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RESEARCH ABOUT THE USE OF INFORMATION TECHNOLOGY IN SCIENCE EDUCATION

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ABSTRACT

In this paper, we investigate some aspects of effectiveness in two different kinds of learning environments with use of information technology. The first part shows research results related to a web-based integrated science environment (WISE) and its effects on changing the role of the teacher, the curriculum, and the student. In the second part, three different approaches for scaffolding conceptual development in physics by using interactive computer models are analysed. Research results about different aspects of their effectiveness are presented. Both parts together show empirical results in relation to different promising approaches of using information technology in science education.

1. INTRODUCTION

Information technology can be used in science education in many different ways. From a social constructivist perspective, those forms bear the most potential for learning in science education, which provide help for social learning in groups combined with interactive work with the computer. The computer then can have several supportive functions: It can supply information, for instance from the Web, it can supply new representations of models and theories, or it can stimulate social interactions about representations on the computer screen. All this is interactive, it can be manipulated by students, thus making thinking visible. In this way, the computer becomes a part of an integrated learning environment to foster social and active learning in science, which can be called “scaffolded knowledge integration” (Linn 1998, 275). This paper does not look for learning processes in detail as in other papers of the same authors (Fischer 1994; Petri & Niedderer 1998). Instead, this paper describes certain features of ICT use in the science classroom and research results about their effectiveness. More studies of that kind will be published elsewhere (Psillos & Niedderer 2002, chapter 5: Labwork Based on Integrated Use of New Information Technology).

2. ICT[1] IN SCIENCE EDUCATION – CHANGING ROLES OF CURRICULUM, TEACHER, AND STUDENT

Web-based Inquiry Science Environment (WISE) - refining our technology and curriculum. The role of teachers and teaching is quickly taking a different pathway as phrases like, "Children responsible for their own learning", "Information, communication and technology" "teaching across the curriculum" and "Project directed teaching" enter the science curriculum (e.g. the national curriculum of Norway in 1997). The WISE learning environment is developed to help scaffold students as they perform innovative science inquiry projects. In our view of *Scaffolded Knowledge Integration,* inquiry activities should engage students in the intentional process of diagnosing problems, critiquing experiments, distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments (see also the paper of Linn *in this book*). WISE provides an Internet-based platform for middle and high school science activities where students work collaboratively on inquiry projects, making use of "Evidence" from the Web. Typical projects engage students in *designing* solutions to problems (e.g., building a desert house that is warm at night and cool during the day), *debating* contemporary science controversies (e.g., should we have wolves in Norway?), or *critiquing* scientific claims found in web sites (e.g., arguments for life on Mars). Figure 1 displays the WISE interface where students navigate through activity steps in the left-hand frame of their Web browser, called the "Inquiry Map." All of these materials can be seen, and activities explored at our project Web site: http://wise.berkeley.edu or at the Norwegian site: http://viten.no

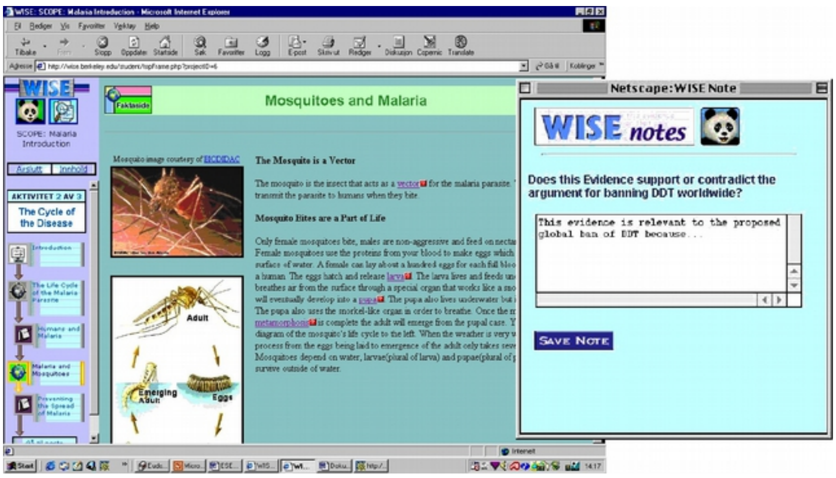

Figure 1: Example of a WISE screen page and the WISE note taking tool

1 Information and Communication Technology

The changing role of the teacher and the curriculum. In an empirical study we followed two teachers in the US (Sandra and Gilbert) and one teacher in Norway (Marit) as they taught the *cycles of Malaria* project first in year one, then in year two. We compared teaching strategies of the three teachers as they integrated the WISE unit into the curriculum, looking for differences in teaching styles. We measured student performance in WISE by analysing pre and post test gains as well as looking at embedded assessments in the form of note taking. Finally, teachers were interviewed after each year's implementation.

In the first year run of *Cycles of Malaria* we started to see the emergence of different teaching styles when using WISE materials. Sandra had a pattern of engaging deeply with individual students for several minutes at a time, while Gilbert and Marit showed a different pattern of cycling through the classroom, stopping at each group to see if they were progressing. Whereas all of the three teachers seemed to be letting the technology run their classes, Marit and Gilbert relied more on the technology to lead the way. In interviews with all of the teachers they expressed concern that they were not familiar enough with the curriculum materials and did not completely understand how the net-based program would work in the science classroom.

In the second run of the curriculum unit (year two of C*ycles of Malaria)*, we started to notice differences in how teachers were preparing their students. Marit planned the Malaria unit as a part of her yearlong syllabus, including chapters on micro-organisms and disease and sickness before using *Cycles of Malaria* as a capstone project to integrate information. She was more careful to ask students to support the answers they provided on their notes and was more successful in talking to groups of students about their progression throughout the unit by looking with them at their completed on-line work. Marit was able to customise the malaria unit to fit into her pedagogical style of teaching as well as into her content goals for her science syllabus. She commented that she was much more comfortable teaching the unit the second time and expressed a sense of ownership in materials as compared to the first year when she was both sceptical and anxious to using this new form in her science teaching. When asked about using WISE, Marit's students commented that they wanted more WISE projects, thus supporting Marit's observation that this is a positive way to introduce variation in teaching science.

Pre-post student learning gains. There were dramatic changes in pre-post gains demonstrated by all three teachers in year two. Using an example from Marit's students we asked about the way malaria could be spread. The pre and post test comparisons demonstrate gains in all classes after completion of the unit.

Student comments. It was not unexpected that students' logs would reflect positive attitudes about using ICT in science teaching. Our experience is that students like most things connected to computers and with variation in teaching methods. A common comment in the student logs was "give us more WISE", especially more about malaria and disease. On the negative side, we have learned that students at this age do not like reading lots of text on the computer and particularly in Norway, they did not all like looking at English language sites.

3. DIFFERENT SOLUTIONS FOR MODELLING PHYSICS

Experiments, models and simulations. Modelling in a general sense is the most fundamental activity in science and science education. An important aspect of learning in science is to connect the two worlds: the world of theories and models and the world of objects and events (Tiberghien 1994). The general task of computer-based modelling is to help students develop a relation between the two worlds. Scaffolding in science education therefore refers not only to the development of particular concepts, but also to the development of an understanding of the process of building explanatory models. In physics teaching, experiments play a crucial role and provide opportunities for students to interact with objects and events in the physical world. In inquiry-based physics courses students are often expected to move directly from these interactions with phenomena in the world to the development of conceptual models that can explain those phenomena. This is a very difficult task for many students (Kuhn, 1993). Researchers have found that very often students do not link theory to their actions during experiments. “To many students, a ‘lab’ means manipulating equipment but not manipulating ideas” (Lunetta 1998). The integration of experimenting and modelling is an important step towards conceptual development, which can be fostered by appropriate computer tools (Schecker 1998). Efforts in computer-enhanced instructional design have led to the development of computer tools that can help students form connections between their experiments and their evolving conceptual models.

Research described in this paper features three different computer tools for fostering model building in physics learning:

- A CPU[2] static electricity and magnetism simulator (Otero, Goldberg)
- SimulaSON - macro and micro models of vibration/sound (Vince, Tiberghien)
- The model building system STELLA (Hucke, Sander, Fischer, Niedderer)

Common features of all three tools are that a model is represented graphically on the computer screen, that the students can manipulate it and that it is related to specific laboratory experiments. In all three learning environments, the interrelation between real experiments and computer representations of models is crucial.

Static Electricity and Magnetism Simulator (Otero, Goldberg). A unique aspect of the CPU materials (Goldberg 1997) is the way that the computer simulator is embedded in the activity documents (Otero et al., 1999). Students are expected to move back and forth between laboratory observations, computer simulators, and the activity documents. The CPU Static Electricity simulator (Goldberg et. al. 2000a, 2000b; Hickman et al. 1999) shows what would happen in a hands-on experiment and overlays representations of a corresponding conceptual model. This property of dual representation was designed to help students to make connections between their hands-on experiments and their evolving conceptual models of observed phenomena. The CPU static electricity simulators colour the surface of objects red (R) or blue (B) indicating the charge.

Figure 2 shows three snapshots while working with the Static Electricity and Magnetism simulator: (a) Two neutral insulators are near each other. (b) After

[2] Project "Constructing Physics Understanding"

rubbing together, the rubbed surfaces are coloured red (R) or blue (B). A neutral conductor with a conducting indicating flag sits nearby. (c) An R-charged insulator brought near the conductor causes the nearby surface of the conductor to be coloured oppositely (B), and the far surface to be coloured the same (R) as the charged insulator. This models the phenomenon of polarisation.

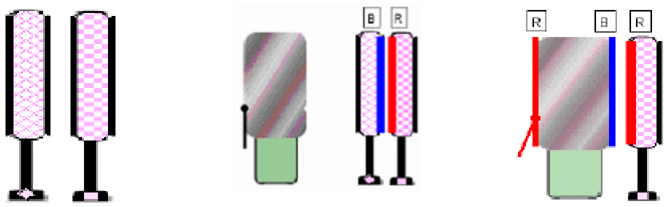

Figure 2: Snapshots from the Static Electricity and Magnetism simulator.

This model-like representation with colours does not depict charge as discrete units and does not use the convention of positive and negative in the visual representations; it does not impose a specific physical description of charge. The students are expected to develop concepts of charges on their own. The model-like results made available by the computer simulator allow students to make "observations" that they could not make with laboratory apparatus. The static electricity simulators provide a variety of tools and set-ups which allow students to make observations that are relevant to concepts in static electricity such as charge transfer by touching, charge polarisation, and charging by induction.

SimulaSON - microscopic models of vibration and sound (Vince, Tiberghien). SimulaSON simultaneously presents the simulated objects and the "observable" events including audio. It includes a microscopic model of vibration and propagation and aims at helping students understand concepts such as vibration, propagation, frequency or amplitude. The user acts on a graphic representation of the amplitude and the frequency of the movement of the vibrating line and simultaneously can hear the sound. This helps to see the relation between frequency and high/low pitches or between amplitude and loud/faint sound (Vince 2000b).

The design of this programme is based on hypotheses about learning along with an analysis of the knowledge to be taught carried out at a fine grain level (Vince & Tiberghien 2000). It is stated that the construction of conceptual understanding is mainly related to the relations established between these different representations.

On the same screen page, depending on the tasks, four main windows can appear (Figure 3): (1) the control window at the centre of the screen represents "the state of a sound" in terms of frequency and amplitude along two orthogonal axes. The user can act on it and modify either the frequency or the amplitude. (2) The vibration window on the left side with a "vibrating line" (in black) between two red lines representing the amplitude. The black line vibrates according to the values given by the user in the window in the middle of the screen. (3) An upper window with a microscopic representation of a particulate model, where one particle and/or a set of particles can be coloured. This particulate representation of a sound tube vibrates like the "black" line of the second window. (4) The oscillo window is on the right side. Its oscilloscope picture is related to two captors, which may be introduced in the microscopic window.

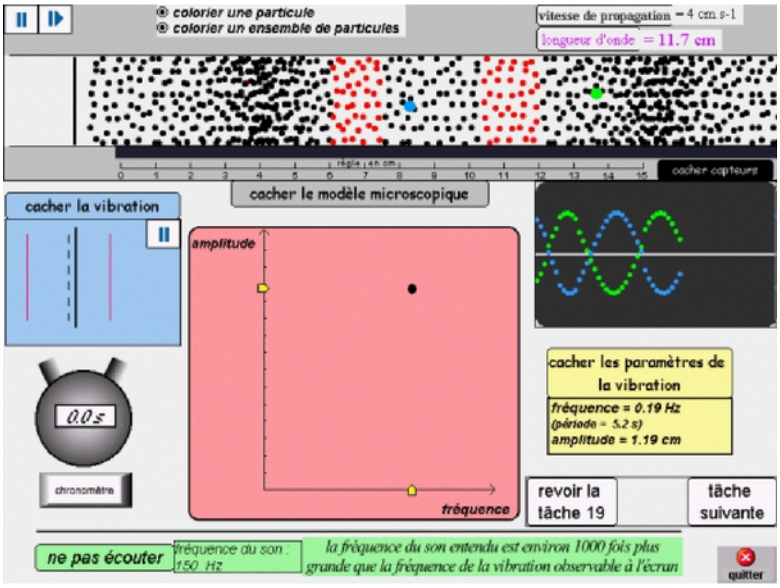

Figure 3: Example of SimulaSON *screen (experimental version).*

Moreover, there is a possibility to hear a sound with the amplitude and frequency chosen in the control window by clicking on the listen button. These different representations aim to help students to construct an understanding of vibration and propagation of sound at different levels: a macroscopic level of vibration and a microscopic particulate level. This understanding requires establishing relations between the behaviours of a single particle, of a set of particles, and the propagation of the vibration with its characteristics (wavelength and velocity).

Applications of model building system STELLA in quantitative mechanics (Hucke, Sander, Fischer, Niedderer). The basic idea of modelling with a model building system software like STELLA is to give students a comfortable computer tool to develop their own theoretical model for an experiment in the form of a concept map, which in addition is powerful enough to carry out calculations. These calculations (graphs) can be compared with results from measurement. Computer tools are used both for theory (STELLA for modelling) and experiment (any MBL device for data collection and processing). We illustrate the integrated use of computer tools for measuring and modelling with a case from a lab about spring oscillations. This started with measuring the free movement of a bob hanging on a spring (Figure 4).

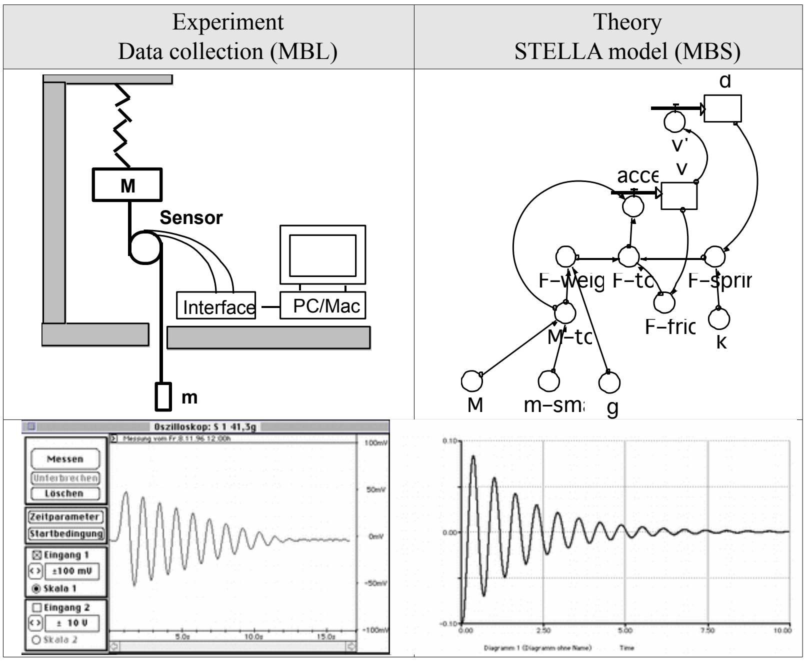

Figure 4: Experiment, computer model and results from both

Afterwards, two students develop their own computer model in many small steps, starting from an empty STELLA desktop. Students can manipulate their own theoretical approach in the following ways:

– They can put elements like concepts or variables on the screen and give them any name they want.
– They can select and specifically define relations between concepts and variables, such as defining the rate of change or more algebraic relations.

Let us keep in mind that the aim is to foster a qualitative understanding of physics phenomena. Students are expected to learn how to use basic physics concepts (like force or momentum) in relation to a specific experiment. The three most important steps in this development are

– to develop the acceleration->velocity->distance sequence of variables and rates of change (kinematics part of the model),
– to apply the force-mass-acceleration relation (Newton 2) as a power tool for all force and motion problems, and
– to introduce the specific forces for the spring problem.

The students performed the following lab activities: With computer measurement (MBL) the students got a graph, which due to friction had decreasing amplitude. Then they built a model with STELLA (MBS). Finally, they got a good agreement between measurement results and the simulation graph from their model (Figure 4).

4. EFFECTS OF COMPUTER MODELLING TOOLS FOR SCAFFOLDING CONCEPTUAL UNDERSTANDING

Research questions and methods. Use of such tools in the classroom has led to interesting research questions in science education about the effects of different kinds of computer modelling tools on students' communication processes, sense making and conceptual development. The three studies deal mainly with two research questions:

- How effective are the computer modelling tools in fostering conceptual development? How effective are they with respect to the aim "to link theory to experiment"? How much do experiments and simulations contribute to sense making processes?
- In what way are the computer modelling tools scaffolding students' learning of conceptual models?

Mainly video data were used. They have been analysed both quantitatively with certain categories, and qualitatively in case studies for analysing scaffolding processes in detail.

Effectiveness of modelling activities. In the studies of Hucke (2000), Sander (2000) and Buty (2000) a method for analysing video tapes from lab work with integrated use of computer tools was developed to investigate the relationship between labwork contexts and the verbal use of knowledge (Niedderer et al. 2002).

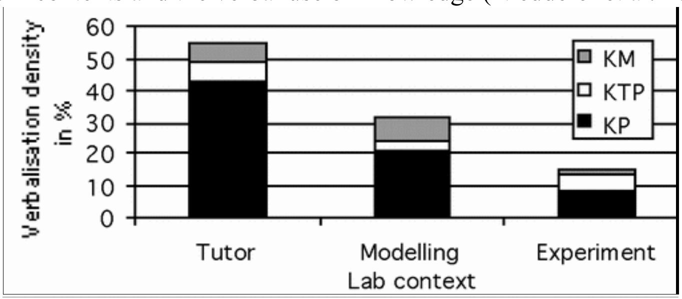

Figure 5: Density of verbalising theoretical knowledge in three types of lab contexts

From Figure 5 we can see that working in experimental contexts contributes little to talking about theoretical knowledge[3] but use up a lot of lab time. On the other hand, during model building phases we see a rather high density of verbalising theoretical knowledge (about 30 %). This is the second highest density behind talking with the tutor. This strongly supports the assumption that the use of model building software (STELLA) in the lab contributes to the objective "to link theory to practice". Hucke (2000) found KP densities in model building contexts up to 75 %. The high

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[3] Categories for verbalising theoretical knowledge: KP: Physics knowledge; KTP: a combination of physics and technological knowledge; KM. Mathematics knowledge.

verbalisation density in the context 'tutor' (55 %) shows the important role of the tutor to link theory and experiment.[4]

With a similar research question and method, Otero (2001) determined the percentage of time the groups were engaged in sense-making (model-based reasoning or discussions) and compared this result to conceptual development of students within one group throughout the electrostatics unit. The percent of activity time spent in sense-making by a group throughout the unit is shown in Figure 6.

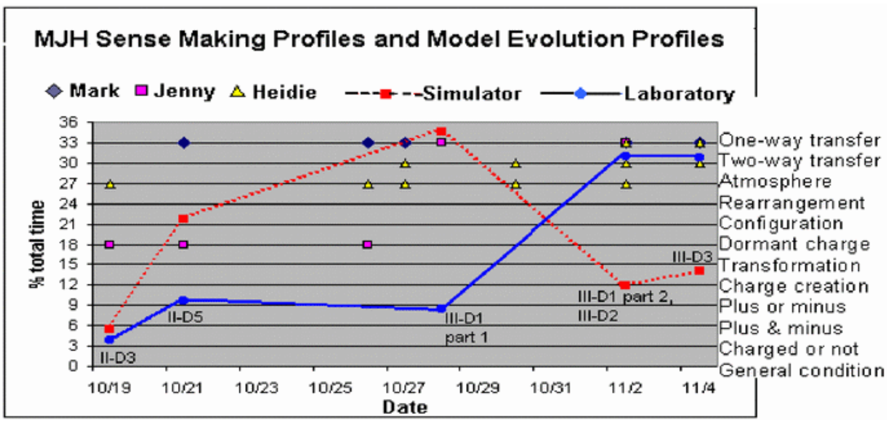

Figure 6: Percentage of sense-making model based discussions and individual student's conceptual models

The upper curve (dotted line) represents the sense-making in simulator experiments and the lower curve (solid line) represents sense-making in laboratory experiments. This data was superimposed with the models inferred for three students in a group throughout the unit (see Figure 6). The student-generated models for charging insulators by rubbing are listed on the right side of the graph (one-way transfer was the target model for instruction). These superimposed graphs suggest that the simulator mediated sense-making discussions when students' models were very different from one another. (Notice that sense making based on the simulator is much greater during the first half of the unit compared to the second half. It was during the first half that students' models were very different, see Figure 6). After students' models for charging insulators by rubbing began to converge to a one-way transfer model (around 11/2), students began engaging in more sense-making discussions directly from their laboratory experiments; they no longer relied on the simulator and colouring-scheme model to mediate their scientific discussions. It was not expected that sense-making with respect to simulator experiments would decrease over time since new features within the simulator became available and the content became increasingly complex. This data (and similar data for another group)

[4] Note that only students' contributions are counted in the knowledge verbalisation densities, not the contributions of the tutor talking himself.

suggests that the simulator served to scaffold the students' learning about the process of constructing explanatory models.

Scaffolding conceptual development with SimulaSON. This software includes a series of 25 tasks corresponding to three sessions of about 1h 30. To carry out these tasks the students have to use a text and schemas giving the physics model and the meaning of the representation of the different windows. Some of the tasks need real experiments. To study the role of SimulaSON software in conceptual understanding, a case study has been carried out. The collected data are an automatic trace and the videos of one dyad during 3 sessions (entirely transcribed). The analysis of students' productions was oriented in terms of steps of the problem solving, the type of students' re-construction of the meaning of the representations in relation to concepts and perception of sound. For example, the concept of vibration should be developed and related to the other concepts of frequency and amplitude, and with objects and events. The main results particularly relevant to simulation software emphasise (1) the importance of the description of the representations for themselves (familiarity); (2) The locality of the correct answers in a rich environment; (3) The crucial role of the questions which should help the students to understand the environment (Vince 2000a).

Concerning the first type of results, the following example shows that describing the representations for themselves is important and is not isolated from the conceptual understanding.

Example 1: During the second task, the dyad takes 6 minutes to solve the following question: If the frequency increases how does the back and forth movement evolve? They give the right answer. The next similar question is: If the amplitude increases how does the back and forth movement evolve? Instead of giving a direct answer using the similar previous question, the dyad takes more than 1 minute to read the question, then tries to modify the amplitude, and describes the symbolic representation (after 2 minutes). Looking to the representation given on the left of the screen page (see Figure 3) representing a black line moving back and forth between two red lines, and acting on the control window to modify the value of the amplitude, the dyad starts a dialogue showing that they construct a meaning to the amplitude. Student 1 says "*the amplitude is the space you see*", and in the same time they relate the variation of the value of amplitude (with a constant frequency) and the behaviour of the vibration. This same student acts on the control window to modify the amplitude and says: "the *more it [amplitude] increases ... the less it* [the red line] *goes fast. No? Ah no because it becomes smaller* [the interval between the two red lines]". The other student agrees and interprets the representation of the vibration: "*the amplitude is the red lines and the back and forth movement is the black line* ". This example also shows how the students' formulation is not straightforward, and time is necessary to construct the relevant language.

Concerning the second type of results, the following example shows both the local construction of knowledge and in the same time how this local construction can contribute to conceptual understanding.

Example 2: During the tasks 10 to 13, the students still relate velocity and amplitude of a sound, which is not right, even after measurements and calculation of the correct value of the sound velocity. In a following task (Task 19), asking how the signal given by a captor[5], when the air at the level of this captor is compressed, evolves, they give a right answer. This answer comes from a relevant interpretation relating two models of the vibration. The representation at the particulate level allows interpreting the behaviour of the particles in the air and an oscillogramme given from a captor indicates the evolution of the vibration at a given point of space. After a teacher's explanation student 2 says "*each time that the air is compressed* [in the microscopic window] *and, well, it makes a curve above* [on the oscillo window, the point tracing the curve is at the maximum]*"*. This animated particulate representation allows the student to construct a behaviour of the vibration and to relate it to the behaviour of the membrane of the captor

[5] in the real experiment a microphone

and the shape of the curve given in the oscilloscope. The main aspects of the conceptual understanding are involved in such a situation even if the intermediary physical quantity, the electrical potential, is omitted.

This case study shows that computer modelling tool can scaffold students' conceptual development under certain conditions. The representation of models should be understood, then specific activities should be devoted to allow students to construct this understanding. Another aspect is the importance to foster the relations between the concepts, their diverse representations and the objects and events that can be interpreted. The analysis shows that the role of the questions associated to modelling tools are crucial factors in the construction of conceptual understanding. More generally, the design of modelling software programme requires a fine grain analysis of the knowledge involved in order to manage meaningful representations and to offer relevant action on them.

Scaffolding conceptual development using STELLA with force and motion. The goal of integrating modelling and measuring tools is to enable students to change freely from theory to experiment and vice versa so that the two activities mutually profit from each other (Schecker 1998, Niedderer & Schecker 1997). Our analyses of lab reports and videotapes show that these intended active interrelations are not found very often. Nevertheless, these are important activities in scaffolding concept development. Below we describe five types of those interrelations found in the data.

- Identify relevant quantities: in the course of modelling students reflect upon which quantities have to be measured in the experiment for the model to work.
- Correct model parameters: students change experimental parameters that are covered in the model, sometimes affording new measurements.
- Explore the system: the model is run in a simulation and the experiment is carried out in order to observe the behaviour of the system; the findings are compared.
- Change basic model structures: the model (conceptual layer and equations layer) is reconsidered and adapted, e.g. in order to include new experimental influences (e.g. friction).
- Develop new experimental ideas: students extend the experimental setting or apply new measurement techniques that were not given in the labguide; this also results in model structure changes.

Example: Students' discussion during the model building process centred on the acting forces. They held two different points of view: A “Newtonian” point of view, due to which forces reduce velocity, and a more “Aristotelian” point of view due to which force is proportional to velocity, and friction is a hindrance but no force. They especially discussed the lower point of the movement. An intermediate model already showed the total force as the sum of spring force and weight force. The spring force related to the distance. No friction force was considered. This resulted in an oscillation with no damping. They compared the model’s prognosis with the graph from measurement (see Figure 4). Although not explicitly demanded in the labguide, the students engaged in a longer session of modelling activities in order to get a decreasing graph like the one measured. They started to discuss friction forces, especially air friction. They needed some time until they found that the friction force is always in the opposite direction of velocity. In more content specific detail, during model building with STELLA, the students talked about the following concepts of physics related to their specific experiment: (1) Weight force and spring force. (2) Acceleration at different points of the oscillation. (3) Balance between different forces. (4) Relation between position of the moving object and the force of the spring. (5) Directions of forces and signs of their values in the equations. (6) Friction conceptualised as a force in addition to the other acting forces;

its direction with respect to movement. (7) Magnitude of the friction force: Is it constant or air friction related to velocity?

The example shows that students are able to actively build their own computer model. During this process, a lot of theory is used and developed, especially in situations, where measurement graph and simulation graph are essentially different.

5. CONCLUSIONS

Two different types of using information technology for scaffolded knowledge integration in science teaching have been investigated. The approach of a Web-based Inquiry Science Environment (WISE) can be seen as a broad frame for integrating several forms of information technology into a social constructivist classroom. This has effects on the role of the teacher, the curriculum, and the role of the students. Specific results are:

- The WISE environment can be localised into science classrooms allowing teachers to personalise the way they adapt the materials into their teaching.
- Students enjoy learning science via ICT; they demonstrate learning gains.

A second type of using information technology in physics education has the main aim to scaffold conceptual development by using different computer modelling tools. Specific results were:

- During modelling phases of the teaching and learning process students spend more time in sense making activities or talking about physics than they do in most other phases of instruction.
- Students develop a deeper understanding of concepts and models by applying them step by step to specific experimental situations.

Results of these studies suggest that manipulating representational objects on the computer screen facilitate communication among students and can serve as a cognitive tool to scaffold students' development of the target instructional model. Through the collaborative construction of ideas, groups of students can come to a consensus on models that are best supported by evidence from both laboratory and simulator experiments. Ultimately, students learn to construct theoretical models for a new observable phenomenon. Conceptual tools such as CPU Simulators, SimulaSON, and STELLA can greatly facilitate this process.

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