Acta Didactica 2/2000

2/2000 Acta Didactica

Institutt for lærerutdanning og skoleutvikling
Det utdanningsvitenskapelige fakultet
Universitetet i Oslo
Postboks 1099 Blindern
0317 Oslo

Dept. of Teacher Education and School Development
Faculty of Education
University of Oslo
P.O.Box 1099 Blindern
0317 Oslo
Norway

www.ils.uio.no

ISSN: 1502-2013
ISBN 82-90904-57-6

9 788290 904574

unipub forlag

Acta Didactica 2/2000

**Andreas Quale, Odd Andresen,
Stein Dankert Kolstø**

Science Teacher Training in an Information Society (STTIS)

Using IT-tools in the teaching of physics in Norwegian upper secondary schools:

– intentions, expectations and practice

DEPARTMENT OF TEACHER EDUCATION AND SCHOOL DEVELOPMENT
UNIVERSITY OF OSLO

EUROPEAN COMMISSION
DG XII (CONTRACT SOE2 CT97 2020)

Science Teacher Training in an Information Society (STTIS)

Using IT-tools in the teaching of physics in Norwegian upper secondary schools: intentions, expectations and practice

by

Andreas Quale, Odd Andresen, Stein Dankert Kolstø

UNIVERSITY OF OSLO
Dept. of Teacher Training and School Development,
P.B. 1099 Blindern,
0316 Oslo, NORWAY

Report coordinator: Andreas Quale
Tel: +47 22 85 48 17
Fax: +47 22 85 44 09
mailto: andreas.quale@ils.uio.no

September 2000

© ILS og forfatterene, Oslo, 2000

ISSN: 1502-2013
ISBN: 82-90904-57-6

Forlag: Unipub forlag
Omslag: Askim Grafix AS
Trykk og innbinding: GCSM AS, Oslo 2000

Henvendelser om denne boka kan rettes til Unipub forlag:
Telefon: 22 85 30 30
Telefaks: 22 85 30 39
E-post: unipubf@sio.uio.no
Unipub forlag er en avdeling i Akademika AS, som eies av Studentsamskipnaden i Oslo.

Rapportserien distribueres av Akademika AS
Akademika nettbokhandel: www.akademika.no

Det må ikke kopieres fra denne boka i strid med åndsverkloven eller avtaler om kopiering inngått med Kopinor, interesseorgan for rettighetshavere til åndsverk.

Abstract

The work described here is part of the cross-national educational research project *Science Teacher Training in an Information Society* (STTIS), a project funded by the European Commission. The participating countries are: Spain, France, Italy, Norway and the United Kingdom.

STTIS comprises several areas of research. Here, we report on an investigation into the use made by science teachers of information technology (IT) tools, with specific reference to the teaching of physics in secondary schools in Norway. We focus on two problem areas: (i) the use of spreadsheets and other software to model and study problems of motion that are in general not amenable to analytic mathematical treatment by pupils at this level; and (ii) the use of data acquisition hardware and software to monitor pupils' experimental work in the physics laboratory.

We investigate how the teachers manage to incorporate these IT tools in their teaching, seeking to identify possible factors favouring (or disfavouring) their use of such tools. Our research questions include:

- What do the teachers report as successful examples of their use of the tool in their teaching?
- How does the intended use of the tool match the way it is actually used in practice?
- Are the teachers conscious of transforming suggested uses of the software, in their own practice?

The data collected include: observation records in the classroom, interviews with the teachers, and documentation of tasks given to pupils and work done by pupils. The data have been subjected to qualitative analysis, and the results of this analysis are reported.

Contents

1 Introduction – the STTIS project

STTIS (Science Teacher Training in an Information Society) is a cross-national educational research project, funded by the EU Commission under the TSER (Targeted Socio-Economic Research) programme, DG XII – Contract SOE2 CT97 2020.

The project started in December 1997, with a projected duration of 36 months. Research groups from five countries are participating in STTIS. The partners and group leaders are:

Roser Pintó (STTIS coordinator)
Departament de Didàctica de les Ciencies Experimentals
Universitat Autònoma de Barcelona
SPAIN

Laurence Viennot
Laboratoire de Didactique de la Physique dans l'Enseignement Supérieur,
Université Denis Diderot, Paris VII,
FRANCE

Elena Sassi
Physics Education Group
Universita "Federico II", Napoli
ITALY

Andreas Quale
Dept. of Teacher Education and School Development
University of Oslo
NORWAY

Jon Ogborn
Institute of Education
University of Sussex
UK

The core of STTIS consists of three parallell empirical investigations (so-called Work Packages), addressing three distinct (but related) problem areas:

- WP1: the nature of the use made by science teachers of information technology tools
- WP2: difficulties in teaching and learning graphic representations
- WP3: transformations when adopting innovative teaching strategies

A detailed description of these Work Packages may be found on the cross-national STTIS website (STTIS, 1999). Some preliminary results, emerging from the investigations into all three of them, have already been presented (ESERA-2, 1999). A complete description of the whole project, with reports of observations and results, may also be found at (STTIS, 1999).

The research methodology adopted by STTIS is qualitative in nature, and designed to be informative to decision making: i.e. to provide data and interpretations that indicate crucial factors to be taken into account, to identify difficulties needing to be overcome, and to suggest priorities for action. By conducting parallell investigations in different European countries, we expect to be able to diagnose the difficulties encountered, asking questions such as: To what extent are they cross-national (common to several of our countries)? How strongly are they tied to local cultural context?

The Norwegian research group in the STTIS project has consisted of:

Andreas Quale (national coordinator)
Dept. of Teacher Education and School Development
University of Oslo, Norway

Odd Andresen
Malvik vgs (upper secondary school)
Trondheim, Norway

Stein Dankert Kolstø
Dept. of Applied Education
University of Bergen, Norway

Our investigations have been situated within the first of the three STTIS Work Packages (WP1), as identified above, with particular emphasis on the teaching of physics at upper secondary school level in Norway. Henceforth, this Norwegian part of the STTIS investigations will be referred to as STTIS-NOR.

A general description of STTIS-NOR, with data, results and other documentation, is accessible on the Norwegian project web site (STTIS-NOR, 1999). The national report of STTIS-NOR is divided in two parts: the main report, available both in paper form (this book) and on the website, and appendices A-E to the report (case stories, and methodology), available only on the website. Thus, any references in the present text to these appendices may be found on the website.

Some preliminary results of STTIS-NOR have been reported previously, at the IOSTE conference (IOSTE-9, 1999) and the ESERA conference (ESERA-2, 1999).

2 Research questions and methodology

2.1 Research questions

The general motivation behind STTIS is the need to address a range of problems ensuing from the rapid and profound changes taking place in the Information Society and the impact of these changes on science education in our schools. In particular, we are concerned with the problems encountered by science teachers, in their need to "keep up" with the new technology and use it in their teaching.

The area of research addressed by STTIS-NOR is that of the work package WP1: the nature of the use made by science teachers of informatic tools. WP1 seeks to identify some of the problems and opportunities that arise, in the use of certain (selected) informatic tools in science classrooms.

Specific research questions include:

- What factors seems to favour or hinder the uptake of the selected informatic tools?
- What do the teachers report as successful or less successful examples of their use of the tools in their teaching, and what reasons do they give for identifying them as such?
- How does the intended or expected use of the tools – what the teacher is "aiming for" – match (or mismatch) the way in which they are actually used in practice?
- Are the teachers conscious of transforming the suggested uses of the tools, in their own practice? If so, how do they justify this; if not, how can we detect whether such transformations have in fact taken place?

Of course, any answers to these questions must be evaluated relative to the teacher's professional background and competence, the sociocultural context of the teaching situation, and the nature and curricular impact and relevance of the tool itself, all of which factors will enter into the data analysis.

Our objective has been to investigate how the teachers manage to incorporate the tools in their teaching, and to identify possible factors favouring (or disfavouring) their use of these tools. Thus, the focus of the research has been on the *teacher* – his intentions, expectations, experiences and conclusions, wrt. using the software as a pedagogic aid in teaching – rather than on the pupils and the effect this may have had on their learning.

Transformations

In this study, we particularly ask: How do the teachers transform the expected use of these tools – what transforming mechanisms can we conjecture to be involved? Concerning the concept of *transformation*, we adopt a viewpoint that may be loosely described as 'constructivist': A communication is never just received, in the form it was sent; on the contrary, it is re-made (or reconstructed) in the mind of the receiver. For example: In the present context of using informatic tools in the classroom, we may expect the original intentions of the tool designer to be reconstructed – or transformed, as we would say – by the teacher, as he constructs his own conception of these intentions, in a way that coheres with his own way of thinking. Thus, his response to the communication from the designer is necessarily transformative, constructing his own meanings for the perceived intentions.

This transformative approach views school education as a planned purposive activity, guided by some directive authority; this authority – which may be a general educational policy, a general curriculum, or (in some cases) perhaps a concrete subject syllabus – we might call the *employer* of education. However, the said activity is then mediated by an *agent* – the teacher – who acts to implement the directives (educational goals etc.) set forth by the employer. In other words, educational planners (or legislators) are obliged to act through teachers. But a teacher will have his own agenda (intentions, purposes and goals), which may conflict with that of the employer. Moreover, teachers have their own understanding of the topics to be taught, which may transform the understanding originally laid down in policies and curricula. Finally, a teacher acts under specific constraints (of time and resources) which may well lead to a transformation of his own planned actions. Therefore, the methodology must provide for the investigation of plans and intentions, and of different understandings of – or different meanings given to – these plans and intentions. Further, it must take into account, not only the intentions of teachers and other agents, but also those of the researchers themselves.

The present situation is one in which the teacher is given an IT tool by the research team, and asked to use this tool in his teaching. There then emerges a rich network of potential transformations:

- from the researcher's intentions (for the use of the tool) to the teacher's intentions
- from the employer's intentions (for the use of the tool) to the teacher's intentions
- from the teacher's original planning (of the use of the tool) to his actual teaching practice
- from the teacher's ideas during the planning and teaching phase (of the use of the tool) to his adjusted ideas based on his experience
- from the teacher's understanding (of the subject matter, as taught using the tool) to the pupils' understanding

We emphasize that the focus of the present investigation is on the *teacher*: his attitude toward and reflections on the use of IT tools in his teaching. This leads us to the following pictorial "flow diagram", illustrating our research arena:

$$\begin{array}{ccc} & \mathbf{E} & \\ & \downarrow & \\ \mathbf{R} \rightarrow & \mathbf{T} & \leftarrow \mathbf{C} \end{array}$$

with the teacher **T** receiving input from:

- **E**, the employer (educational policies, curricula, subject syllabuses etc.)
- **R**, the researcher (who has requested the use of the IT tool)
- **C**, the classroom (the teaching arena, with back reaction from pupils, time pressures, upcoming exams etc.)

Our objective has been to investigate how the teachers manage to incorporate the software in their teaching, and to identify possible factors favouring (or disfavouring) their use of this informatic tool. Thus, we are lead to ask: How does the teacher transform (construct in his own mind) these various inputs? How does he see his own original agenda (intentions and goals), wrt. the use of the IT tool in his teaching? And what are his reflections on the actual use that was made of this tool, in the teaching periods that were observed by the STTIS researchers? What are his present conclusions and attitudes wrt. the use of such tools?

2.2 School context

The subject of physics in Norwegian upper secondary school is organized and taught as follows: First, every pupil in upper secondary school has to take (normally in the first year) an integrated course in natural science, comprising some elementary physics, chemistry and biology. After this, he may choose to take an introductory physics course known as 2FY, which concludes with an oral exam; this is normally done in the second year. Having completed 2FY, he may then choose to take an advanced course known as 3FY, which concludes with a written exam; and this is normally done in the third (final) year. (For "he / his", please read "he or she" / "his or her", etc.)

Concerning the pupils' qualifications for using such IT tools: Norwegian upper secondary education is organized in several different "study tracks", that provide schooling and/or technical training in various vocational and non-vocational areas. All the pupils participating in the STTIS-NOR project were enrolled in the so-called "academic" track *General and Business Studies* – this is the track that prepares them for higher studies, at university or college level. Here, IT appears as a compulsory subject in the curriculum: it forms (together with basic economics) a course of 5 hours/week, usually taken in the first year of upper secondary school. In this course, they are introduced to the handling of standard user software, such as word processors and spreadsheets. (In the following two years, several elective courses are offered, in Computer Science – system engineering, application programming and network administration – but we could not assume that our pupils were taking, or had taken, any of these courses.)

Thus, with reference to the kind of IT tool that was relevant for the STTIS investigation, our expectation was that the typical STTIS-NOR pupil would be reasonably competent in the use of a spreadsheet, but with no experience in the handling of data acquisition software.

2.3 Data collection

The general research methodology of the STTIS project is described in the cross-national STTIS documentation (STTIS (1999). Let us just recapitulate some main points, of importance to the present investigation STTIS-NOR.

The research methodology of STTIS is qualitative in nature, and applied in character: i.e. directed towards informing practical decision-making and action in educational policies. In other words, we hope to provide data and interpretations that suggest priorities for action, indicate crucial factors which should be taken into account, and identify difficulties which need to be addressed.

Case studies

In accordance with the methodology outlined in the STTIS-RW0 report, a number of case studies were carried out. The Norwegian STTIS group has conducted altogether nine case studies: five in the Oslo area, with the teachers using simulation software; and four in the Trondheim area, with the teachers using hardware and software for datalogging. This focus on only two main types of IT-tools opens up for a kind of triangulation that offers the possibility of gaining trustworthy knowledge of what sort of factors are affecting teachers' uptake and successful use of informatic tools.

Selection criterion

The teachers who participated in STTIS-NOR were all selected by their willingness – even enthusiasm in some cases – to try out this new approach to teaching physics. They were all well qualified: with a master's degree or major in physics, and mostly with long experience in physics teaching at upper secondary level. They used designated information technology tools in their teaching of physics, at both 2FY and 3FY levels. The particular choice of IT-tools was made partly by the teachers: the researchers would suggest the use of dataloggers or simulations when contacting the teachers, but each teacher was then free to choose between different simulation tools or different dataloggers. Willingness was an adequate selection criterion, since the research aimed to explore what is possible, rather than what is typical.

Sources of data
Multiple sources of data were used in this study to be able to explore the different research questions. The main source was field notes based on the researcher's observations of a lesson where the IT-tools were used, and an interview with the teacher after the lesson. In addition, a short interview was done prior to the lesson, where the teacher presented his main ideas for why and how to use the IT-tools. A fourth source was field notes made by the researcher concerning contextual aspects: such as the resource situation at the school, the class and the impression of the teacher.

A fifth potential source would be the teaching strategies suggested by the producers of the IT-tools used. This source was, however, lacking from the cases where dataloggers were used, as no written material on the exercise observed was accompanying the hardware and software from the producer. On the other hand, the spreadsheet model implemented by two of the researchers (see section 3.3, and also appendix C), and offered to the teachers for use in the simulation teaching sequence, would fall within this source category.

This use of multiple sources made it possible to look for transformations of rationales and teaching strategies, through the whole process from producers' intentions to teachers' intentions, further on to the teachers' realisation of intentions during the lesson, and finally to their reflections after the lesson. The use of multiple sources also made it possible to triangulate findings related to the teachers' pedagogical ideas and views about the teaching and learning process.

For each case study, the field work was planned and executed in three stages: a pre-phase, the run (i.e. the observed lesson where the IT-tools were used), and a post-phase.

The pre-phase
Before the run, the researcher met with the teacher, to discuss the project. The idea here was to reach agreement on practical details of implementation (dates and times, software, subject matter to be taught etc.); and also (equally important) to arrive at a common "platform of understanding", about the aims of the project.

The teacher then filled in and returned a "statement of intention". This statement contained information about the school, the teacher, the pupils, the topic to be covered, the informatic tools to be used, and the general teaching context (sociocultural, curricular, previous experience with informatic tools, etc.) It also allowed the teacher to describe, in some detail, his intentions in using the tool in teaching, what positive/negative effects he anticipated for the pupils' learning, what problems (if any) were expected, and how he intended to evaluate the effect of this experience on the pupils. A template of this statement of intention is shown in appendix D.

The run

During the run, we visited the classroom and observed the teaching, taking notes. We also gathered in any documentation of tasks given to pupils, and of work done by pupils, that was potentially relevant for our investigation.

After the lesson a text was made based on the observations and fieldnotes made during the lesson. The focus of the observations was on teacher and pupil activities and interactions throughout the lesson. Special attention was given to the teacher's statement of intentions, and to the kind of tasks given to the pupils.

The post-phase

After the run, we interviewed the teacher, recording the session on tape. In the course of this interview, the interviewer was guided by the data gathered in the two proceeding phases. The general planning of the interview was as follows:

1. The interviewee repeats what were his original intentions, in using the informatic tool. Comparison with the document of intention may then indicate whether any transfomation has occurred in his original views (wrt. using informatic tools in teaching), and if this may then have "acted back" on his perception of his own intentions.
2. The interviewee describes in detail his own planning for the run: preparing the informatic tool, available hardware/software, assumed preknowledge and motivation on the part of the pupils, timing and duration, pupil activities/evaluation, pupil homework/tests.
3. To what extent was this planning actually followed? Were there changes in the choice of informatic tool, unexpected limitations in

available hardware/software, changes in the curriculum, time pressures, increase/decrease in the pupil number?
4. How (as seen by the interviewee) did the pupils respond to this way of teaching? Did they have the expected preknowledge and motivation, did they perceive the use of the tool to be easy/difficult, did they experience any additional "learning profit" from the use of the tool? How was the spread of understanding/performance in the class? Were cultural and gender differences observed?
5. How did the interviewee himself perceive the use of the tool - did it live up to expectations? Did it deliver any "educational added value", justifying the time spent on using it in the teaching? Was it easy to use for the teacher? Did any unexpected problems (of a technical or pedagogical character) arise when it was used? To what extent did this use (of the tool) deviate from the usual teaching style of the teacher?
6. Concerning the use of this tool in teaching physics: How does it fit in with the curriculum, and with the content being taught? How does it impact on the planning of the teacher (time constraints, exam requirements, topic crowding)?
7. Does the interviewee feel that his own views/opinions about the use of the tool have changed, as a consequence of using it here? Was it used in other ways than that perceived by him to be the intention of its creators - and if so, why?
8. In retrospect: What conclusions would the interviewee draw, from his experience with using the informatic tool? Was it successful - would he want to repeat it, or continue to make use of such informatic tools in his teaching? Alternatively: which aspects of the use of the tool were in his opinion successful/unsuccessful, and for what reasons?

Through these questions we hoped to gain knowledge of the teacher's goals for the lesson and his evaluation of the learning outcome. Moreover, we hoped to gain some insight into the pedagogical views guiding his decisions, and contextual factors influencing his evaluations concerning how (and whether) to use the IT-tools. All interviews were fully transcribed by the interviewers.

In STTIS-NOR we chose to perform the in-depth interview after the run. The reason for this was that the teacher's intentions prior to the run were known to us, through his "statement of intentions". In addition, we wanted to focus specifically on the teacher's own evaluation of the chosen goals and teaching strategies. We feel that this evaluation is of special interest, as this research also intends to inform practical decision-making and action in educational policies.

Summing up, the data of the STTIS-NOR case studies are the following:
- statements of intention, as filled in and returned by each of the participating teachers
- conversations with the teacher before the observations
- classroom observations by the researcher (taking notes)
- interviews (recorded on audio tape) with the teachers, after the observations

All these data, originally in the Norwegian language, have been written up (in English) as *case summaries*, one for each case studied. In these summaries we have attempted, in the interview parts, to capture some of the "flavour" or "atmosphere" of the interaction between teacher and researcher. The summaries are given in appendices A and B (see STTIS-NOR, 1999).

2.4 Data analysis

The data were subjected to inductive analysis. "Inductive analysis begins with specific observations and builds towards general patterns" (Patton, p.44). This means that the analysis was explorative in character. There were no predefined categories which the data was sought identified into. Characteristic aspects of the different cases were sought identified through an inductive process, where the data were systematically examined for ideas and evaluations. In this way findings were sought grounded in the data, and descriptive categories were developed.

Analysis during data collection

The analysis of qualitative data begins with interviews and field observations. This is an important part of the analysis, as it is based on a wider range of factors than the subsequent systematic analysis. In the field, and throughout the interview, the researcher's immediate analysis also draws upon mimicry, gestures, the actors' intonations, the physical context and so forth. Some of these immediate impressions and analysis were written down after the visits to the involved schools, and incorporated into the case summaries (see appendices A and B). This analysis, performed during the fieldwork, is used as a reference for the results of the structured part of the analysis.

Structured analysis

The structured part of the analysis consisted of coding of the data, followed by analysis of the coded texts, seeking patterns. Before coding the data, some main foci for the analysis were identified. From the research questions specific themes for the analysis were identified. These themes are summarised in table 1.

Id.	Theme	Description
G	Goals	Goals and rationales for the lessons and activities explicitly stated by producer and/or the teacher, or implicit in teaching strategy or teachers thinking.
S	Strategies	teachers teaching practice and ideas about teaching strategies, and producer's descriptions
F	Uptake factors	Factors interpreted to have an (potential) impact on teachers' decision to use the IT-tools
D	Facts	Facts related to the school, class, teacher's situation, ideas or resources. These facts might be viewed as potential factors, but were not talked about as such, explicitly or implicitly, by the teacher
Tg	Transformations of goals	Changes in ideas about goals for the lesson identified by comparing producers and teachers ideas, or by comparing articulated goals and goals implicitly realised in the lesson.
Ts	Transformations of strategies	Changes in ideas about teaching strategies for the lesson identified by comparing producers and teachers ideas, or by comparing articulated goals and goals implicitly realised in the lesson.
Fs	Success factors	Factors interpreted to have an impact on the pupils' learning outcome

Table 1: Foci for the structured analysis, with classification codes to the left

The foci with classification codes **G**, **S**, **F** and **D** were used in the coding of the data. The data were thus coded by looking for goals, strategies, uptake factors and facts, and all data were marked with an classification code for easy identification – see appendix E (STTIS-NOR, 1999), part 1. After coding, all the data were sorted by classification code, and analysed for patterns. Through this process, more general categories describing the different research foci were identified. For a detailed example, illustrating this coding and analysing procedure, see appendix E, part 2.

For the analysis focused on transformations, it was important to keep track of the source of different ideas during the coding and analysis. All codes were therefore also augmented by a classification code related to the data source under consideration. The sources and their classification codes are given in table 2.

Classification codes	**Sources of data**
m	IT tool description by designer/**m**anufacturer (not existing for this case)
p	Notes made by the researchers, based on conversations with the teacher **p**rior to the lesson observed.
t	Ideas and comments expressed by the **t**eacher prior to the lesson
o	Notes from the researcher's **o**bservations of the lesson
i	Transcribed **i**nterview with the teacher after the lesson

Table 2: Classification codes for the different sources of data used.

Several steps were taken to increase the reliability of the coding process. First and foremost, the foci for the analysis were articulated and discussed in the researcher group, to ensure that the analysis had clear and relevant foci. In addition, the coding of a few cases was discussed in detail, to ensure a common understanding of the foci and of the coding process. Last, but not least, a tentative analysis of each case was inspected by at least one other researcher, and discrepancies in interpretations were discussed.

Factors interpreted to have an impact on the pupils' learning outcome (as perceived by the teacher), i.e. factors influencing the successful use, were identified by inspecting the goals, strategies and uptake factors that were found – and also by drawing upon the researcher's impression of the teacher's pedagogical ideas and ideas about the teaching and learning process.

The analysis based on the three foci **Tg**, **Ts** and **Fs** were based on findings from the analysis of goals, strategies and factors (see appendix E, part 3). In addition, the general impression from a careful reading of the data, and the impressions received during data collection, were drawn upon.

This method is illustrated by a detailed example (shown in appendix E), describing the analysis of one of our cases: the case of Bjørn.

By inspecting the teacher's articulated and realised goals and teaching strategies, it was also possible to achieve some insight into his more unarticulated ideas about teaching and learning. Such ideas might be crucial for the teacher's evaluation of whether or not to use IT-tools, and for the success of this use.

3 Case studies on the use of simulation

3.1 The problem area

The work reported in this section focusses on *simulation*. Five teachers (three female, two male) in five different schools participated in this section of STTIS-NOR, all teaching the course 3FY (cf. section 2.1). Specifically, they used designated software (see below) in their teaching in the class, to model and simulate two different types of motion in external force fields: ballistic trajectories with air resistance in a homogeneous gravity field, and general satellite orbits in a centrally symmetric Newtonian gravity field.

Note that these problems are of a type that are, in general, not amenable to analytic treatment by pupils at the level we are considering, since they lack the necessary mathematical skills:

- For a body in ballistic motion, air resistance produces a retarding force acting opposite to the instantaneous velocity of the body. This introduces nonlinear terms into the equations of motion, making them difficult for the pupils to handle (except in very idealized cases).
- Motion under Newtonian gravity is mathematically complicated, except in the idealized case where the orbit is circular: the computation of general (elliptic or hyperbolic) orbits is generally beyond the capability of pupils at secondary school level. Thus, statements often found in the text books, such as "...planetary orbits are elliptical, with the Sun at one focal point", become rather abstract and theoretical for them.

The physics teacher can tackle this situation by using information technology, in (at least) two different ways:

1. by employing so-called "educational software": that is, a dedicated computer program, specifically designed for teaching/learning in this particular problem area
2. by using a common spreadsheet program

Both these approaches are investigated in STTIS-NOR.

3.2 The informatic tools

Some of our teachers used *dedicated software*, for the treatment of satellite motion under Newtonian gravity. In the present context, such software generally presents a user interface that allows the user to choose and type in various initial parameters – such as the number of interacting bodies, their masses, initial positions and velocities – and then traces out the resulting trajectories dynamically (i.e. in "quasi-realtime") on the screen. Several programs of this kind are available on the market. (In fact, one of our teachers even designed and implemented one for himself, which worked quite as well as the commercially available ones in the class situation..!)

Note that this kind of dedicated informatic tool serves to *illustrate* only: the pupils see the trajectories, but the driving dynamics (the equations of motion in the given force field) is hidden "inside" the software. Put in another way: the informatic tool is *dynamically opaque*.

Other teachers made use of a *spreadsheet*, for the treatment of both ballistic motion with air resistance and satellite motion under Newtonian gravity. In this case, the software lets the user specify initial conditions, as static input data in the spreadsheet model, and then computes the motion and displays it graphically on the screen. The two models that were given to the teachers to use in the class, are described in the next section, and also in appendix C.

Here, the user (i.e. teacher and/or pupils) has to build the dynamics of the motion into the model first, in the form of iterative dynamic computations, as shown in appendix C. Thus, the informatic tool is *dynamically transparent* in this case: the physical force fields driving the motion are open for inspection and manipulation by the pupils.

The data emerging from the statements of intention, classroom observations and post-session interviews have been written up in "case summaries", given in appendix A (STTIS-NOR, 1999). These summaries form the basis for the **case stories** given below, describing the part of STTIS-NOR that dealt with simulation.

3.3 The dynamical spreadsheet model

We can use a standard spreadsheet to make models of physical systems and processes. Such a model can then simulate virtually any physical phenomenon, as long as the dynamical description of the phenomenon (typically, in the form of differential equations) is known.

The spreadsheet provides us with a tool that can handle problems of this kind in a uniform way, and illustrate the results graphically on the screen, quite independently of whether the problem itself is mathematically tractable or not. This is done by using the general method of *successive iteration*, which may be summarized as follows:
- Specify an initial state S_0 by parameters describing the system at time t_0
- Increment the time by a small amount dt. The dynamical equations governing the system then enable us to compute the state S_1 at the later time $t_1 = t_0 + dt$. (This computation is, of course, only approximately correct – but the inaccuracy decreases with the size of dt.)
- Increment the time again by dt, and compute the new state S_2 at the time $t_2 = t_1 + dt$.
- Increment the time again by dt, and compute the new state S_3 at the time $t_3 = t_2 + dt$.
- Increment the time again....etc.

This method corresponds, of course, to a *numerical integration* of the equation of motion describing the system:

$$S(t+dt) = S(t) + S'(t)*dt$$

which lets us compute the state S at the time $t+dt$, starting from the state "immediately before", at the time t. As an example, consider motion along a straight line:

$$X(t+dt) = X(t) + V(t)*dt, \quad V(t+dt) = V(t) + A(t)*dt$$

giving us the position X and the velocity V at time $t+dt$, when the position, velocity and acceleration A is known at time t. The dynamics here resides, of course, in the expression for the acceleration $A(t)$: We find it from the law of force that drives the motion, using Newton's second law.

Normally, we would resort to methods of this kind when the dynamical equations are of a form that cannot be integrated analytically. Such numerical methods have traditionally not been taught in our secondary schools – understandably enough, since their use would be far too tedious and time consuming for the pupils, using the tools available at that level (pencil and paper, and possibly a pocket calculator). Thus, the teaching of physics has been restricted to treating only those (often unrealistically simple) cases that the pupils are able to solve analytically.

Now, however, the use of modern spreadsheets (with graphical capability) has opened up new possibilities for physics teachers. The iteration method outlined above is easily implemented in the spreadsheet, and the result may be immediately shown graphically on the screen.

The dynamics driving the system must be known - but note that it does *not* have to be at all "mathematically tractable"..! On the contrary, the acceleration expression may be quite complex (for a complicated force law), but this poses no problem for the learner – the spreadsheet takes care of all computations. In other words: The learner may concentrate attention on the *physics* of the problem at hand – i.e. understanding and setting up the right equations to solve the problem. He is relieved of the mathematical drudgery of the computations that must be done, in order to obtain the solution..! Thus, school physics need no longer be subjected to the old "tyranny of mathematics": the obstacle that only those problems that are analytically solvable may be tackled by the learners!

Below, we describe two models (implemented in Excel), that have been made available for physics teachers on the Norwegian School Net web site: one that simulates ballistic motion (Quale & Andresen, 1996a), and one that simulates satellite orbits (Quale & Andresen, 1996b). However, it is worth noting that this simulation technique is *not* limited to the modelling of motion in external force fields! On the contrary, virtually any physical process that is governed by differential equations can be usefully treated, using a spreadsheet in the same manner as outlined below – for example, a number of suggestions may be found in Dykstra & Fuller (1988).

1: Ballistic motion in a homogeneous gravity field

Choose initial position at the origin, component values for the initial velocity (V_x, V_y) at the time $t = 0$, the mass m and the time increment dt. With no air resistance, the acceleration is constant: $(A_x, A_y) = (0, g)$. The iteration then has the form:

$$
\begin{aligned}
A_x(t) &= 0 , & A_y(t) &= -g \\
X(t+dt) &= X(t) + V_x * dt , & Y(t+dt) &= Y(t) + V_y * dt \\
V_x(t+dt) &= V_x(t) + A_x * dt , & V_y(t+dt) &= V_y(t) + A_y * dt
\end{aligned}
$$

Now refine this, by assuming that the air resistance is proportional to the square of the velocity, and that it retards the motion tangentially to the trajectory. Choose a value for the resistance factor k. The dynamics in the acceleration expressions then become more complicated:

$$A_x(t) = -k/m * V * V_x , \qquad A_y(t) = -g - k/m * V * V_y$$

where: $V^2 = V_x^2 + V_y^2$

and the iterative equations of motion to be plugged into the spreadsheet take the form:

$$
\begin{aligned}
A_{i,x} &= -k/m * V_i * V_{i,x} , & A_{i,y} &= -g - k/m * V_i * V_{i,y} \\
X_{i+1} &= X_i + V_{i,x} * dt , & Y_{i+1} &= Y_i + V_{i,y} * dt \\
V_{i+1,x} &= V_{i,x} + A_{i,x} * dt , & V_{i+1,y} &= V_{i,y} + A_{i,y} * dt
\end{aligned}
$$

for $i = 0,1,2,..$

Below we show the resulting orbit for the ballistic motion with air resistance k, of a body with unit mass, under the acceleration of gravity g: the parameter values are as given in the two columns on the left. The body is assumed to have initial position at the origin, and initial velocity 25 m/s with angle of elevation 25 degrees, as shown in the iteration row for $t = 0$ in the table. In the row below are given the accelerations (A_x, A_y), as computed from the expressions above. All these values are then successively iterated, with time increment $dt = 0.04$, and given in the rows below.

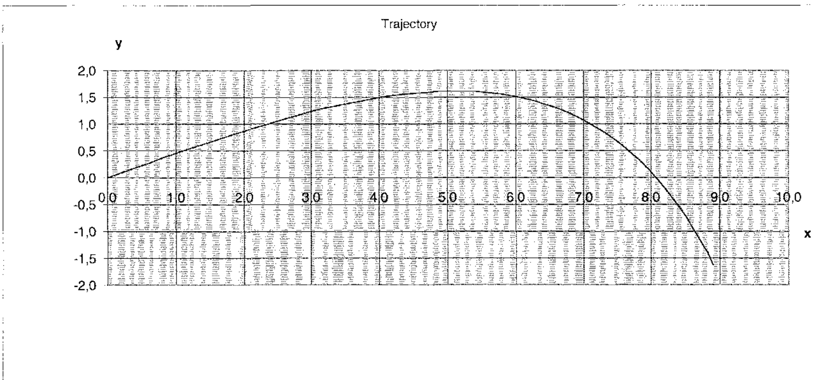
The first six rows are shown with numbers, and a few selected columns are shown (for purposes of illustration) with formulas. Note that formulas need not be retyped for each row: We may use the capacity of the spreadsheet to "drag" a row downwards, copying it to the rows below by relative cell addressing.

The resulting orbit, as drawn by the spreadsheet, is shown in the diagram.

BALLISTIC MOTION, WITH AIR RESISTANCE			
a = *g* =	-9,81	m/s^2	Acceleration of gravity
v =	25.0		Angle of elevation (in degrees)
u =	0,44		Angle, converted to radians
dt =	0,04	s	Time increment
Vo =	25,0	m/s	Initial speed
Xo,Yo=	0, 0	m	Starting position, at origin
F =	*k*V^2*		Air resistance, assumed proportional to V^2
k =	0,20	m^{-1}	Air resistance factor
Ax =	*- k * (sqrt(Vx^2 + Vy^2)) * Vx*		Formulas used in the calculations
Ay=	*g-k * (sqrt(Vx^2 + Vy^2))* Vy*		

t	**Ax**	**Ay**	**Vx**	**Vy**	**V**	**X**	**Y**
[s]	[m/s^2]	[m/s^2]	[m/s]	[m/s]	[m/s]	[m]	[m]
0,00			22,66	10,57	25,00	0,00	0,00
0,04	-113,29	-62,64	18,13	8,06	19,84	0,82	0,37
0,08	-71,91	-41,79	15,25	6,39	16,53	1,48	0,66
0,12	-50,43	-30,93	13,23	5,15	14,20	2,05	0,89
0,16	-37,58	-24,44	11,73	4,17	12,45	2,55	1,08
0,20	-29,21	-20,20	10,56	3,37	11,08	3,00	1,23
....	....	....	....	....	....	....	....

Ax	*Ay*	*Vx*	*Vy*
		=B$6 * cos(B$4)	=B$6 * sin(B$4)
= - B$10 * sqrt(D18^2+E18^2) * D18	= B3 - B10 * sqrt(D18^2+E18^2) * E18	=D18 + B19*B5	=E18 + C19*B$5
= -B10 * sqrt(D19^2+E19^2) * D19	= B3 - B10 * sqrt(D19^2+E19^2) * E19	=D19 + B20*B5	=E19 + C20*B$5
= -B10 * sqrt(D20^2+E20^2) * D20	= B3 - B10 * sqrt(D20^2+E20^2) * E20	=D20 + B21*B5	=E20 + C21*B$5
= -B10 * sqrt(D21^2+E21^2) * D21	= B3 - B10 * sqrt(D21^2+E21^2) * E21	=D21 + B22*B5	=E21 + C22*B$5
= -B10 * sqrt(D22^2+E22^2) * D22	= B3 - B10 * sqrt(D22^2+E22^2) * E22	=D22 + B23*B5	=E22 + C23*B$5
....	....	....	....



2: Satellite motion in a Newtonian gravity field

The model computes iteratively the position (X, Y), velocity (V_x, V_y) and – using Newton's law of gravity – the acceleration (A_x, A_y) of the satellite with mass m in the field of the mass M, which is assumed to lie in the origin of the Cartesian XY-plane.

Let the mass m have initial position (X_0, Y_0) and initial velocity $(V_{0,x}, V_{0,y})$, and let the time increment be dt - all suitably chosen and plugged into the spreadsheet model. The iterative equations of motion for m then take the form:

$$A_{i,x} = \frac{-G * M * X_i}{R_i^3}, \qquad A_{i,y} = \frac{-G * M * X_i}{R_i^3}$$

$$X_{i+1} = X_i + V_{i,x} * dt, \qquad Y_{i+1} = Y_i + V_{i,y} * dt$$

$$V_{i+1,x} = V_{i,x} + A_{i,x} * dt, \qquad V_{i+1,y} = V_{i,y} + A_{i,y} * dt$$

where G is the gravitational constant, and:

$$R_i^2 = X_i^2 + Y_i^2$$

for $i = 0,1,2,..$

Note again that the dynamics of the system lies in the acceleration expressions, deduced from Newton's force law (driving the motion) and Newton's second law of motion.

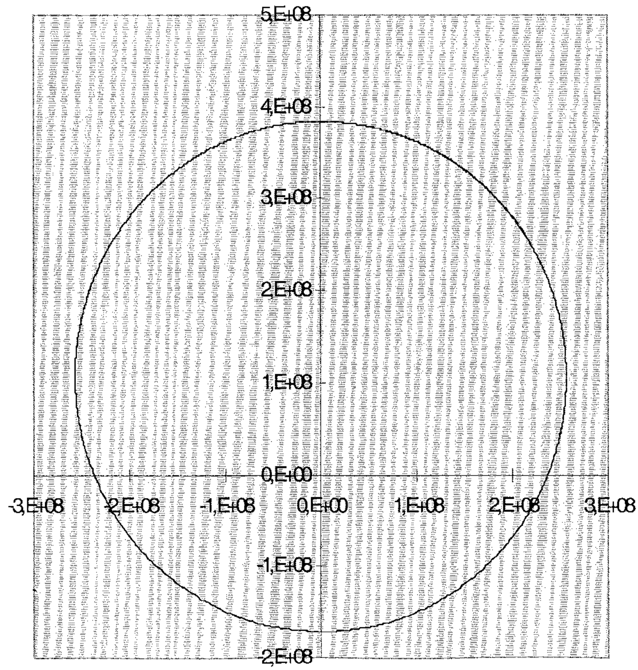
(The dynamical equations above may be refined somewhat: We notice that the velocity vector V_{i+1} at time $t+dt$ is computed on the basis of the acceleration vector A_i at time t. Geometrically, this corresponds to a parallell translation of A_i in the direction of V_i, as is easily seen; and thus a systematic error is introduced: an extra tangential acceleration in the direction of motion. In the XY-diagram generated by the spreadsheet, the effect appears as a spurious "pumping of energy" into the motion: the trajectory spirals outwards!

This error may be rectified by using the *average* of the acceleration between the two points: i.e. by replacing the velocity expressions above with:

$$V_{i+1,x} = V_{i,x} + (A_{i,x} + A_{i+1,x})/2 * dt$$

and similarly for $V_{i+1,y}$. This leads to nice elliptical orbits.)

An example, using the corrected model, is shown below: the initial parameters (given in the top left cells) correspond roughly to the Moon orbiting the Earth. The number of iterations is 950; we see from the resulting diagram, as drawn by the spreadsheet, that this yields a slightly flattened elliptical orbit.



3.4 Simulation: case stories of Einar, Eva, Jorun, Tone and Øyvind

Case 1: Using a spreadsheet to model vertical falling with air resistance

Einar – 'a conflict of pupil ambitions with the use of IT tools'
This is a story of a wellqualified and competent teacher, with long experience in teaching mathematics and science. He takes a great interest in the use of computer tools in science teaching. He joined the STTIS project because he felt that this was a new way of teaching, that might contribute to a more positive attitude to the subject, among his pupils: ... *my hope was that the use of this tool would make them become more enthusiastic about doing physics.*

The school is situated in the centre of the city, and has a high academic standing among Oslo schools. It traditionally attracts high-achieving and high-ambition pupils. The class (11 boys, 6 girls) has some spread, wrt. achievement and interest in science. They all have access to computers at home. The school is not overly well equipped with IT resources – in fact, due to an unfortunate collision in the administrative scheduling of teaching hours in the school this term, this class rarely has access to the computer lab in the periods allotted to physics. Einar tries to deal with this situation by giving the pupils (voluntary) home assignments to work out on their computers.

The lesson observed (2 x 45 minutes) was about ballistic motion – specifically, vertical falling (no initial velocity) with air resistance – to be studied using the method of successive iterations in a spreadsheet model. Since computers were not available to the pupils, Einar demonstrated the action of the spreadsheet on the blackboard and on an overhead projector screen, using a laptop: *I had to organize the work as classroom teaching: letting the pupils work with their pocket calculators, showing them the working of the spreadsheet on the board, and appealing to them to work* *on their computers at home...very unsatisfactory, I felt, but that was how it had to be..!*

Einar's main motivation for using this IT tool in his teaching was pragmatic: He wanted to demonstrate for the pupils the effect of air resistance on falling bodies. This physical process is unamenable to ordinary analytic treatment by pupils, except in very idealized situations; but the IT tool offers a possibility for them to study some features of it. Ideally, he would have wanted them to work hands-on with the software themselves; but he hoped that even with only a classroom demonstration, they would still be able to grasp some of the physics involved.

He did not anticipate any technical problems with the use of the hardware and software, and indeed no such problems arose in the session observed. The demonstrations were carried out in an ongoing dialog with the class, who seemed to be able to follow the explanations and arguments without too much trouble.

Einar feels that the use of this IT tool fits in well with his own teaching style, and also that it accords well with the requirements of the national curriculum plans for science teaching in general. However, he did anticipate some difficulties: *...problems may arise, with pupils' access to computers...(and) time constraints are narrow: this activity may take too much time.*

Einar states his learning goals for the lesson thus:

- *they should understand that the forces at each moment of the motion act to change the velocity of the moving body*
- *the ability to compute realistic problems should be a stimulus for them to learn more physics*
- *they should understand that the formulas are our attempts to describe the real world as well as possible*
- *the ...(mathematically) weaker pupils should experience this tool as easier to master*

He feels that at least some of these goals were reached: *Yes, I really think most of them got some understanding of the physics of ballistic motion with air resistance...there were some things that had to be explained...about the iteration algorithm, but they quickly seemed to get the hang of it.*

However, the net outcome of this experiment was (for Einar) a rather disappointing one: the pupils explicitly asked that such tools not be used again! In his own words: *...the majority response was clear: they did not want to work with this kind of tool in physics...they did not feel it was worthwhile spending time on it. They are ambitious to do well in the final exam, and this does not contribute to their mastery of the kind of questions they will meet there.*

The pupils were not altogether negative – some said that it had been *...a nice break in the usual routine...but we can't have too much of that, we haven't got the time!* And two of them *...said that they would like to work a little more on this task on their computers at home: try to determine the air resistance constant **k** on a pingpong ball, and so on.*

Einar expresses regret, as a physics teacher: *This technology is eminently suited to illustrate and clarify topics that are not readily accessible by the old methods..*; and *in the long run, we cannot accept this state of affairs... the general curriculum guidelines explicitly requires us to use this technology in our teaching.* He identifies where the problem lies, in his view: *this subject...is too full of topics, the pupils do not have enough time to really get into the content"*, and states that *...if (such a tool) is to be used to advantage, the curriculum must allow the necessary time for it - and also...make provision for it to enter into exams...*

In hindsight, he sees that he could have planned the lesson differently: *I probably should have taken the class into the planning from the start, explained the project to them and tried to motivate them for it...(and) to meet the argument of 'time wasted', I might have organized it more as a homework project, which they could have worked on in parallell to their activity at school.*

Summary

Einar believes that the use of IT-tools, such as a spreadsheet, can make a very positive contribution to the teaching of many topics in physics. The fact that it did not work out so well in this case, he attributes to three factors: (i) the nature of the school subject 3FY (heavily laden with content material, and with exams not rewarding or favouring the use of IT-tools); (ii) the nonavailability of computer equipment for the pupils to work with in the class (though he believes that this was not the main reason for their rejection of IT-tools in physics teaching); and (iii) his own teaching strategy. He intends to use the tool again, *...but perhaps in a 2FY class...where the content is not so packed, and with only an oral exam after...the time pressure is not so heavy...and there are many topics where the spreadsheet model could be put to use.*

We may interpret this as a transformation of Einar's teaching strategy, but not of his intentions or learning goals: *as regards my intentions, I think they are the same: to give the pupils an improved understanding of physical topics that are not readily addressed by other methods.*

Case 2: Using a dedicated program to model and illustrate motion in a Newtonian gravity field

Eva – 'from spreadsheet models to dedicated simulation programs'
This is a story of a mature teacher, who has a long experience in teaching physics and mathematics, in both lower and upper secondary school. Eva is quite enthusiastic about the use of informatic tools in science education: *I feel very strongly that we (the physics teachers) should make much more use of it than we are doing at the moment...after all, this is the way physics research is being done today.* As a consequence, she tries to use IT-tools in her physics teaching whenever this "fits in with the topic": data logging in the lab, simulation etc.

The school is situated in a small town near Oslo, in a middle class district. The class is grade 12, and has 10 pupils (6 boys, 4 girls) of age around 18, with some spread among the pupils wrt. achievement and interest in science. The access to IT equipment is satisfactory: the observed STTIS lesson was held in a computer room, with enough computers so that each pupil could have her own (though some elected to work in pairs).

Eva's main motivation for joining the STTIS project was that she wanted to use the suggested software (for both ballistic motion and motion in Newtonian gravity fields), hoping that it would give the pupils a deeper understanding of the physics involved, without getting them too involved in mathematical difficulties. But she did have some reservations: *I was a little afraid that 'the physics might disappear', in particular for the weaker pupils, in the effort to make the computer program work.*

The lesson observed (2 x 45 minutes) was about motion in a Newtonian gravity field. The software used was a dedicated program "GravSim", which simulates motions in such fields. Here the user is given various options, such as "find the acceleration of gravity on Mars", "let two stars pass close to each other" etc; and she can then run the program interactively: choose initial parameters (masses, positions and velocities) and see the resulting orbits traced on the screen, and have various answers computed. The class had previously been exposed to the theory of Newtonian gravity: the force law, and notions of orbital speed, kinetic and potential energy, and escape velocity. (In addition Eva had recently been using, with this same class, other software of relevance to the STTIS project, such as a spreadsheet model for simulating ballistic motion with air resistance, and dataloggers for lab work. These lessons, however, were not observed by us.)

In the observed lesson, the teacher first gave a short demonstration (with a video projector) of how the program worked. After that, the pupils were given various tasks to do, such as: *find the orbital velocity for a Mars satellite, with given initial parameters*, and *find the orbital velocity of the Moon around the Earth.* The pupils worked on the computers, while Eva moved around in the classroom, helping on demand. The noise level was low: the pupils seemed to enjoy working at the computer, and did not need much help from the teacher.

Different working strategies among the pupils soon became apparent. Some would "go by the book": solve the problem by computation on their pocket calculators, test this against a program run, and then (having found the ”correct answer”) move on to the next task set by the teacher, without any discussion/reflection. Eva attempted to make them reflect about their findings, by asking them questions such as *...is that a reasonable result?...what would it be like if...?* However, some of them seemed to find this a little intrusive: *...if the answer is right, what more do you want..?*

Others chose a different strategy: They would solve the task manually, test answers against a program run, and then carry on working with the same problem: change parameters "to see what happens then", discuss why it happened – in general, play around with the situation. After some time, they would decide that they wanted to try out some of the other options available in the program, to investigate questions such *as ...can we make stars collide?... can planets escape from their sun?...*

Eva's original plan had been to use the spreadsheet model to study Newtonian gravity, but after having tried out this model for ballistic motion, she decided to make a transformation of strategy: *...for the majority of pupils, dedicated software such as GravSim is probably easier to use and understand. In this case, no mathematical manipulations is needed - you just input initial parameters, and the orbit is drawn immediately.*

On the other hand: *one gets closer to the physics of the situation...when using the spreadsheet – here, the dynamics is directly visible in the acceleration terms of the iteration (...but) in order to achieve deeper understanding, we should have had the possibility to work with this tool for a longer time.* In fact, *some of the pupils have...asked me to repeat some of this work with the spreadsheet, to get a firmer grip on it...*

She also comments on the time pressure problem, finding it to be *...a problem, but not insurmountable.* On the other hand, she experienced no technical difficulties; once the software was installed and tested, it was easy to use. And the rapid computation and curve tracing made possible by the tools (compared to doing it by hand, in the traditional manner) was quite impressive, to both teacher and pupils.

Summary

Eva believes that the IT-tools of the STTIS project (the spreadsheet model and the dedicated software for simulation, and also the dataloggers for data acquisition) can make a very positive contribution to the teaching of many topics in physics. She feels that her goals have not changed, though there have been some transformations of strategy: the main one being the switch from the spreadsheet model to the dedicated software for simulation.

Concerning the spreadsheet model, she states that: *...at the time I thought that they (...understood)...but later...I found that the understanding was not as deep as (I had hoped)...* She would have liked to have more time to work with the class on that: *As I see it now, the successful use of the spreadsheet models requires that the pupils be prepared beforehand, to master the algorithm... whereas the dedicated software needs very little such preparation...On the other hand, I still think that the spreadsheet models, once mastered, can give the pupils a better insight into the dynamics of the situation.*

She definitely wants to continue using these (and other) IT-tools in the future, in her teaching of both the present 3FY course and other physics courses.

Case 3: Using a dedicated program to model and illustrate motion in a Newtonian gravity field

Jorun – 'positive, with some reservations'

This is a story of a young and dedicated teacher of physics, mathematics and computer science. Jorun is responsible for the computer network at the school, and takes a great interest in the use of computer tools in science education. She agreed to participate in the STTIS project, though with some reservations: *I was a little sceptical about the use of information technology just for its own sake... I wanted to use it where it could do some good: to do something that would be impossible, or at least impractical, to do without it.*

The school, situated in a middle-class suburban district of Oslo, has a high academic reputation and is very popular with the pupils. It is reasonably well equipped with IT resources, but still pupil access to the computer room can sometimes be a problem. The class that was taught in the STTIS lesson has 21 pupils (19 boys, 2 girls), of age 17-18. It is not homogeneous: there is a considerable spread among the pupils, wrt. achievement and interest in science.

The lessons observed was about motion in a Newtonian gravity field. The software used was a dedicated program "GravSim", which simulates motions in such fields. Here the user is given various options, such as "find the acceleration of gravity on Mars", "let two stars pass close to each other" etc. The user interface is interactive: the user is given various options such as: "find the acceleration of gravity on Mars", "two stars pass close to each other", etc.; and she may then choose initial parameters (masses, positions and velocities) and see the resulting orbits traced on the screen, and also have various answers computed.

The lessons were two single periods (each of 45 minutes), on successive days. In the first of these periods the computer lab was not available, so that the pupils could not work hands-on. This apparently happens not infrequently, and Jorun therefore often has to resort to giving them (voluntary) home assignments to work out on the computer – those who do not have home computers can then use the school equipment after hours.

In the first period, Jorun went quickly through some theoretical deductions on the blackboard (expressions for potential energy, etc.) After that, she demonstrated (with a video projector) how the program "GravSim" worked, showing how one may choose an orbital radius, and then let the program trace the orbit and display the computed value of the resulting orbital velocity. This took 15-20 minutes.

For the remaining time the pupils were given various tasks, such as: "find the orbital velocity for an Earth satellite with given initial parameters". They solved them on a pocket calculator, and then appealed to "GravSim" (as demonstrated by Jorun on the large screen) to "check out their answers". The noise level was rather high, with many pupils shouting out their results and demanding recognition from the teacher. But gradually they became absorbed in the tasks, and started asking questions, such as: *Can we make stars collide? Can they escape from each other?* etc.

Jorun's comment afterwards: *One period is too short for this kind of activity, the pupils need more time to settle in with the work... all physics teaching should be done in double-periods!*

In the second period, the pupils worked on the computers. First they "played" with the program, familiarizing themselves with the user interface. After that, they were given assignments, such as: "find the orbital radius and velocity of a satellite in synchronous circular orbit around the Earth, and ditto around Mars". Jorun went around helping them. Not much help was needed – they seemed to handle the user interface quite well, and the system worked without any technical hangups.

The pupils were encouraged by Jorun to first solve the problem by hand, using their pocket calculators, and then use the program to check their results. Most of them seemed to understand what was to be done, and to manage. Some asked: *why are we doing this – will it help us do better in exams..?*

Jorun's original intention had been to use the spreadsheet for modelling Newtonian gravity, but: *...it turned out that we did not have time to prepare the pupils for using the spreadsheet software...would have had to use too much time explaining the algorithm... I rather regret that now,*

...my fault for falling behind in my planning. However, we had by then acquired the GravSim program, and I decided to use that.

Concerning the learning goals for this lesson, Jorun stated that it should:
- *act as a motivating factor for the pupils, make physics more interesting*
- *provide variation, see how the technology can be applied in physics contexts*

As to whether these goals were in fact reached, her attitude seems to be a little ambivalent: *I am not sure about the learning effects of using such software in physics. Perhaps a little, in the overall understanding. But mainly, I think they experience it as a (more or less) welcome variation in the usual teaching.* In fact, a similar ambivalence was also expressed by the pupils: *I gave them a questionnaire after...to find out what they thought...some said that it was OK (but were not enthusiastic)...others were very critical. The highest achiever of them said that it was a "waste of time"..."much easier to do the relevant calculations by hand"...*

Jorun feels that her original intentions and expectations, wrt. using IT-tools in her teaching have essentially not changed. About her shift from the spreadsheet to GravSim: *I see this change as dictated by practical circumstances, not as a shift in intention. I hope to be able to use the spreadsheet in my teaching, at a later opportunity.* On the other hand, we may perhaps discern a transformation of teaching strategies: *I have learnt a lot about the reactions of the pupils...we must vary (the use of IT-tools) so that they do not get bored, technical things have to work smoothly, computer algorithms should not stand in the way of physical understanding...*

She also comments on the problem of time pressure: *...there is a lot of material to go through...the pupils want to be well prepared for the end-of-year exam, and will question our using too much time on "non-productive" activites...* On the other hand, using IT-tools is: *the way physics research is done these days... they should have some exposure to this fact also...*

Summary

Jorun believes that it is important *...that we get serious about the incorporation of informatic tools in our teaching of physics*. She also feels that: *...there are many instances where this technology can be used to advantage, for illustrating/simulating processes that are difficult to compute or reproduce in the laboratory.* However, many difficulties must then be overcome, not least economic: *hardware and software cost money, and we have a tight school budget.*

The main factors influencing her uptake of IT-tools in her teaching seem to be: (i) the explicit requirement in the curriculum that they be used, and (ii) her own professional interest (as a science teacher) in the use of such tools. The problems posed by time pressure (creating a tension between the use of IT-tools and exam requirements), and economic constraints (lack of necessary IT equipment), she sees as issues that have to be resolved somehow – not as acceptable excuses for not using IT-tools..!

She wants to continue using the STTIS IT-tools (and others) in the future, in her teaching of both the present 3FY course and other physics courses.

Case 4: Using a spreadsheet to simulate ballistic motion

Tone – 'IT tools for interpreting graphical information'

This is a story of a young and dedicated teacher, who takes an active interest in the use of IT tools in science education, and is keen to try out the use of such tools in physics teaching – though she describes herself as a non-expert on computers: *It has been on my mind for some time now, that I ought to get into this mode of teaching (using informatic tools), and this was just the kind of 'push' that I needed.*

The school is situated in a middle class suburban district, and is reasonably well equipped with IT resources. The class that was taught in the STTIS lesson has 11 pupils (all boys), with a notable spread of achievement and interest in science. About half have an immigrant background, but the spread seems to be much the same in both groups.

The lesson (2 x 45 minutes) was about ballistic motion – a refresher before the final exam: they had been through the subject matter previously (without air resistance), but then not using IT. The plan was to study such motions, both without and with air resistance, using the method of successive iterations in a spreadsheet model. After a demonstration of this method (on the blackboard, by the teacher), the pupils were to work with it on the computers, first solving problems set by the teacher and then playing around with the model on their own. And this plan was followed quite closely, essentially with no deviations. (As stated by Tone: for reasons of illness, this lesson was not observed by the STTIS researcher.)

Tone's main motivation for using the spreadsheet in her teaching physics was one of exploration: *I was interested in...using the spreadsheet, with its great computational power, for problems too complex to tackle by hand...(and) to explore the use of this tool to give the pupils more experience in interpreting and analysing curve diagrams.*

Tone feels that this use of the spreadsheet fits quite well with the requirements of the national curriculum plans for physics teaching, of ballistic motions and many other physical phenomena. However, concrete guidelines are lacking in the plans: *...it does not say much about how it should be used; I think many of us feel that to be a problem.* She also remarks on the problem of time pressure: *...there is a lot of material to go* *through in the curriculum, in the time available... Still, I do not feel that this...has been a waste of time, I think the pupils have learnt some physics from it.*

Tone states her learning goals for the lesson thus:

- *I hope that it will help them to interpret graphs that describe physical processes – perhaps even give them a better understanding of the concept of a 'limiting velocity'.*
- *Maybe it can even lead to some insight into the concept of a model in physics: a simplified description of a system, to understand it better*

And she feels that, on the whole, it was a success: The technology worked smoothly, and the pupils agreed afterwards *...that it had been fun, and that they had learnt and understood some physics from it.* However, this learning/understanding was not tested.

Tone states explicitly that she feels herself to be very much in tune with the intentions of the "producers" (here, the researchers, who had implemented the spreadsheet model), wrt. to the use of the software in her teaching: *...I felt quite free to experiment with the tool, adapt it to the classroom situation – not just follow a predetermined procedure.* And she felt that it was easy to use, both for her and for her pupils. As it turned out, the pupils preferred to work in pairs, even though there were enough computers to allow each of them to work alone.

Summary

For Tone, a main factor favouring the uptake of IT tools in physics teaching was: the challenge of trying new teaching strategies, not possible without the use of IT, together with the fact that such tools are explicitly required in the national curriculum plans. She saw, and sees, no significant negative factors (working against the use of IT). However, the successful use of such tools require careful preparations, making sure that the equipment is set up properly, before the lesson.

In the interview after the lesson, Tone states that things had gone more or less as planned, and that she was very satisfied with the outcome – though she would have liked to have more time with the class, working with the spreadsheet: *...two hours is too little...* She wants to use it, as well as other IT tools, more in the future: teaching both the present physics course and other courses.

Case 5: Using software to simulate motion in gravitational force fields

Øyvind – 'understanding through familiarization'

This is a story of a competent and selfconfident teacher, with a long experience in teaching mathematics and science. He is dedicated to his work, and takes a great interest in the use of computer tools in science teaching. These last years, he has experimented with using selfmade software (designed and implemented in Visual Basic) to illustrate various physical situations for the pupils. He joined the STTIS project because he felt that this was a new and exciting way of teaching, and a novel way to use a spreadsheet, but also with some scepticism:

> *...it may increase the gap between the ones (usually boys) that are proficient in handling computers, and those that are not, (and it) may also serve to alienate them from physics, and leave them with the impression that it is 'distanced from reality'*

The school is situated in a suburban middle-to-upper class district, and has a high academic standing among Oslo schools. The class (11 boys, 2 girls) is quite homogeneous, with pupils of middling achievement in and interest for science; most of them have access to computers at home. The school is not overly well equipped with IT resources – in fact, the STTIS lesson had to be conducted in the class room, since the school's computer room was not available at the time. This apparently is not uncommon, and Øyvind therefore often has to resort to giving the pupils home assignments to work out on a computer.

The lesson observed was about motion in a homogeneous gravity field (ballistic motion), and about motion of bodies interacting by Newtonian gravitational forces. The ballistic motions were to be studied, both with and without air resistance, using the method of successive iterations in a spreadsheet model. The motions under Newtonian interactions were to be studied using the spreadsheet model, and also with a dedicated program (implemented by Øivind, see above). All these were to be demonstrated by the teacher, on the blackboard and on a large screen, using a laptop and overhead projector.

Øyvind's main motivation for using these IT tools in his teaching was pragmatic. He wanted to: (i) demonstrate to the pupils the effects of air resistance on ballistic motions , and (ii) show the effects of Newton's gravitational force law. These two physical processes are both unamenable to ordinary analytic treatment by pupils, except in very idealized situations; but the IT tools offers a possibility for the pupils to study some features of them. Ideally, he would have wanted them to work hands-on with the software themselves; but he felt that even with only a classroom demonstration, they would still be able to grasp some of the physics being studied: *It is a good class to teach. The pupils choosing (the advanced physics course) tend to be ok to work with.*

The teacher did not anticipate any problems with the use of the hardware and software, and indeed no such problems arose in the session observed. The demonstrations were carried out in a ongoing dialog with the class, who seeme dto be able to follow the explanations and arguments without too much trouble.

Øyvind feels that the use of IT tools fits in well with his own teaching style, and also that it accords well with the requirements of the national curriculum plans for science teaching in general. He is, however, concerned that the use of such tools can take too much time:

> *The main problem is that of time: There are all sorts of fascinating things that one would like to bring into physics teaching, but that increases the work load.... I doubt whether we could make use of it in many other parts of physics, for reasons of time pressure.*

In particular, he had to spend some time on methodical instruction, explaining the iteration method in the spreadsheet model; and he feels that this really should be done in a math lesson, in order not to stress the (already tight) time constraints of the physics course.
Øyvind states his learning goals for the lesson thus: that the use of the IT tools will have the following effects on his pupils:

- *act as a motivating factor for them, when they see that what they have learnt in computer science class can actually be used in physics*
- *provide variation and give room for individual creativity and action*
- *demonstrate the spreadsheet as a very powerful and versatile tool*
- *lead to a better understanding of the inherent limitations of a model*

As to whether these goals were actually reached, he seems to be a little ambivalent: On the one hand, he does not really expect that they understood very much of the physics involved; on the other hand, he reflects that:

> *what does it mean to 'understand' something? In my opinion, this is often no more than having made oneself more familiar with it... To my way of thinking, this sort of 'familiarizing yourself with the problem' must surely count as an 'increase of understanding'.*

Here we may discern a transformation in the goal of the teacher, away from the traditional one where understanding means "ability to compute the right answers", and towards a more qualitative aim of "getting a feeling for the physical process". This should be seen in conjunction with an apparent shift of emphasis that emerged when the pupils were discussing Newtonian orbits: They were very engaged and interested, but mainly in exploring and testing questions connected with chaotic (nonregular) orbits:

> *Can we make the stars collide? Why is sometimes one star "thrown out" of the system? Can this happen to the Earth? Do such systems exist in the Universe?*

rather than in the regular orbits traditionally emphasized in school physics. Here we can see an interesting transformation in the activity of the pupils, as they discover the new possibilities offered by the IT tool.

Summary

Øyvind believes that "playing around" with a physical process (in this case, a simulation of one) enables the learner to gain in insight and understanding, by making himself/herself more familiar with the process studied. This was his main motivation for using this kind of IT tool in his teaching.

In this case, there were no "directions for use", concerning potential learning outcomes from the exercise – the teacher had to rely solely on the idea of visualisation implicit in the hardware and software used, and encourage the pupils to "play with" the visual representations and use them to explore the outcomes of chosen initial constraints. He did not direct this activity, but encouraged them to come up with their own suggestions – in accord with the Vygotskian idea that learning is supported by, or even presupposes, the pupils engagement in the learning goals. Using this teaching strategy, he also was quite inventive in exploiting the possibilities of visualisation inherent in the IT tools.

In the interview after the lesson, Øyvind expressed the view that things had gone more or less as planned, and stated that he would have liked to spend more time with this class working with the IT tools, if time had permitted. Moreover, he has thoughts for the future: elaborating on home assignments, implementing more spreadsheet models for other physical problems, and organising all this on the school's web page, to encourage discussion and collaboration among pupils.

The reasons why this lesson became a story of success might be several: The competence and IT know-how of the teacher clearly played a role, as did the positive attitude and willingness of the pupils. But more important were probably his careful planning and execution of the teaching, based on his ideas on how to use the IT-tools to bring about "understanding through familiarization".

4 Case studies on the use of data acquisition

The work reported in this section focusses on *acquisition and processing of data in physics laboratory work.* Four case studies in STTIS-NOR were conducted in the Trondheim area, with four teachers – one female and three male – participating in this project. (One of the teachers was observed in two different sessions, teaching physics classes at different levels.)

4.1 The informatic tools

Data acquisition tools for the school physics laboratory, relying on IT technology, fall into two broad categories:

- tools based on programmable calculators with a graphical display – so-called "graphical calculators". Such tools are usually referred to by the acronym CBL (Calculator-Based Laboratory)
- tools based on microcomputers – similarly referred to by the acronym MBL (Microcomputer-Based Laboratory)

There are some similarities between these two categories of IT tool, and some distinct differences.

CBL and MBL are similar with respect to

- the capacity to *register* and *store* physical data, as acquired from one or more sensors; these are connected to the data collection unit, and used to probe whatever physical system is to be studied in the laboratory
- the need for a *programming* of the data collection unit
- the range of *user environment*: it may be used either in the laboratory (powered from an AC outlet), or out in the field (powered by batteries)
- the ability (of both types of data collection units) to *transfer* their collected data to an external processing unit: to either a graphical calculator or a computer in the CBL case, or to a computer in the MBL case.

They are different with respect to

- ease of use: In most cases, MBLs are more easy to program and handle
- price: The MBL is by far the most expensive, at typically three times the price of a CBL unit
- software available for the analysis of the collected data: In the MBL case, there are many analysing tools to choose from; in the CBL case, one must use the built-in programming capabilities of the particular graphical calculator employed
- ease of incorporating and processing collected data, for a written report or a presentation: The MBL data are ready at hand in the computer; while the CBL data must be transferred to a computer – which in some cases may be a bit awkward to do
- choice of brands: There are at least five or six producers of MBL equipment, but only two producers of CBL equipment (as presently available for Norwegian schools)

In Norway, there are some schools that use CBL-type equipment only in their laboratory work, some that use only MBL, and some that use both. The reason for the relatively widespread use of CBL is that pupils who are enrolled in the study track *General and Business Studies* (see section 2.1) are all obliged to purchase a graphical calculator, for use in their mathematics classes. For this reason, almost 50% of all pupils in Norwegian upper secondary school will already have this part of the data acquisition equipment readily available at hand.

Each of the participating teachers had already elected to adopt CBL as the data acquisition IT tool in his physics teaching – before the question of participating in the STTIS project came up, and without any knowledge of whatever choice the other participants had made. On entering into STTIS-NOR, they all agreed to use this activity as an attempt to create an "all-electronic" laboratory session: from the collection of data in the CBL unit, to the processing and presentation of results in a report or presentation, made using a computer (here: a PC). The primary tool of analysis was the spreadsheet (in all our cases: a version of Excel).

The teachers' intentions were to use this IT tool in whichever way turned out to be the most suitable, in view of the laboratory tasks they were planning to perform and the laboratory equipment that was available at their schools. The problem areas of the physics curriculum to be treated in the STTIS-NOR sessions were selected to be:

- thermodynamics, in the 2FY course
- mechanics, in the 2FY and 3FY courses
- electromagnetism, in the 3FY course

In each of these areas, the CBL equipment was used to register the values of physical variables in the system being treated, and afterwards these values were transferred to a computer for further processing and presentation.

At the start of the project, a "statement of intention" document was filled in by the teacher and returned to the STTIS researcher,(see appendix D). This was done in order to attain a (reasonably) common starting point for the sessions observed. In this document it was stated that:

- the researcher should be present in the laboratory during the CBL sessions, in order to make observations and to register comments etc. from the pupils
- an interview should be performed with the teacher, after the sessions – here we would focus on what happened in the sessions, and on their outcome, in the light of what was written in the statement

The data emerging from the statements of intention, classroom observations and post-session interviews have been written up in "case summaries", given in appendix B (STTIS-NOR, 1999). These summaries form the basis for the **case stories** given below, describing the part of STTIS-NOR that dealt with data acquisition.

4.2 Data acquisition: case stories of Bjørn, Ingjerd, Ivar and Tor-Olav

Case 1: Using a hand-held datalogger to explore electromagnetic induction

Bjørn - 'Stimulated in-depth learning'

This is a story of an experienced teacher who is very dedicated to his work. He believes that the use of dataloggers for measurements and accompanying software for analysis of the measured data will make it possible for the pupils to learn physics in an stimulating and enjoyable manner. He also believes that as a professional he should try out new ways and opportunities for teaching physics. The use of new IT-based teaching methods also feels quite interesting and stimulating to him.

The school is situated in the countryside, but pupils from a very varied background attend it. The school's physics laboratory is very well equipped regarding dataloggers, laptops and software. Therefore Bjørn regards his opportunities to fulfil the curriculum plans, with respect to IT implementation, as very good indeed. The class is gender biased, with one girl and seventeen boys. Their interest and skills, both in physics and in using IT-tools, are rather widely spread; but the teacher believes the pupils find it absolutely natural that IT-tools are used in the physics laboratory.

Bjørn is also himself very positive towards the use of IT in science education, and he does not fear any negative impact from using dataloggers and laptops. Nevertheless, he has only used this equipment once before with this class, and has no concrete plans to use it a third time.

The lesson observed was about electromagnetic induction. The use of dataloggers here provides an opportunity to make a visualisation of this phenomenon, based on the pupils' own measurements. The datalogger used was the CBL, connected to a pocket calculator with a graphical display. In this exercise it was only necessary to use one voltage probe, as time measurements are done automatically by the datalogger. The exercise was a rather simple one, with the pupils dropping a permanent magnet through a coil connected to the voltage probe. The collected data were then transferred to the laptop, to be visualised using the software

'Graphical Analysis' from Vernier. When finished, pupils were encouraged to try to import the data into 'MS-Excel' and make a second visualisation. Only a few pupils reached this part. Bjørn felt quite comfortable with the equipment, and did not anticipate any special problems with the pupils' use of it.

The teacher's stated main reason for using the IT tools in his teaching was that he believed they would have an "positive impact" on the pupils: they would stimulate and inspire them, provide variation and would be fun for them to work with. In line with this belief (in the stimulating aspect of the IT-tools used), Bjørn chose to let groups of pupils work independently with the exercise, with the teacher acting only as supervisor and "online help".

More implicitly though, it was clear that his main goal for all physics lessons was for the pupils to learn content knowledge. Explicitly he stated that

> *...we must not, however – I would like to emphasise that – let the use of IT destroy the good, solid work of making our pupils really understand physics. We can not, and must not, try to cover up lack of fundamental physical knowledge with some 'IT icing'...*

This fear, that the use of IT-tools might come into conflict with the priority of content learning, was his only critical comment concerning the general use of IT-tools in science education. His own use of IT-tools he viewed as being well within his prioritised goal for physics teaching.

When Bjørn introduced the exercise on electromagnetic induction, it had already been studied theoretically by the pupils. He had also used between one and two lessons to prepare the pupils for the exercise – this was done, he said, to ensure that the pupils would know the equipment and be able to understand their findings:

> *When the pupils are prepared, they are aware of what they should find, and they work faster and more dedicated in the laboratory. They are also able to sort out "anomalies" in the results, and to find out why these occur and to start over again, if necessary: "This result is not consistent with what I expected, why is this so...?"*

This rationale indicates one learning goal for the lesson: in-depth learning through relating observations to theory. This goal was identified as implicit in the teaching strategies used. Bjørn encouraged his pupils to try different types of coil, to vary the falling heights for the magnetic rods, and to try to predict the outcome of the experiment in each case with such changes in the setting. The learning goal for the exercise, which he talks about as an experiment, therefore seemed to be to induce in-depth learning through visualisation of the phenomena, and through getting pupils to use theory to predict observations.

There was no documentation from the makers of the equipment, indicating potential learning outcomes from this exercise. The teacher thus had to relate only to the ideas of visualisation that were implicit in the hardware and software used. These implicit ideas he then transformed into an opportunity for pupils to achieve more in-depth understanding of the phenomena, through encouraging them to use theory to predict observations. He did not explicitly direct all the pupils to do this, but apparently relied on the stimulating effects of the exercise and the IT-tool used. He thus seems to adhere to the Vygotskian idea that learning is supported by, and indeed presupposes, the pupils' engagement in the learning goals.

Summary

In summary we can say that Bjørn believes in inspiration and joy, visualisation, exploration and independence as a means to learn physics. He emphasises the need to relate observations to theory, and to let the pupils make their own decisions on how to explore the phenomena. Through such a teaching strategy he hopes that the pupils will achieve in-depth learning. Using this strategy, he was also quite innovative with respect to the narrow goal of visualisation that was implicit in the hardware and software used.

Another motive for Bjørn to use IT-tools in his physics teaching was that as a professional teacher he wanted to stay "up front". Moreover, he felt that the use of IT-tools was interesting and stimulating for himself, as a teacher.

The main reasons why Bjørn chose to use the IT-tool the way he did seem to be the following; The school was amply equipped, so that the pupils could work in small groups. He believed the pupils to be very positive towards the use of IT-tools in the physics laboratory, and to find the use of the CBL and the 'Graphical Analysis' package inspiring and fun. He also expected that there would be no technical problems or negative impacts on the pupils' learning.

In the interview after the lesson, Bjørn expressed the view that it all went as planned, and he stated that ...*I will most certainly continue to use it.* He thus seems to be satisfied with the pupils' learning outcome. The reasons why this lesson became a story of success might be several: The school had ample IT equipment, and both the pupils and the teacher had a positive attitude towards the use of IT in physics laboratory work. But the most important factor was probably the teacher's careful planning and preparation of the lesson, based on his ideas on how to use the IT-tools to bring about in-depth learning through the use of the special characteristics of these tools. The use of dataloggers made it possible to test out several predictions within a relatively short time, through the rapid measuring procedures provided by these tools.

Case 2: **Using CBL-based laboratory measurements to determine the heat capacity of a calorimeter**

Ingjerd – 'doesn't really see why there should be any problems at all'
Ingjerd is a relatively "fresh" teacher, with a major in biophysics. She practised during her teacher training period in the same school where Ivar works, and she even had him as tutor for her practice teaching in physics.

The school is situated in a suburban area; it is a Christian school with a good academic reputation, and is very popular among the pupils. The traditional laboratory equipment is ample and of good quality, and so is the new data logging hardware and software. Access to the computer rooms is sometimes rather difficult. On the whole, she finds that the equipment available in the school, both with respect to physics and computer hardware, is well adapted to be used in the 2FY-curriculum.

Her class has 22 pupils, 9 girls and 13 boys, aged 17-20. In her opinion, the pupils are on the whole kind of "middle of the road" with respect to interest in physics and informatics

For Ingjerd the work with data logging equipment in the laboratory is a matter of course, because she was used to working this way throughout her science studies: *For me, it was quite natural to start using these tools in my class. I even did not read the curriculum plans to see what they stated with respect to this.*

The experiment was set up to let the pupils perform a CBL-conducted experiment, in order to determine the heat capacity of a calorimeter.

The preparations were as they normally are before the pupils start working with a new experiment and with new equipment. She did not anticipate any problems in using these tools: *When it comes to using the computers and programs such as Excel, they are almost as good as I am, if not better.* She is aware of the problems which can arise when they try to transfer data from the calculators to the PC, though, but she was not going to stress this point:

For me, IT is a tool; and if the tool is not good enough, I will not use it. She is not going to let the pupils struggle with the kind of problems that is caused by the tool and not the physics.

The pupils worked as normally, in groups of 3 or 4, and they worked very well during the observation. Some of the groups were very eager to start the experiment, some of the others were discussing intently, and seemed to put a lot of thinking into the setting-up of the experiment. Ingjerd tried to convince them all to "think twice" and be well prepared, before performing the data acquisition.

When the experimental results were available for comparison, the result from one of the groups turned out to be rather different from the others. Ingjerd did not regard this as a negative outcome, however, because the groups had designed their own set-ups and this particular group had done that in a quite unorthodox way. So, the result was somewhat expected, because of the "adventurous" experimental set-up by this group – which she deliberately let them work through, to gain experience.

Ingjerd is quite certain that she will continue to use this tool in her future teaching: *I will most certainly use the CBL again, and perhaps more and earlier, in order to make the pupils even more acquainted with it.* She will also try to implement some computer simulations in the future, because she sees this to be just as natural as doing experiments using IT tools: *I am very interested in computer simulation, and I would like to try it in my courses, because I used it in my own studies. The use of simulation, as I see it, is just as good as collecting data when it comes to implementing IT in the physics courses. From my own studying years, I am accustomed to use IT in these two ways: collection of data and simulation of processes. Therefore, I will introduce IT as a simulation tool later on.*

Summary

Ingjerd has an uncomplicated attitude to using the new IT equipment in the physics laboratory. She has always used it in her own studies, both in the laboratory and in simulations, and she does not see why there should be any problems with doing the same thing in upper secondary school. She has never taught the old curriculum, so that presents no obstacle for her: *Remember, I have not used any of the earlier curriculum plans in my teaching, so the current plan is quite natural to me.* This attitude is giving her the opportunity to transfer her own positive experiences to the pupils. She regards this as a successful way of working in the laboratory: *Nowadays, this kind of experimental equipment is presented from day-1 in university courses, so why not in upper secondary school? For me, it is not a problem at all.*

She does not fear any problems with using this equipment, because the pupils are well prepared: *The first time I used it, I did certainly put quite a lot of work into preparing my pupils for the use of this equipment; but after that, it was quite easy for them, and these tools are exactly what they are supposed to be: just tools that we use in learning physics.* This she stresses quite a lot: the main thing is to learn physics! *...as I said earlier, I am genuinely positive to work this way, and do not see it as a problem that I have to "overcome". But I will only use it when I am certain that my pupils see the point of using it for learning physics, not just some "black boxes".*

This is an important point for her – when discussing the experiment with the pupils before actually performing it, she states that: *I think that they became aware of some aspects of physics that they possibly might have overlooked. But it is a way of thinking that takes some time to develop – the first time you see the displays of the outcome from an experiment on the computer screen, it is not easy to establish the logical connection between "what is up here" and "what is down there"...*

Case 3: Using CBL-based laboratory measurements in calorimetric investigations and in induction experiments

Ivar – 'The outcome is well worth the hard work'

This teacher is very experienced and dedicated to his work and is prepared to put a lot of work into the preparations of an experiment and the use of the equipment, in order to reach his goals. He wants the pupils to achieve high standards in his class, and he hopes that the use of IT tools will create curiosity and interests among them in addition to fulfil curriculum plans. He has a relaxed, calm and very positive attitude to his pupils, and he encourages them to work hard, formulate their own problems and seek the answers in co-operation with their fellow pupils.

The school is situated in a suburban area, and is academically very well reputed. Generally, the pupils are of a high standard. The science department is very well organised and has ample equipment, both with respect to traditional and IT-based tools.

Ivar does not fear any negative impacts at all from using IT tools in the laboratory. On the contrary, he believes that the use of it will have considerable positive effects on the pupils: *I hope to create interest and curiosity, to make them feel pleased in working with new and advanced tools in the laboratory and with experiments we previously could not perform.*

Apart from this, he hopes to learn something for himself: *Taking part in this investigation is a sort of external push you can benefit from, when you are adapting new ways of doing things. When you are working with somebody else, you have to make sure that you are doing this the best way possible.*

The lessons observed were about calorimetric measurements of specific heat of a solid and of induction voltage and current in a solenoid. The use of data logging equipment means that accurate measurements can take place with very short time intervals, thus providing the pupils with the possibility of creating very smooth graphical displays of the data collected. Analysing these graphs will give the pupils further knowledge of the processes they are studying, and give them an excellent opportunity to compare with theoretical results.

When the class were doing the experiments, the pupils were well prepared for the lessons. They had "played" with the equipment earlier on, and had also been given experimental notes to study in order to know what is going to take place.

Consistent with his way of normally doing things in the laboratory, Ivar did not give any detailed information to his pupils – merely a "framework", which meant that they had to formulate problems and seek solutions by themselves, in co-operation with their fellow workers in the groups. In this way he forces them to take an active part in the learning process during the laboratory sessions.

The outcome of the induction experiments presented the pupils and the teacher with some strange results, which were very surprising. Instead of accepting these results and make up an explanation based on some "mysterious physics", Ivar decided to find out what was really the reason behind these results – and thus he gained further knowledge, both in the programming of the CBL and the experimental set-up.

There were some additional problems. Transforming the collected data to a format readable by the spreadsheet (Excel) turned out to be cumbersome and awkward. *That part was really hard – much harder than I have anticipated.* However, the problems they encountered have not put him off from using these tools in the future: *... we have all learned a lot from this. I am going to use it (the CBL) a lot more in the future, now that I am aware of the problems that can arise and how to cope with them.*

Ivar is not certain that the use of these tools is going to have any major impact of the understanding of physics among his pupils: *I am not sure that they have learned the topics better this way than we could have managed doing things the more 'ordinary' way.* Thus, he does not regard these tools as some "magical wand" to gain deeper physical understanding. But he will continue to use them, because of the additional impacts he finds: *I think that my pupils find it interesting and a bit of fun to use*, and *I hope that some of them can suggest some experiments that they would like to perform.*

Summary

Ivar believes that the use of IT tools will stimulate his pupils and make them look upon laboratory work as something interesting and fun to do. He works in a way that forces the pupils to formulate their problems and to seek the solutions in co-operation with their fellow workers in the laboratory. He likes to use these tools himself, and wants to develop some new and exciting experiments, and hopes that even some of his pupils can do so. He did not fear any problems using these tools, but experienced in fact a lot of trouble that was demanding and difficult to overcome. This, he regards as not solely a negative outcome, but also as something of a valuable experience, that they all have learned a lot from and that has made them confident that they can cope with similar problems in the future.

Case 4: Using CBL-based laboratory measurements to investigate the air resistance on a falling body

Tor-Olav - "Getting more from it than actually anticipated"

Tor-Olav is a very experienced teacher of both mathematics and physics. He is dedicated to his work and wants to do his best to fulfil the curriculum plans, to vary his teaching and to stimulate his pupils and make them work. He wants the pupils to get used to different kind of laboratory equipment in their collecting and analysing of the experimental data. He is not afraid of trying new techniques and wants to try new ways of working in the laboratory: *I did this because I wanted to do something I had never done before.* He directly states that he has a positive attitude towards working with IT tools, and that *we have to learn to use this new kind of equipment.*

The school is situated in a suburban area; it is regarded as a very good school, and is popular among the pupils. The ordinary laboratory equipment is ample and very good, but the amount of the new data logging equipment could have been better. Access to the computer rooms is sometimes rather difficult. His class has 18 pupils, both girls and boys. *It is a rather clever group, well above the average level.*

Tor-Olav finds that the use of the data logging equipment fits well within the curriculum plans and his own view of working in physics. Moreover, he finds that the equipment gives him the opportunity to do something very interesting for a science teacher: let the pupils try the testing of hypotheses in their own laboratory work.

The experiment was set up in such a way as to let the pupils experience how an outcome of the experiment can strengthen or weaken their hypothesis. The idea was to let them use the motion detector to measure the <u>distance traversed</u> by a falling object vs the <u>time of fall</u>, in order to investigate the hypothesis of an air resistance proportional to the 2^{nd} power of the speed for such an object.

The preparations were as they normally would be, before starting on a new experiment and with new equipment. Tor-Olav did not fear any special problems due to the fact that he was going to use IT equipment: *No, no more than I do with ordinary experimental work (concerning fear of problems working with this equipment).*

The pupils worked as they normally do, in groups of 3 or 4. Due to the fact that they are not very experienced in working with the equipment, they now and then tended to disturb each other: *it was sometimes a lot of arms and legs in the room.* However, they also helped each other during the data collecting and data transferring phases of the work. After collecting the data, they tried to find curves that fit and that they could use to verify (or falsify) their hypothesis. Thus, they had to relate the visual displays of their measurements to the anticipated outcome, in order to validate their hypothesis. The teacher found that they learnt a lot from their analysis of these graphical displays.

Tor-Olav was very pleased with the outcome of the experiment: *The pupils found this type of work stimulating, they worked hard and they did actually more than we have planned... It seems to me that this kind of equipment actually stimulates the "what if..." kind of thinking we love to see in our pupils...It was a very nice experience, and I am very pleased with the outcome.*

Summary

Tor-Olav sees these new IT tools as an opportunity to vary his own teaching, fulfil curriculum plans, learn something new himself, force the pupils to participate in the laboratory lessons, and make them learn from setting up experiments in order to verify their hypotheses in the school laboratory. In doing so, he found that the outcome more than fulfilled his expectations. During the work, he found that the testing of the hypothesis was far more accurate than he had expected, and that both he and his pupils learnt a lot from it. The success of this way of working is reflected in his own statements: *Now I know that the equipment actually works and performs well in the laboratory... I am going to use it whenever appropriate in the future.*

5 Observations, discussion and conclusions

5.1 Some general observations

To start with, we wish to make a general remark concerning the question of transformations of teaching practice: It should be pointed out that such transformations were, in a sense, going on all the time in STTIS-NOR! During the teaching sessions that we observed, the teachers were constantly inventing and trying out, in big ways or small, new ways of teaching. In fact, we would maintain that such a process of "constantly transforming" one's teaching practice – by continuously adjusting to input from the classroom situation – is one important characteristic of good teaching in general..!

In the present context, we are looking for transformations specifically connected with the use of designated IT tools. So, we make first some general observations, not directly correlated with the particular software (simulation or data acquisition) that was actually used.

Concerning educational directives: It is explicitly stated in the Norwegian school curriculum that IT should be used in the teaching of virtually all school subjects; but very little is said about how this should be done, and (more importantly) it is tacitly accepted when this requirement is not met.

Thus, "our" teachers are among those (a minority?) who have actively taken steps to use IT tools in their teaching of physics. Moreover, they all come from either the Oslo region (five) or the Trondheim region (four); we (the STTIS-NOR research group) have used our net of acquaintances, from our present and former practice as physics teachers, to select the participants. This, in fact, turned out to be fairly easy – we did not have to look very far to find willing teachers. On the other hand, it is then clear that no degree of representativity can be claimed for our observations. In other words: our teachers are not representative cases; and our case studies should be regarded as indicative of what is possible, not of what happens on the average. Still, it is our impression that computer modelling and data monitoring are not widely used in the teaching of physics in Norwegian secondary schools. Indeed, this observation agrees with what was found in a recent survey (SITES, 1999) made in Norway and other countries.

As previously stated, our teachers were quite enthusiastic about trying out the software in their teaching. In particular, they did show a marked willingness to experiment with new kinds of software – and even (in one case) to design and implement proprietary simulation software, for use in the classroom. Several of them have stated that this project had been a strong stimulant for them to increase their own competence in teaching physics, and that they were now eager to "spread the good word" (about using IT tools in teaching) to their colleagues! On the other hand, they also report that many of said colleagues had expressed a large degree of scepticism to the whole idea...

We have not observed great differences between our teachers (perhaps not surprising, considering the circumstances of their selection...) They are all professionally well trained in physics – with a master's degree or major in physics, and mostly with long experience in physics teaching at upper secondary level – and project a large degree of selfconfidence in their teaching. They come from much the same social and educational background, and the schools where they teach are located in similar (middle to upper class) areas. Moreover, they all express a shared didactic goal: to make clear to the pupils that the technology is a tool only – the physics is the main thing:

> *...teaching (of physics) should aim at having the pupils: (i) gain additional insight into and understanding of physical phenomena, and (ii) realize that physics research today is done with an extensive use of informatic tools...*

They had varying previous experience with using IT tools in their teaching – ranging from "quite a lot" to "hardly any" – but this did not seem to make much difference to their performance in STTIS-NOR. Some of them did experience a few "glitches" in the installing and use of the IT tools in the classroom, but on the whole there were no serious difficulties reported. Note, however, that they all emphasize the necessity of careful preliminary planning and testing of the equipment, to ensure a smooth run in the classroom session.

Somewhat unexpectedly, the pupils also tended to experience the software as being easy to use, with little preinstruction needed. Indeed, most of the pupils were attentive and interested, and seemed to "have fun" with the use of the tools – there were no problems of "keeping control". Many of them came up with innovative strategies, in experimenting with initial parameters and adjustments; and they readily shared their know-how and discoveries with each other. We did not see any apparent regional differences, but some gender bias: the boys being on the whole somewhat more enthusiastic and knowledgeable than the girls, wrt using these IT tools. (Of course, no statistical significance can be attached to this observation, considering the small number of cases observed.)

Our teachers have expressed before the run of STTIS-NOR – and have reaffirmed after that – the following attitude, toward IT tools in the teaching of physics: Such tools should be used only if and when they can make a positive contribution to the understanding of the subject matter. In other words, they should not be used simply to learn about IT! On the other hand, some also voiced as an opinion that it is important to expose pupils to IT as a standard tool in the teaching of physics, because it is an indispensable ingredient in physics research: "*...they should be brought to realize that this is the way physics is done nowadays...*"

About the infrastructure: The survey referred to above (SITES 1999) indicates that upper secondary schools in Norway are fairly well provisioned with hardware: they have, on the average, around five pupils per computer – with, however, large variations between regions and also between individual schools in a region.

In STTIS-NOR the availability of the necessary hardware for the pupils, in the classroom session observed, varied considerably between the participating schools: from "no access" to "one computer per pupil". Indeed, our teachers report that access to computers is often a problem, even when the school is well equipped. The hardware is usually located in a separate "computer room", and every teacher then has to "book in" for the use of this room with his class, whenever he needs it in his teaching. This presents the school (and the individual teacher) with a logistic problem of queuing for the computer room, which requires careful planning at the start and adherence to a rather rigid schedule of teaching throughout the school year. Our case studies support our impression of the general attitude prevalent in our school community today: namely, that many (most?) teachers feel this situation to be too constraining, and hence tend to minimize (or even avoid) the use of computers in their teaching practice.

Summing up: Our case studies indicate that the use of IT tools in the teaching of physics is still a somewhat "unorthodox" practice in Norwegian upper secondary schools. It does not appear as a natural ingredient in the teaching and learning process, and the physics teacher consequently may feel that he has to "justify" it, i.e. argue (to himself, and to colleagues) why such tools should be used. On the other hand, it is no longer extremely rare: more and more teachers are incorporating, or at least considering, IT tools as part of their classroom teaching. Moreover, there is a noticeable pressure on the teacher, both from educational directives (the curriculum) and from the general "trend of society", to do this: i.e. start using IT tools in their teaching practice.

5.2 Findings specifically related to the simulation studies

Uptake of the informatic tool

The five teachers observed in the simulation studies were all teaching 3FY classes: Two of them used a spreadsheet model to study ballistic motion; two used a (commercially available) dedicated program to study satellite motion; and one used both: the spreadsheet to study both satellite and ballistic motion, and a (self-produced) dedicated program to study satellite motion. (For a description of the school physics subjects of 2FY/3FY, see section 2.2.)

On the whole, the teachers had no trouble installing and using the software. But, planning had to be done carefully, and early: One teacher wanted to use the spreadsheet model in teaching Newtonian gravity, but left this unplanned until (she felt that) there was too little time available to prepare the class for it, and hence had to use the dedicated software instead.

Time pressure was an major issue: With many topics to cover in the syllabus, our teachers tended to feel (to varying degrees) that not too much time could be spent on letting the pupils "play with the computer". The expressed attitude was that the STTIS-NOR project was "fun to do", both for the pupils and the teacher – but, regrettably, not productive in preparing for the written exams. (This time pressure was perceived to be less of a problem in the data acquisition case studies, see section 5.5.)

All the teachers remark on the problem posed by the tension existing between curriculum requirements and exam practice. More specifically:

- The curriculum explicitly states that IT tools should be extensively used in the teaching of physics (and, indeed, of almost all school subjects at this level).
- The exams, on the other hand, do not favour such use – exam questions tend to be of a type that does not reward, or even require, the use of information technology.

This problem is aggravated by the fact that the school subject in which the simulation studies were conducted (3FY) is heavily packed with content material, and concludes with a centrally given written exam. Indeed, the teachers all express as their opinion that the use of IT-tools in physics teaching would be much easier and more productive in the subject 2FY: an introductory physics course at K11 level, which is much less content-laden, and concludes with a locally given oral exam.

Indeed, it seems that many (most?) Norwegian physics teachers show little enthusiasm for using simulation tools in their teaching – of 3FY, at least. They tend to blame this on time pressure: "We can't waste time on the computer, our obligation is to prepare the pupils for their physics exam..!"

Summing up possible factors influencing uptake

Clearly time pressure, combined with lack of direct relevance for exams, was felt as a hinder for further use to some of the teachers. The lack of relevance resulted in negative response from the pupils, as reported i.e. by Einar. This response the teachers felt obliged to take into consideration in their future planning. Curriculum demands were mentioned as a motivation for the uptake of informatic tools by some of the teachers. However, the simulation cases shows that curriculum demands are not enough, if they are not supported by relevance for exams.

Other factors that stimulated the teachers' uptake of the informatic tool in the first place included the possibility of varying teaching methods, as emphasised by Jorun, and of stimulating and motivating the pupils. Moreover, the teachers hoped that the simulations could facilitate physics learning through the possibility of visualisation and exploration of complex phenomena. Tone also emphasised the challenge involved in trying a new teaching strategies as a motivation, and Jorunn pointed to her own personal interest in the use of informatic tools.

Factors that made some of the teachers a little sceptical about using simulations was the fear that the physics might disappear, due to the complexity of the tools, and that the use of informatic tools could involve a gender issue. The concern, as articulated by Øyvind, was that differences in competencies in handling computers could lead to differences in learning outcome. Obviously the availability of sufficient computers to allow for 'hands on' simulations, instead of just demonstrations, was an important factor in the teachers' evaluation prior to uptake.

The teachers' evaluation of the use of simulations

From the above discussion it follows that the pupils' acceptance of the focus for the lesson is a prerequisite for the teachers' evaluation of the use of the informatic tool as successful. Of similar importance was ample equipment. For two cases, the computer room was not available for the observed sessions; and in one case, it was only available for half the time. Here the teacher had to make do with demonstrating the action of the software for the class, using an overhead projector with LCD panel and/or transparencies. This unfortunate state of affairs was slightly mitigated by the fact that almost all the pupils had access to computers at home.

In those cases where computers were not available for the pupils to explore the phenomenon 'hands on', the teachers suspected a diminished learning outcome. Thus, a sufficient number of computers to allow 'hands-on' exploration seemed to be viewed as important for the success of the lesson.

Possible 'disturbing features' of the programs – like inaccuracies in the program leading to 'forbidden' phenomena – clearly also affected the learning process, with respect to the teachers' intended goals, and thus diminished the success of the use of the informatic tool. Moreover, Øyvind pointed to the fact that the tool allowed for exploration of a phenomenon (chaotic orbits) that are not included in the curriculum. This phenomenon was discovered and focused on by the pupils, again leading away from some of the intended learning goals for the lesson.

For Einar, Eva, Tone and Øyvind, who used the spreadsheet model and implemented the simulations themselves, competency in programming and in handling of computers seemed to be a prerequisite for using this informatic tool with success in the physics lesson.

Summing up factors influencing success

The use of a spreadsheet to simulate ballistic motion was viewed only as a limited success by the teachers. The main reason for this was the combination of (i) a packed curriculum and (ii) a lack of perceived relevance of both intended and realised learning goals for the exam at the end of the year. Relevance, with respect to both curriculum demands and exams, thus seems to be a premise for success.

The possibility for the pupils to use the computer to explore physical phenomena 'hands-on' was also highly valued by the teachers. The complexity, both of the phenomenon and of the model inherent in the informatic tool, was nevertheless viewed as a factor that could hinder successful learning.

Transformations related to the use of simulations

In the sessions on satellite motion, both types of software (spreadsheet and dedicated) were used. Here, we observed two apparent transformations in the intended use of the software:

- The main interest among the pupils – as evidenced by their discussions and activities in class – seemed to be in displaying and discussing instances of chaotic motion, rather than regular orbits.
- Concerning the spreadsheet model, in particular: the pupils interest and activity were directed more toward studying the method itself (the technique of iteration), than toward the dynamical content (the physical force field).

This, of course, contributed to the conclusions drawn by the teachers after the session, as shown in the interviews. Some expressed a little uncertainty, or even doubt, about whether the pupils had really learnt much from using the IT tool (that they would not have learnt without it).

The time pressure problem discussed earlier seems to bear on several individual transformations that we could observe in our teachers:

- Eva and Jorun concluded that dedicated software is easier to use for the pupils than spreadsheet models are, and hence will be preferred in the future. They agreed that some physical understanding may be sacrificed, in using the dedicated software, since the dynamics driving the process is then hidden from the learners. But (they argue) it is not possible, in the advanced physics course 3FY at least, to allow sufficient time for the pupils to become really familiar with using the spreadsheet as a modelling tool.
- Einar, Tone and Øyvind did conclude, somewhat regretfully, that the use of such informatic tools would probably be more appropriate in the introductory physics course 2FY than in the advanced course 3FY. Two reasons were given:
  - the content load is lighter in the K11 course, thus leaving more time to spend on learning to use appropriate IT tools
  - an oral exam is more suitable than a written exam, since it can be organized such as to allow the pupil to demonstrate the extra insight gained from the use of such tools
- One of our teachers has decided, with regret, to refrain altogether from using informatic tools – at least in the teaching of his present physics class – because of the pupils' protest that they should concentrate more on preparing for their exam (the time pressure again, but now as felt by the learners..!)

5.3 Findings specifically related to the data acquisition studies

Uptake of the informatic tool

The Norwegian Curriculum Plan for physics studies in upper secondary school states that the pupils shall, with respect to laboratory activities:

... *understand the experimental nature of physics*
... *perform experiments in a wide area*
... *suggest and perform their own experiments*
... *manage to use experimental equipment, also based on IT*
... *manage to observe, analyse, interpret and present laboratory results*

One should have these aspects in mind when investigating the use of the IT tools by the teachers and pupils that participated in the STTIS-NOR project. Moreover, it is a fact that the plan appears in the pupils' textbooks, and that it is also the topic of a lesson or two in the beginning of the term; hence, the pupils are well aware of the plan requirements, such as those quoted above. The schools may then purchase CBLs and/or MBLs, in order to fulfil the plans in this respect. The equipment is rather expensive, however; and the teachers need both training and time to experience a little on their own, in order to make this really come together in the laboratory. In general, the training of teachers tends to lag a little behind the purchase of hardware in the schools.

The use of CBL data acquisition tools was, in general, readily accepted both by the participating teachers and their pupils – perhaps more readily than the use of other kinds of IT tools in physics. It would also seem that the STTIS-NOR work with these tools has been a "success story" – in fact, all the teachers report that they will try to increase this use in their future teaching, and that they are eager to find new, well-suited lab experiments for this purpose.

The teachers also found that such use of IT tools falls well within the intentions stated in the curriculum plans, and that it made the laboratory work more inspiring and fun both for themselves and for their pupils. Indeed, one teacher states explicitly that one of the reasons why he chose to use this tool was that he would then acquire another instrument in his "toolbox", for future use in varying his teaching.

None of the teachers report that they felt constrained in any way by time pressure, or by the workload of using CBL in the laboratory; neither did the pupils express such an attitude. In this respect, no difference was found between the 2FY and 3FY teachers / groups – somewhat contrary to what was observed in the groups that were using simulation tools, see section 5.3. It seems that both pupils and teachers find this type of IT tool very well suited for fulfilling the goals stated in the curriculum, that: *"...the pupil shall be able to perform laboratory experiments..."* and to *"...suggest and perform their own experiments..."* and to *"...analyse and present experimental data..."*

In fact, one of the teachers stated that she was rather surprised that the use of such tools was an issue at all! Being recently graduated from the Technical University in Trondheim, she was very much used to working with data acquisition equipment, and found the use of it quite natural and inevitable in all science.

There were two brands of CBL equipment represented among the schools. In each case the working groups had their own CBL experimental set-up at their own desks, and performed the experiment there. In general, 3 - 4 complete data acquisition sets were available. However, the schools did differ with respect to computer resources in the laboratory. In one case the pupils worked mainly with laptop computers on their desks, in another there was only one computer present in the laboratory. This was intended for transferring the data from the CBLs into the computer network, so that the pupils could go to the computer room later on, to analyse their data and to finish their reports. Access to the computer room was the real bottleneck in this process – the teachers normally had to "book in" their pupils in order to gain access.

Since Norway is a small country, with a correspondingly small language market, the hardware (CBL and MBL) is generally a mixture of American, English and Japanese origin, and therefore with software and manuals mainly in English. This made the transfer of the collected data from the CBL to a computer (in order to perform analysis and presentations) a bit difficult in some cases, because the Norwegian computer software uses some non-standard (ASCII) letters and punctuation characters. This was particularly evident when they tried to use the Norwegian version of the Excel spreadsheet as a data-analysing tool – the data format from the CBL simply was not compatible, and this problem had to be overcome, either manually or by the use of dedicated software.

However, there is a specially designed and very capable piece of software that can be used to analyse the CBL and MBL data. This so-called *Graphical Analysis Program*, from Vernier Software (USA), is quite popular; it is cheap and runs on virtually every Windows or Mac computer, imports data readily and is capable of drawing and analysing curves from experimental data in every way one can possibly think of. It comes as no surprise that this program is a best seller in this field in Norway.

The programming of the CBL unit is sometimes rather laborious – it can be done manually, but most of the experiments have their own control programs than can be downloaded into the CBL from the calculator. (One teacher reported some bugs in the ready-made software he used for programming the CBL.) Nevertheless, this did not put the participating teachers off in their work. On the contrary, they all stated that they had learnt a lot themselves from doing this. It should be noted that most of these problems are connected with the CBL; the MBL-type data acquisition equipment is normally a lot easier to handle, and the accompanying software is very capable and powerful.

The producers of such software generally encourage the schools to let the pupils install this software on their home computers (at no extra cost), because then the pupils are able to experiment with the set-up of a laboratory experiment and to analyse the outcome of it at home.

Summing up possible factors influencing uptake

In total, it appears that the general impression of both the teachers and the pupils – that the use of CBL was a relevant and time efficient method to fulfil curriculum demands – was important for the teachers' decision to use this IT-tool in their teaching. The teachers' ideas of what it takes to be professional (like Bjørn's wish to stay up front), and their attitude towards informatic tools more generally (like Ingjerd, who took for granted the use of such tools), also seem to be important. Several of the teachers and pupils experienced the use of CBL as inspiring and fun, and such experiences undoubtedly makes it more probable that they will use the CBL data acquisition tool again.

Availability of equipment obviously was important for the uptake, together with ease of use. Possible factors that could hinder the uptake of CBL seem to be the need for training in using the equipment, and (in the Norwegian context) the fact that programs and manuals usually only exist in English. However, this did not appear to be a problem in the cases using CBL in this study.

The teachers' evaluations of the success of the use of CBL

None of the teachers have shown any reluctance after the STTIS-NOR run, with regard to the possible use of this tool. On the contrary, they all report that they had gained valuable experience in the field, and that they would try to broaden this type of work in the future. In this sense we find a transformation – from (more or less) the attitude of "...ok, let's try it and see what happens...", to a definite "...yes, it worked really well – I will continue to use it in the future..!" However, as mentioned earlier, all our teachers were at the outset very positive wrt. the use of IT tools in physics, so that initial scepticism was not too deep anyway.

As observed by the STTIS researcher, the use of these tools generated a lot of work and interest by the pupils. It seemed to stimulate them, leading to questions like "...could we possibly measure this..?", or "...what happens if we try to..?", because the equipment responds almost instantaneously and can be adapted to many nontraditional working situations. Of course, this "learning by doing" effect was very much welcomed by the teachers; and their perspectives for future laboratory sessions appear to point towards a more investigative type of activity, instead of the old-fashioned "cook-book" recipe that has often held sway in traditional school laboratories in physics.

The work done by the pupils, as observed in the laboratory sessions, was quite impressive – they worked fast and efficiently, which clearly reflected the well-done preparations made by the teachers. However, none of the teachers report any significantly more laborious preparation before such an IT-laboratory lesson (compared with the traditional kind), once the pupils had got the hang of using these tools. And this, in fact, the pupils quite easily did. Though one should have in mind the fact that these pupils were accustomed to having IT tools ready at hand, throughout their previous schooling, and for them the use of such tools in the laboratory seemed to be rather a matter of course. One teacher reports that his school will now put an introduction to the use of CBLs into the general science course in the 1st year of upper secondary school. By doing this, they hope that the pupils whould "grow into" the use of these tools even faster.

Typically, the pupils worked in groups of three or four, and did so without much "interference" by the teachers. These working groups would then do the experimental set-up, and carry out the measurements, almost all by themselves. They were very eager to compare their results with the other groups, and seemed to have a really good time working this way in the laboratory.

All the teachers report that they are now trying to find – or to devise themselves – laboratory experiments that can really take advantage of these new fast and accurate data acquisition tools: they see no point in re-doing a well-constructed "manual" experiment over again with CBL, just for the sake of doing it..! They are searching for experimental situations that run "really fast" or "really slow", or that are "not yet thought of " – in short, experiments that we traditionally do not perform in "normal" physics laboratory sessions in school.

Summing up factors influencing success

The teachers using CBL clearly regarded their use of this informatic tool as successful. Several of them experienced that the pupils found the use of CBL fun, interesting and stimulating, and that it even inspired them to work harder. This aspect obviously contributed to the teachers approval of the use of CBL.

The teachers differed in their evaluations of the learning outcome. Tor-Olav thought the pupils had learned how to verify hypotheses, while Ivar was not sure the use of CBL increased the learning outcome compared with traditional methods. But the learning outcome of the single lesson was probably not what was most important for the teachers. Some of them, like Ivar, emphasised the motivating factor which made it 'well worth the hard work'. The fact that the pupils enjoyed the use of CBL seems to be valued as paramount – probably because this both stimulates further learning and develops a positive attitude towards physics among the pupils.

Another factor, that seemed to be valued by the teachers, is that the teaching method inspired by the use of CBL was in line with their own pedagogical ideas. This is clearly expressed by Bjørn, who appreciated the explorative and pupil-driven (or autonomous) learning method. This teaching method was possible because of the relatively easy handling of the CBL equipment, together with the possibility of making several data runs within a short time.

All the teachers were well prepared before the lessons, and this probably also contributed to the lack of problems and the teachers' positive evaluation of the outcome of the lessons.

Transformations related to the use of CBL

We could see no sign that the teachers were "changing their goals", in the process of using data acquisition tools in the laboratory as described above: their actions during the laboratory lessons were quite consonant with their stated intentions beforehand. This does not mean that they did not accept suggestions and proposals from their pupils as they were working – on the contrary, they stimulated and welcomed the suggestions of new experiments from their pupils. Indeed, the very nature of doing laboratory sessions in this way seems to encourage both the pupils and the teachers in this field of science.

There was no documentation from the makers of the equipment indicating potential learning outcomes from this exercise. The teachers had to relate only to the ideas of visualisation that were implicit in the hardware and software used. Hence they had to 'transform' and develop both learning goals and teaching strategies.

Here, perhaps, we can see a significant transformation that occurs in the minds of both the pupils and the teachers: The use of such IT tools for data acquisition seems to broaden their "research horizon", encouraging the investigation of physical phenomena that one simply does not examine, in the traditional mode of doing laboratory work in secondary school.

5.4 Data acquisition and simulation studies - summary and conclusion

Uptake factors - similarities and differences

All the teachers experienced that the pupils thought the use of informatic tools was fun, stimulating and motivating. This was a hoped-for outcome, and obviously served as an important uptake factor.

All of them, moreover, viewed the learning outcome as satisfactory. The informatic tools used in the case studies allowed for 'hands-on' exploration and visualisation. This possibility also seemed to serve as a uptake factor, as it fitted well with the teachers' pedagogical ideas.

However, due to time pressure and the lacking relevance for exams, the pupils responded negatively to the use of the simulation tools. This negative response seemed to serve as a factor that will result in reduced uptake of such informatic tools by these teachers in the future. This was in stark contrast to the experiences of those teachers who used the CBL tool, where all of them wanted to continue or even increase their use of this in the future.

Table 1 gives an overview over factors identified as influencing the teachers' uptake of informatic tools.

Table 1: Factors stimulating the teachers' uptake of IT tools	
Curriculum demands	The wish to fulfil curriculum demands regarding implementation of ICT in teaching
Self-image	The wish to be professional and up-to-date
Attitudes	A positive attitude towards ICT
	A perception of the pupils, as having a positive attitudes to the use of ICT in the physics classroom
	The view that the nature of physics today requires the use of informatic tools
	The view that informatic tools represent a positive challenge to develop a new teaching method
Technical competencies	Teachers' technical competence and confidence in using ICT
	Teachers' perception of pupils' competence im the use of ICT
Pedagogical competencies	Teachers ability to take advantage of the characteristics and new possibilities offered by the IT tool
	Careful planning
Pedagogical evaluations	A hope that the use of informatic tools will serve as motivating factor
	A hope for learning through 'hands on' exploration of phenomena
Evaluation of prior experiences	A successful experience stimulates further uptake

Table 1 (cont):	Factors stimulating the teachers' uptake of IT tools
Factors hindering uptake of informatic tools	
Resources	Lack of equipment
Time efficiency	Time pressure. Implication: Teaching methods using ICT are either ineffective compared with more traditional methods, or they focus on learning objectives more or less outside those emphasized in the curriculum.
	Pupils' negative attitudes, due to their impression of low time efficiency in learning physics when ICT is used. Implication: There is a lack of teaching methods/models that are time-efficient and focus on preparation for exams.
Pedagogical evaluations	A concern that the physics may disappear in technicalities and mathematical complexities.
	A concern that the use of IT-tools will favourite pupils that are proficient in handling computers, typically boys.

A last type of uptake factor, which involved all the teachers, relates to their own personal attitudes and competencies. All were dedicated to their work, and several mentioned that they wanted to be 'professional' and 'stay up front'. They had, in general, a positive attitude towards information technologies, and an interest in developing new teaching methods to make possible increased variation in their teaching

Success factors - similarities and differences

The pupils experienced the use of informatic tools to be fun and stimulating. This resulted in enthusiasm and even 'hard work'. This situation is very desirable for a teacher, and was probably one of the reasons why most of the teachers concluded that the use of the informatic tool made a 'positive contribution' to the pupils physics learning, or that it was a success.

In many of the case studies the teachers used, or intended to use, a teaching strategy that allowed the pupils to work autonomously in small groups, exploring a physical phenomenon while the teacher worked as a supervisor, counsellor and a friendly but stimulating critic. This pedagogy, taking advantage of the characteristics and possibilities offered by the informatic tools, probably contributed substantially to the pupils engagement and learning in relation to the physical phenomenon studied.

The learning outcome was viewed differently by the two groups of teachers. Most teachers thought the pupils had achieved a better grasp of the phenomena studied. However, complexities of the informatic tools used for simulation resulted in shifts in the pupils' focus which reduced the success of the lesson in relation to the teachers' expected learning outcomes.

All teachers involved in this study made careful preparations for their lessons. This probably contributed to the fact that very few technical problems were observed.

Table 2 gives an overview over factors identified as influencing the success of the use of the informatic tools.

Table 2:	Factors influencing the teachers' evaluation of success
Factors contributing to success	
Relevance	The relevance of intended and realised learning goals in relation to both curriculum demands and exams.
Pupils responses	Experienced as fun by the pupils, and stimulating their interest in physics.
Pedagogical possibilities	A good match between the teachers' teaching style and pedagogical ideas on the one hand, and the possibilities offered by the informatic tool on the other: - learning through pupil-driven exploration of phenomenon - possible to learn about modelling, and learn interpretation of data and diagrams through visualisation - implies variation in teaching method
Awareness of tool characteristics	Teachers' ability to take advantage of the characteristics and new possibilities offered by the IT tool (i.e. to visualise phenomena and to explore phenomenon through fast and varied simulations or measurements).
Equipment	Enough equipment to allow for 'hands-on' exploration of physical phenomena.

Table 2 (cont.):	Factors influencing the teachers' evaluation of success
Factors making success harder to achieve	
Relevance for exams	The lack of relevance for exams seemed to override curriculum demands.
Time pressure	A heavily packed curriculum made it harder to spend time on 'interesting' topics.
Informatic tool	Inaccuracies in the simulation program runs attracted some attention, and thus disturbed the intended learning process.
	The complexities of the mathematical iteration process underlying the simulations became an time consuming obstacle in some instances.
	The complexities of the explored phenomena made it difficult for some pupils to concentrate on aspects included in the curriculum.

Transformations

Only two main kinds of transformations were identified. Firstly, due to lack of prescriptions from the suppliers, all teachers had to make 'transformations' by identifying their own learning goals and inventing their own teaching strategies.

Secondly, there were identified transformations from intended to realised learning goals in the simulation cases. There was a shift in focused subject matter, from regular to chaotic orbits, which were viewed as more interesting by the pupils. There was also a shift of pupil focus, from physical subject matter to the mathematical method of iteration.

In addition, the teachers using simulations underwent a 'transformation' of intention. Some teachers decided to use dedicated software instead of spreadsheet next time, in spite of anticipated diminish of physical understanding, while others concluded that the use of the simulation tools were not appropriate for the advanced physics course.

Looking to the future

Summing up, all the STTIS-NOR teachers concluded as follows:

- It is very desirable, and indeed high time, for physics teachers to start implementing the expressed requirement in the curriculum, that informatic tools be widely used in the teaching of physics.
- But a shift in syllabus content and exam emphasis is needed, both for the 2FY and 3FY courses, before this can happen:
  - The syllabus should be modified, by including topics that explicitly require informatic tools to handle (such as motion with air resistance). Working with idealised situations (e.g. motion in a vacuum) should then be correspondingly de-emphasised.
  - Exam design and practice should be correspondingly changed, to become more suited for testing the physical insight and learning to be gained by using informatic tools. (It should be mentioned that the Ministry of Education has recognized this problem, and has initiated efforts to implement some changes here.)
  - The total workload should be reduced, in 3FY at least, to allow time for concentration and for getting deeper into the subject matter.

One may hope – and, indeed, many do expect – that both the physics syllabus content and the exam design will evolve with time, to take account of the increasing availability of computers, and competence in their use, in Norwegian schools. This applies especially to the topics of simulation and modelling, where computer techniques have much to offer, in making realistic physical processes amenable to investigation by the pupils.

In addition, it is (in our opinion) essential that computer-monitoring become the natural thing to use in the pupils' laboratory work in physics – whether using the CBL or MBL type of technology, see section 4. This because it will greatly extend the range of interesting laboratory exercises accessible and manageable for the pupils; and also because they should learn that this is the way research is done in physics (and, indeed, in modern science as a whole) nowadays.

Computer skill training is now an established part of the pre-service education of teachers, in physics as well as in other school subjects. But in addition, many teachers need to have their computer competence upgraded, through in-service training courses. This is now a recognized priority in our Government Plan for reforms in teacher education.

It is to be hoped that these two factors: evolution of syllabus content / exam practice, and improved training of teachers, will contribute significantly toward changing the prevailing attitude of many physics teachers – that using IT tools wastes valuable teaching time, better spent on preparing for exams – and thus help to establish the acceptance of such tools as essential assets in the teaching of physics.

* * * * * * * * * * *

References

Dykstra, D. & Fuller, R. (1988): "Wondering about physics", John Wiley, New York

ESERA-2 (1999) – the 2nd ESERA (European Science Education Research Association) conference, Kiel, Germany, July-August 1999.
Web reference:
http://www.ppm.ipn.uni-kiel.de/ipn/projekte/esera/book/eserbook.htm

IOSTE-9 (1999) – the 9th IOSTE (International Organization for Science and Technology Education) conference, held in Durban, South Africa, June-July 1999. *Web reference:*
http://its.udw.ac.za/~.edu.department.udw/ioste/confinfo.htm

Patton, M.Q. (1991). *Qualitative evaluation and research methods.* (2nd ed.). London: Sage.

Quale, A. & Andresen, O. (1996a): "Teaching ballistic motion with air resistance, using a spreadsheet" (in Norwegian). *Web reference:*
http://skolenettet.nls.no/fag/fysikk/laringsres/fag.fysikk.kast_0.html

Quale, A, & Andresen, O. (1996b): "Teaching motion under Newtonian gravity, using a spreadsheet" (in Norwegian). *Web reference:*
http://skolenettet.nls.no/fag/fysikk/laringsres/fag.fysikk.satell_0.html

SITES (1999): *ICT and the Emerging Paradigm for Life Long Learning.* Report of the Second Information Technology in Education Study (SITES), conducted by the International Association for the Evaluation of Educational Achievement (IEA), in 1998-99. *Web reference:*
http://www.mscp.edte.utwente.nl/sitesm1/

STTIS (1999) – the cross-national STTIS web site. *Web reference:*
http://www.blues.uab.es/~idmc42/sttis.html

STTIS-NOR (1999) – the Norwegian STTIS web site. *Web reference:*
http://www.ils.uio.no/forskning/sttis/index.html