt 1 - MBL98/4:1
34.  Eric:  first you stand still (.) then you accelerate backwards
            (.) then you continue to walk backwards at a constant
            speed (.) then slo::w down (.) then you stand still again
            (.) then you change direction and accelerate towards the
            detector (.) then you s- slow down and finally you stand
            still.
```

In the performance phase, the students turned the sensor on and walked towards and away from the detector, trying to match the pre-defined graph. As previously noted, the students received direct feedback from the computer screen, which they could then act on. Finally, in the evaluation phase, the students discussed similarities and dissimilarities between the two graphs, they also decided whether to make a new graph or to print out the graph they had made and hand it in to the instructor. The students in this material usually constructed between four and fifteen graphs, with a mean of seven, before they continued with a new task. During this time, they developed an emerging sense of graph interpretation and graph production using interpretive resources of different kinds.

In the analysis of this first lab, we will present three interrelated themes relating to the students' use of graphs and which could be seen as both typical of and central to the completion of this task. In the first section, we highlight something Nemirovsky et al. (1998) call *adopting a tool perspective*. Before they could continue with their task, the students had to know what the motion-detector registered. The instructions gave them some clues to this, but, as we will show, these instructions were not enough, and some groups tried several different ways of verbally describing the graph and moving in the room before they came to a conclusion. In the second section, we will show how the students developed an emerging sense of the relationship between verbal concepts, motions in space and graphical representations by making some *conceptual distinctions*. Finally, in the third section, we will show and discuss how the graph was translated into a kinaesthetic and/or verbal *sequence with increasing refinement*.

Adopting a tool perspective

Before working on the task discussed here, the students' experience of the motion sensor was limited to the production and interpretation of a single position-time graph. With this limited experience, they were not sure what the motion detector was designed to measure or what they had to do to produce velocity-time graphs. They were also uncertain about how the sensor responded. In Excerpt 2, we can see one group having trouble relating the recent movement in front of the detector to the constructed and pre-defined graph. The reason for their problems was related to their interpretation of a horizontal line as representing a constant position instead of constant velocity, as if they were dealing with a position-time graph. This was the first velocity-time graph they had constructed, and they expressed concern about how to get the graph 'to stay up'. Thus, they initially made sense of this task by using previous ways of interpreting the graph where horizontal lines very concretely meant standing still. Because of the real-time graphing, the students, when performing the movement in front of the detector, could immediately observe that standing still did not produce a graph that corresponded to the pre-defined one. Thus, the students are presented with a problem they have to deal with in order to complete the task.

Excerpt 2 – Group 1 (MBL1292a:oj1)

22. Alice: m:: [it can't sta:y up there like that
[((points at the part of the graph that represents constant positive velocity))

23 Jens: (Lab assistant) [so this is, this is a constant
[((points at the part of the graph that represents constant positive velocity))

24. (3.6)

25. Betty: you have to- [you should move to the side,
[((points at the part of the graph that represents constant positive velocity))
sideways [a little bit *like this*
[((stands up and moves upper body to the left))

26. Alice: no but you can't move <u>sideways</u> 'cause then you disappear out of the picture

In the excerpt, Betty suggests that they should move sideways as a solution to the problem of 'staying up'. Here, it is obvious that Betty's previous experience of graph production in this particular setting, where a horizontal line instructing the students to stand still, is intertwined with their current problem of preventing the results in the graph from dropping to the x-axis. Alice responds to Betty's suggestion of moving sideways by saying that this would not present a proper behaviour, and that she would 'disappear out of the picture'. Thus, Alice highlights what the tool measures or, to use an anthropomorphic metaphor commonly used by the students, what it could 'see'. Developing and adopting such a perspective on what the sensor measured – and consequently what became central to the task – was one of the goals of the lab and something that was more or less necessary to consider if the students were to complete the lab in a satisfactory way. It was also something all the groups in this study explicitly dealt with. Later in this task, Betty suggested that they should walk on the spot as a solution to the stipulated problem of moving without going forward or backward, a suggestion that was paralleled in other groups.

The students did not only have to struggle with ideas about linear motion in their completion of the task. Other things that became central for the students included: how far they could walk until they were out of the range of the sensor, how their steps influenced the appearance of their graph, and how a thick sweater made the ultrasonic sounds from the motion detector reflect in another way, thus resulting in anomalies in the graph. In this way, the students had to reason about which aspects of their movements were central in the production of the graph and what kind of noise was inevitable. By becoming increasingly sensitive to what the tool actually measured, the students also approached kinematics and graphing in refined ways, i.e. they become more sensitive to the distinctions that were central to accomplishing the task, something we will explore further in the next two sections.

Making distinctions and using concepts

The conceptual differences between position-time and velocity-time graphs, and between the communicative and scientific concepts of position and velocity, create problems related to the difficulties in realising that the detector measures linear motion. In the data, these differences became central to the task, something all groups in different ways brought up in their completion of the task. As mentioned in the previous section, many things could influence the production of graphs, and it was not until the students expressed specific conceptual distinctions that they were able to make graphs approximating the pre-defined one.

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Excerpt 3 – Group 7 (MBL1492b:oj2)
1.  Hannah:  ((reads the instructions and opens the file)) so this
             was velocity (0.9) time
2.           (1.9)
3.  Inez:    I kno- [what was the first one we did?
                    [((looks at the instructions))
4.  Hannah:  well it was-
             (0.7)
5.  Inez:    it was only motion
6.  Hannah:  posi:tion and time
```

In the excerpt above, Hannah and Inez start on the task by highlighting the difference between position and velocity. This distinction between the two graphs later became a central resource in the interpretation, construction and evaluation of this task. Here, Inez also introduces the somewhat vague expression ‘only motion’ (turn 5). One drawback is that it makes it hard to discriminate between position-time and velocity-time graphs. Another problem is that the term does not discriminate between walking with an increased velocity, walking with a constant velocity, or even walking sideways (see Excerpt 2). In response to Inez' utterance, Hannah draws attention to the difference between the two graphs by dividing the graph into two dimensions, pointing out that the last graph represented 'position and time' (turn 6), which contrasts with the earlier description of the graph as 'velocity time' (turn 1). Seeing, or rather (en)acting, this difference was necessary for the completion of the task: in this course, all eight participating groups managed to make the difference after some struggling.

In Excerpt 2, we gave an example of how two students, Alice and Betty, had great trouble realising what kind of motion was central (i.e. walking on the spot and walking sideways were not relevant actions in this activity). Below, we present an excerpt from a group, which has similar problems interpreting and constructing the horizontal part of the graph that represents constant positive velocity. The group presented in Excerpt 4 had tried to match the graph (in Figure 3) five times, every time they interpreted the constant positive velocity as if they should stand still. During their fifth attempt, they began to realise why there was a discrepancy between the graph they had constructed and the pre-defined graph, why their graph 'goes down', as they put it.

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Excerpt 4 – Group 5 (MBL1492a:oj2)
220.  Emily:    [backwards (0.3) a::nd
                [((takes a step backwards and stops, the graph
                   rises and drops))
221.  Felicia:  *oops*
222.  Emily:    *but what's it doing* (0.7) yeah but it [is
223.  Felicia:                                          [yea:h
224.  Emily:    ='cause you stand still here
225.  Felicia:  no::
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226.  Emily:    then it [goes down to zero
227.  Felicia           [yes you shouldn't stand still
228.  Gina:     =no
229.  Felicia:  =no it's the velocity that should be [constant
230.  Gina:                                          [cons- yea:h
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As shown in the excerpt, Emily walks backwards while watching the graph on the computer screen. Then she stops, and the graph drops to the x-axis. Emily responds verbally to the graph in a questioning way, but she then continues and relates the graph to their actions ('it is 'cause you stand still here', turn 224). Subsequently, she draws the conclusion that the graph 'goes down' (turn 226) because of this. Felicia responds very excitedly to Emily's utterances by proposing that they should not stand still, and that the velocity should be constant. Thus, by referring to the movements and to how these movements resulted in certain behaviours of the graphical representation, they establish a distinction between position-time and velocity-time graphs. Consequently, it is through the practical task of making a certain graph by moving in the room that velocity – as a concept contrasting with the undifferentiated notion of motion or speed – becomes a central and helpful resource for the students. In a similar way, the students deal with negative velocity and the difference between acceleration and constant velocity.

As we can see in the excerpts above, the students intertwined different interpretative (and communicative) resources as well as different experiential domains, such as graphical shapes, with verbal accounts of past actions when interpreting, performing and evaluating the graph and the movement. The most obvious intertwinement in this material is between the *graph as a shape* and the *graph as a response to action* (see Nemirovsky et al., 1998). This means that the students, when trying to make sense of the graph and complete the task, could be seen as putting themselves both into the world of physical movements and the world of graphical representations. This was something characteristic of all the groups and during almost all the tasks using probeware. Thus, it was often by way of movements in space that the concepts of kinematics became relevant.

Refining descriptions through sequential translations

When verbally analysing the graph, the students had to translate the graphs into discrete sections. Such an interpretation, where the student splits the graph into several episodes, is presented in the excerpt below.

Excerpt 5 – Group 8 (MBL1492a:oj2)

2 Julia: so first we stand still (0.2) >right here< then we go backwards (0.8) then we stand still (0.2) then we go towards. (0.4) you can't go (1.8) it feels like you'll end up- at- (0.5) the starting-point (1.0) then you should stand still then you move even closer

Julia's description could be seen as a verbal translation of the graph (pictured in Figure 3) separated into six sections. The sections she mentions do not correspond well to the movement they should perform when attempting to replicate the graph (for such a description, see Excerpt 1). Although the description may be seen as less compelling than other descriptions, it is not arbitrary. Julia divides the graph into approximately the same sections as many other groups; she translates the graph from left to right, and her interpretation has much in common with the interpretations in previous excerpts, where the graph was treated as a position-time graph. A couple of turns later, after struggling with the latter part of the graph (representing negative velocity), and realising that the graph did not represent position and time but velocity and time, Julia and Kylie revise their previous description and make a new interpretation. Together, both students construct a new account of the graph that corresponds to the represented movement in a better way.

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Excerpt 6 – Group 8 (MBL1492a:oj2)
15.  Kylie:  no. no you don't do that or do you? (0.6) no (0.6) no
             you can't do that, [you (0.5) stand still, and then
                                [((points at the beginning of the
                                  graph))
16.  Julia:  you go [backwards
17.  Kylie:         [you go backwards (0.8)
             [and then you continuously increase your speed
             [((points at the graph where they should
                accelerate
18.  Julia:  m::
19.  Kylie:  [then you walk at the same speed
             [((points at the constant velocity))
20.          (1.2)
21.  Kylie:  at that velocity the whole ti- or in ((laughs)) two
             seconds then.
22.  Julia:  yeah that's right you have to walk there. it's yeah
23.  Kylie:  [yes (0.5) and then you decrease the velocity
             [((points at the decreasing velocity))
```

In the excerpt, the students make an interpretation of the first part of the graph (the part where the students move away from the sensor). Again, the students separate the graph into discrete sections and, again, they translate it into a verbal account of a two-dimensional movement. Thus, in both cases, the students are oriented toward the practical problem of graph production and they translate the graph into a verbal description with a focus on qualitative changes in velocity and direction, which could be used as a resource in the production of a graph similar to the pre-defined one. Even though it is not as structured and tidy as the earlier account (which took place in a single turn), it could be seen as a more compelling description of the movement they are instructed to perform. Compared with the earlier interpretation, this includes ‘increased velocity’, ‘constant velocity’ and ‘decreased velocity’ instead of ‘only motion’ (or non-motion) with a particular direction. By doing this, the students introduce one more dimensions (change of velocity) that – as we already have shown – could be seen as central both to the interpretation of graphs and in the completion of the task.

In excerpts 5 and 6, we have presented two examples of students’ verbal, and sequential, translation of the graphs, but the ways the graph could be translated into a verbal description are in principle (although not in practice) infinite. For instance, one of the groups’ readings of the graph at first focused on quantitative aspects of how they had to walk before they changed the velocity or speed. Thus, the students in this group did not focus, as did the other groups, on the qualitative aspects of the graph, but instead on the exact distances and velocities. After they had calculated the different distances, they put small pieces of paper on the floor, signifying distances and points where they should change velocity. Later, however, when they had constructed one graph by moving in front of the detector, they started to use real-time graphing as a resource for their actions and interactions instead of calculations of the distances from the detector. They found it complicated to look at the pieces of paper on the floor, and it was easier to look at how the graph was plotted on the computer screen. Much of the task is a about timing the movement, and even if the bits of papers indicated *where* the students should change their movements, the students did not get any visual aid in evaluating the *speed* of the movement.

Trying to use strategies, other than real-time graphing, was not something special for this group. Attempts to use more quantitative ways of interpreting the graph were explored and abandoned by most of the groups. Thus, the most important findings, from the empirical observations, are that the task of graph matching made some resources and some distinctions more useful than other resources and distinctions, and, furthermore, that the sequential translation of the graph eventually became fairly uniform between the groups, with the students focusing on approximately the same things, dividing the graph into the same sections, and using the same concepts.

We have now highlighted three evolving themes connected to the students' courses of action that were characteristic of the work with probeware: The adoption of a tool perspective, the emerging use of conceptual distinctions and the making of increasingly refined descriptions of the graph. Not only were the strategies and resources adopted during this lab helpful for the students, but these three themes can also be seen as progressive in the sense that the following theme builds on the former. With this last point in mind, we now turn to the analysis of the second lab. The aim is to show an example how a lab, which has the same goal, is directed toward the same content as the previous lab, and uses a tool that – at least on a superficial level – has many structural similarities with probeware, can lead to very different courses of action. As we will demonstrate, what the students do, what they focus on and what interpretative resources they use to complete the lab are quite different from what we found in the previous case. To show this, we will again characterise typical and central features of the students' courses of action in this particular lab.

The second lab: Graphs & Tracks

The second lab on kinematics took place about one week after the first hands-on activity. This time, the same eight groups of students worked with a simulation called Graphs & Tracks, which was new to them. The purpose of this lab was the same as the previous one and it was emphasised that the program had been specially designed to promote understanding of the connections between motion and its different forms of representation. As pointed out in the introduction, however, there were some differences between the tasks that included probeware and the tasks they were now going to perform with the simulation. Since Graphs & Tracks is a purely virtual environment, the students did not measure anything "real" outside the computer. Instead, the students, in eight tasks of increasing difficulty, were to arrange a symbolized track and some initial conditions in such a way that the motion of a ball corresponded to a predefined graph.

In the program, the five segments of the track are of approximately the same length and supported by six posts (see figure 2). The students could alter the height of the posts as well as the initial values for both position and velocity. In addition, there was the possibility of viewing the corresponding velocity and acceleration versus time graphs as they could provide additional information. At any time, the students could roll the ball and watch the computer generate the resulting graph. One of the easiest ways of solving the tasks is to use the position-time graph for the initial position, the velocity-time graph for the initial velocity, and the acceleration-time graph for the slope of the track. As we will show, however, this was not a strategy used by many students.

In the analysis, we will first discuss how some groups struggled with *discrepancies* arising between the different representations. Secondly, we will illustrate the frequent making of sequential translations, and how these translations could highlight *time* as a relevant concept. Finally, we will go into the problems of using an *iterative* course of action, and how the students' hasty conduct seems to impede progression.

Coordinating representations.

Throughout the material, a recurrent difficulty for many of the groups was to find a match between the track and the predefined graphs. This could be seen as a trivial and hence not a surprising theme to find – matching the track and the predefined graphs is exactly what the students are supposed to do in all tasks that included Graphs & Tracks. What is interesting, however, is the different ways in which these difficulties were handled.

```
Excerpt 7 – Group 5 (G&T2191b:oj4)
51.            ((the simulation is run))
52.  Gina:     this is pretty good (0.2) but eh::
53.  Felicia:  where does it go wrong then (0.6) *where does it
               [fail*
54.  Gina:     [*where does it fail* (0.2) I don't kno:w (1.9)
                 [it's going down too fast
                 [((points at the discrepancy between the two
                    graphs))
```

Although the students in this group explicitly comment on their deviant graph, they are not certain about what resources to bring in to correct it. In order to establish relations between certain parts of the graph and the static sections of the track, a number of different resources could be employed. One hypothetical way to start this task would be to use real-time graphing, which in this case would imply relating the simulated rolling of the ball with the accompanying plotting of the graph. The simultaneity in this process could be seen as a natural basis in an examination of the interrelationship between the two representations. A small feature in the construction of the program, however, makes this possibility almost non-existent. Since the time it takes for the simulation to run is dependent on the speed of the computer, the simulation tends to be over in only a fraction of a second, especially when using up-to-date hardware. This causes real-time graphing in the simulation program to become an almost invisible, or at least a very marginal, event and only the traces remain.

In the next excerpt, the same group of students still grapple with the problem of coordinating the two representations and insists on using real-time graphing as a productive resource despite the problems. To overcome the swiftness of the simulation, they have to divide the actual observation between them and each focus on one single point of reference. By engaging in this procedure, the group manages to translate one point of the graph into one section of the track and vice versa.

```
Excerpt 8 – Group 5 (G&T2191b:oj4)
72.  Gina:     now I'm gonna see exactly (0.2) when I say no::w you
               check where the ball is
71.  Felicia:  m::
72.            ((the simulation is run))
73.  Gina:     now
74.  Felicia:  now it's at four five
```

This example is a unique occurrence and not a representative course of action for the groups. It does, however, illustrate to what extremes the students have to go to in order to establish a singular translation in this environment. Doing this by means of the simulated event requires extensive coordinating work. Accordingly, focusing on these features in Graphs &

Tracks is hardly rewarding, especially in comparison with the use of probeware where the simultaneity of graph production and motion is unavoidable. The aspects of the task, which are highlighted by the students in the process of completing the tasks, are different.

Making sequential translations.

Instead of employing real-time graphing, most groups took the predefined graph and the traces of the simulation as their starting-point. Structured by the discrete sections of the track, the static graph was treated in a similar way as containing several smaller parts (although the graph could be see as continuous). When treated in this way, the graph was most often translated from left to right.

Engaging in the procedure of sequential translations took some groups further than others. Some of the groups soon ran into trouble and tried out other approaches (one of which will be discussed in the next section). For the students who held on to this strategy, time eventually became necessary to consider. This is exemplified in Excerpt 9. Here, the two students have arranged three of the five sections of the track correctly but are now struggling with the fact that they have only managed to reproduce one fourth of the graph.

```
Excerpt 9 – Group 8 (G&T2193c:oj4)
73.  Kylie:  it doesn't feel like [they're enough for you
74.                                [((points at the two rightmost
                                      sections of the track))
75.  Julia:  no
76.          (5.6)
77.  Julia:  well (0.5) no never mind
78.  Kylie:  sure it feels like it should
             [move like that for quite a while
```

79. [((points along the declining part of the graph))

80. Julia: ye:s and then it's going up he::re and

81. Kylie: ye:ah

82. (4.2)

83. Julia: but here eh- (0.8) I have trouble thinking should we
run it once and see

One of the students highlights the two rightmost sections of the track by pointing at them and commenting on the problem of temporal duration. The specific problem these students are facing is that the predefined graph represents a pendulous motion. Thus, the track has to be used more than once and the correct design looks something like a dish (see Figure 2). From a curricular perspective, the kind of discussion found in Excerpt 9 is interesting. The exercises are deliberately constructed in order to highlight issues like this. For the group in question, the problem was eventually overcome when they discovered what a dish-like construction would imply. It is important to note, however, that the design of the program in no way automatically kept the students focused on the problem. Instead of struggling with such incongruities by means of joint reasoning, one could just as easily switch to strategies of repeated trials, something that will be explored further in the next section

Solving the problem by trial-and-error

Although the production of graphs and the tuning of the track in the exercises are actions that are dependent on concepts from kinematics, the kind of kinematics that the students were doing was not determined by this inherent connection. This is exemplified by a trial-and-error attitude fostered in most groups. Rather than suggesting hypotheses and reasoning about possible outcomes, an activity that requires a certain amount of effort by the students, the simulation was run and the calculations were left to the computer to perform. In the process, repetition became a very important resource for reaching the correct configuration. One group using this strategy needed as many as forty trials while another group, using a different strategy, solved the same task in five trials.

Excerpt 10 – Group 3 (G&T2191a:oj4)

150. Carol: think it should down (0.5) a little bit (1.3) what
happens if it is like this (0.6) oops (1.6) why no ϒI
am pulling upwardsϒ (5.3) did we have it like that?

151. Diana: no:: I don't know

152. ((the simulation is run))

153. Diana: well (.) it's not that bad

154. Carol: but no: it was up at five before right? (1.2) then it
was better. (1.2) should these be equal then?

Excerpt 10 shows a group, which had made many small adjustments previously and has now returned to an earlier configuration. The group members do not remember whether or not this track is similar to an earlier trial, and they try to consult each other about this. Even in other cases, when repetition was used as the primary means, it affected how the students progressed.

In Graphs & Tracks, it is very easy to make small corrections to the track, run the simulation and then watch the result. The new result can quickly be compared to the previous trial, and the students often highlighted the difference between attempts. In spite of this, the effect of this strategy is not cumulative and as a result, many groups forgot what adjustments they had already made, something found to be both frustrating and boring.

The use of sequential translations and trial-and-error were the two most prominent courses of action in this lab, but there where also other ways of solving the task. Two groups at some point made use of the possibility of switching graphs in order to extract additional information, and one of these groups used physical reasoning as a productive resource. In addition, one group asked the teacher for help, and still another group simply skipped the task.

Discussion

With this empirical account of the students' activity as a basis, we can now turn to the comparison. The aim of this comparison is, as stated earlier, to acquire a deeper understanding of why probeware often results in better scores on conceptual tests than other similar activities. The most important issue here is what kind of kinematics emerged in the two environments, that is, the question of how the representations and phenomena where interlinked during the two labs.

A basic difference between the environments, as observed in the analysis, was the kind of interpretative resources that were used in the co-ordination of actions and in the completion of the tasks. In the probeware setting the graph could be referred to by synchronised pointing gestures and verbal descriptions of prospective actions. When dealing with this graph, the students almost all the time, and in different ways, dealt with *motion*. The graph was not just an abstract symbol system, but also something that was talked about in terms of 'velocity' or 'speed' and physically acted upon by moving in front of the detector. In Graphs & Tracks however, the graph was managed differently. A central idea governing the design of Graphs & Tracks is that students should shift between the three available graphs and, in this way, compile information about the motion of the ball (McDermott, 1990). Nevertheless, very few students used this possibility as an interpretative strategy when tackling the task. The prototypical strategy was to avail oneself of mainly one graph, usually position or velocity, and work with this until finished. In this way the work performed by the students mainly consisted of the digital manipulation of the simulation, and, it did not involve *motion* in any way relevant for the graph.

This basic difference, as regards the kind of work the students had to perform through the course of the two labs, had further consequences for what subject matter that became enacted.

In using probeware, the graphs were often translated into a verbal description, prescribing how the student should move. These descriptions developed over time and gradually began to involve an increasing number of physical concepts and distinctions. The probeware environment is designed to be used by dyads or smaller groups, and this was also reflected in the need of co-ordination among the participants. Even though probeware is a very rich environment appealing to several senses, the students often *had* to co-ordinate their behaviour verbally in order to produce a graph that approximated the predefined graph. As shown in excerpts 2 and 3, it was essential to separate velocity-time from position-time graphs. This difference was the result of a struggle between previous experiences of position-time graphs and the current graph presented by the computer. Furthermore, the students had to make distinctions between constant versus changing velocity, and between positive and negative velocity. Not only did they have to make these distinctions discursively (as communicative means), they also had to enact them physically with their own bodies. The students had to relate all this to the sensor in certain ways, something that often led to discussions about the actual process of data collection and possible sources of noise.

This developing use of relevant distinctions and physical concepts when using probeware stands out as an important observation, especially as the successful solving of tasks in the second lab did not *necessarily* involve any relevant distinctions. In the work with Graphs & Tracks, the language had a more subordinate role in the sense that progress could be made more silently. This, again, could be seen as a result of the design of the software. A single user can easily handle Graphs & Tracks, and there is nothing in the design that encourages collaboration. When working together on these tasks, the students most often talked about adjustments of the track, but they hardly ever used any concepts concerning *motion*. The verbal communication was more directed at specific details, like the height of individual posts or the inclination of a certain section, and it was never about the overall character of the represented motion. The tasks could be solved by everything from initiated physical reasoning to trial-and-error, ‘cheating’, or sheer luck. Some groups managed to solve the tasks using only the position-time graph, while other groups only used the velocity-time graph – a fact that indicates that a distinction between these two graphs was not a prerequisite for solving the tasks.

Remembering that we have studied the same groups of students, these discrepancies illustrate how two designs, which share the same goals, can be used very differently with respect to the ‘same’ subject matter. We believe that this observed difference – the enactment of basically two kinds of kinematics – is of crucial importance for what experiences the students had and, hence, for what they learned.

Conclusion

By making the comparison between the students’ interaction in the two environments, we have shown some central aspects that could explain why students perform better after working with probeware, in comparison to simulations or other similar activities. The focus of this study has been on how the students handle the content of kinematics in two different computer-based learning environments. The original problem was students’ difficulties in handling graphical representations.

The results suggest that any designer, trying to deal with this issue, needs to ensure that students’ *interaction* with the technology involves connections between the phenomena (e.g. motion) and its graphical representations and, in addition, that these connections are mediated by the appropriate conceptual apparatus (cf. Säljö, 1999). That the technology itself embodies such interconnections is in no way a sufficient condition. The real educational challenge lies in promoting the students' use of conceptual resources when working on the tasks. And it is on this point, we argue, that one can begin to understand the success of probeware. Although both probeware and Graphs & Tracks have been described as having almost the same set of characteristics, the analysis shows that there are huge differences in how the students approach and enact kinematics in the two environments. Connections between motion and graphs were made in a satisfactory way in the case of probeware, but not in the case of Graphs & Tracks. Without such connections, the phenomena and the representations will remain detached from each other, and one could question whether such an activity should be regarded as dealing with kinematics at all.

In addition, an interesting question could be raised in relation to the students' educational background. Would not students more experienced in kinematics turn the lab with Graphs & Tracks into a more productive exercise than the one observed here? Such a scenario is most likely. But again, we argue, that these observations, of students with limited experience of kinematics, are important because they accentuate the role of the learning environment. As educational researchers, our focus should be on those students more prone to conceptual difficulties, or the population as a whole, since the group of 'better' students seems to get by more or less regardless of the conditions.

By necessitate a certain way of solving the tasks, students had to explore conceptual issues. After all, when using probeware all students *did* develop an increasingly refined way of describing and conceptualising the graph. In our view, this was due to the demands of the task in combination with the properties of the technology – there were no other *easy* ways of achieving a satisfying result.

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[1] In a paper dealing with similar assignments, Russell et al (2003) identifies five stages in the students' completion of the lab: "(a) understanding the problem and predicting; (b) setting up the experiment and display; (c) collecting, observing and assessing the graphic data; (d) analysing; and (e), explaining and recording the results." (p. 222). In a previous paper (X & Y, 1999), we have made a similar division of the different phases. Here, however, we have chosen to use only three phases since it has proved to be difficult to make a temporal division between "predicting" and "setting up the experiment" as well as between "analysing" and "explaining and recording" (cf. X, Y, & Z, 2001).

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Figure Captions

Figure 1. Probeware. Two students interacting with the motion sensor (left) and the interface (right).

Figure 2. Graphs & Tracks. The (position-time) graph and the track match each other.

Figure 3. The pre-defined graph used in the task and a graph produced by a student. When constructing the graph, the student changed direction instead of decreasing the velocity, which resulted in the anomaly represented in the right part of the graph.

Figure 1.

Figure 2.

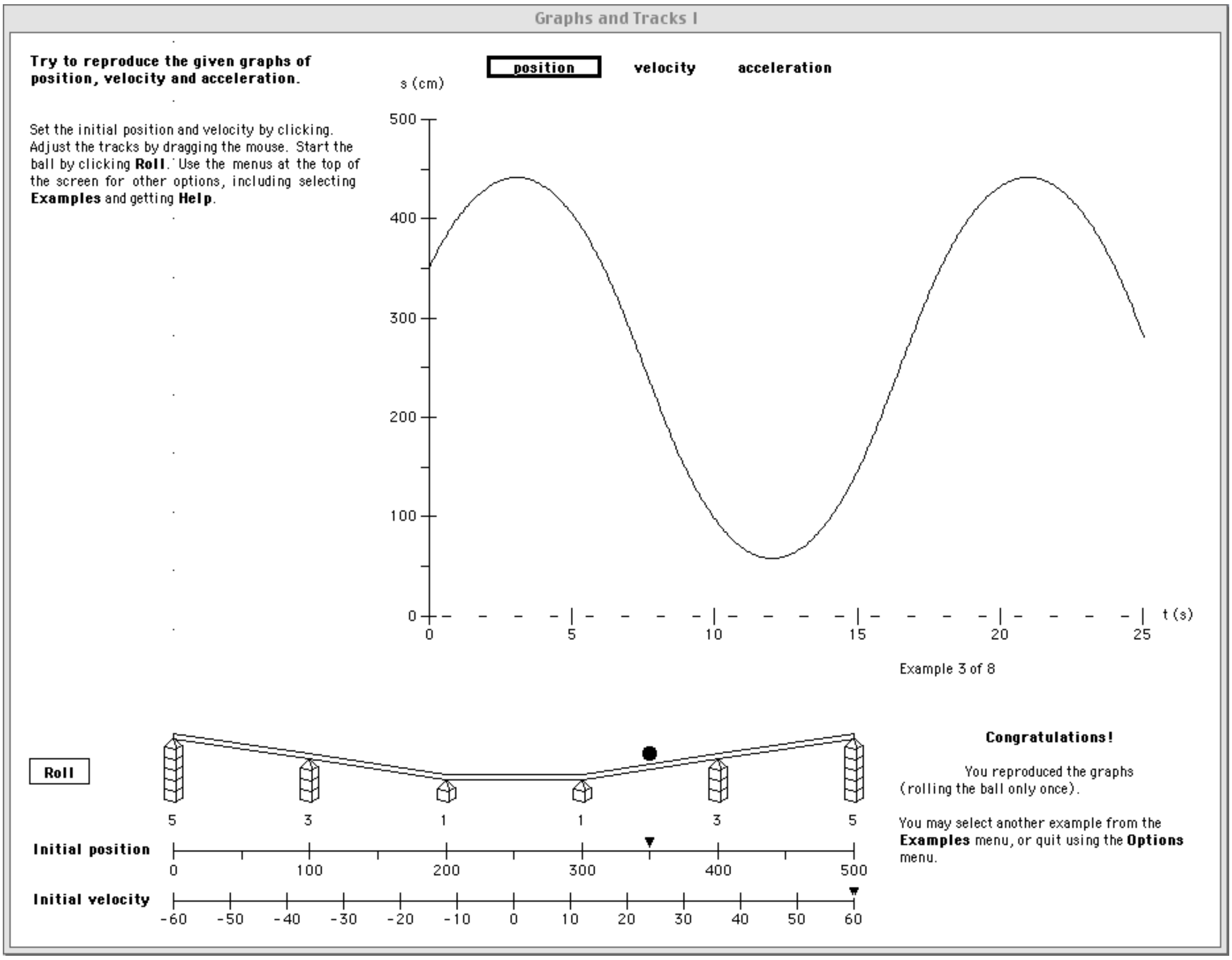
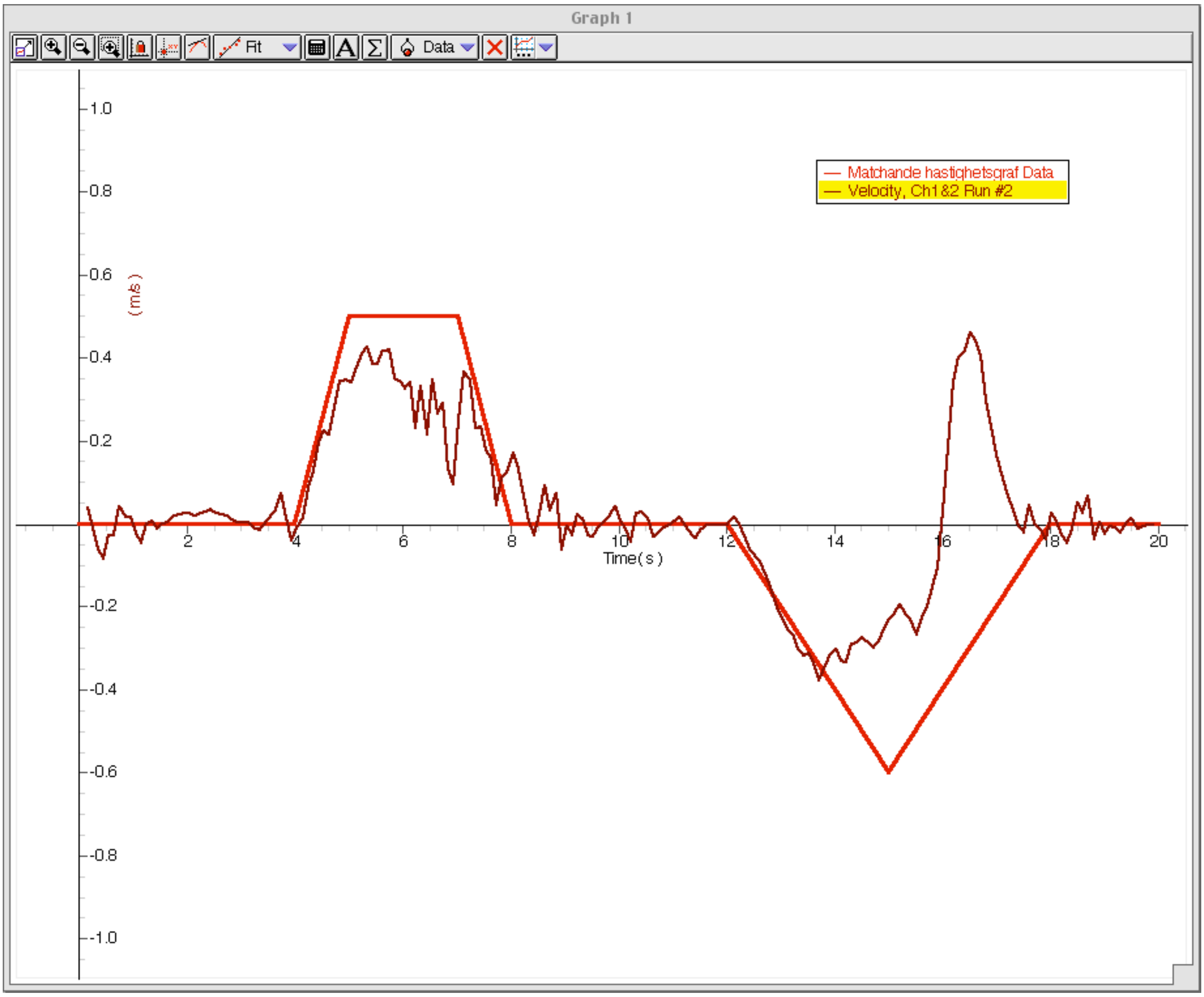

Graphs and Tracks I
Try to reproduce the given graphs of position, velocity and acceleration.
Set the initial position and velocity by clicking. Adjust the tracks by dragging the mouse. Start the ball by clicking Roll. Use the menus at the top of the screen for other options, including selecting Examples and getting Help.
position
velocity
acceleration
s (cm)
500
400
300
200
100
0
0
5
10
15
20
25
t (s)
Example 3 of 8
Roll
5
3
1
1
3
5
Initial position
0
100
200
300
400
500
Initial velocity
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
Congratulations!
You reproduced the graphs (rolling the ball only once).
You may select another example from the Examples menu, or quit using the Options menu.

Figure 3.



Graph 1
Fit
Data
1.0
0.8
0.6
0.4
0.2
-0.2
-0.4
-0.6
-0.8
-1.0
(m/s)
2
4
6
8
10
12
14
16
18
20
Time(s)
Matchande hastighetsgraf Data
Velocity, Ch1&2 Run #2