SIMULATIONS, APPLETS AND LEARNING IN SCHOOLS

Imme de Bruijn, Brian Martin, Wytze Brouwer

ABSTRACT
This paper reviews the problem of establishing learning effects with computer simulation packages in science teaching. It is stated that evidence is accumulating about the effects of simulations in a laboratory environment and about the conditions or interventions which promote this learning effect. In schools, however, these learning effects have not been proven to occur, which could be a consequence of lack of control over experiments and fewer possibilities to set up decisive testing strategies. On this subject a small literature review was conducted. On the other hand, when implementing a computer simulation package, the insufficient adoption of the environment by teachers might be a factor influencing the use and the effect of such packages. A series of teacher interviews in Canada and the Netherlands sheds light on this phenomenon. In the discussion of this paper, we evaluate those laboratory based instructional measures which are successful in promoting learning effects and which can also be of use in school situations. Part of this discussion concerns the use of JAVA applets to produce robust tools that are effective in both laboratory and school settings.

KEYWORDS
Simulation, applet, implementation, learning outcomes, evaluation

INTRODUCTION

Simulations, in one form or another have a long history in science education. Prior to the 1980's, the output of simulations was primarily in the form of data-tables and graphs. Since that era, however, and with the advent of the personal computer, the kind of output available to researchers, teachers and students has enjoyed a remarkable growth in sophistication. This includes realistic 2-dimensional rendering of time dependent phenomena and calculation and graphing of all manner of abstract concepts. More recent developments are now capable of giving outputs in the form of even more realistic situations, in three dimensions (Haertel, 2000) or in Virtual Reality (Shin, 2002).

In the literature a massive collection of simulations can be found. Many studies only describe the development process and the merits of the final product: De Jong and Van Joolingen (1998) refer to these as *engineering studies*. In the same article a number of evaluation studies about simulations are reviewed and an inventory made for the conditions that contribute to improved learning effects. All these studies are, however, conducted within the educational laboratory. In fact, only a few studies were done at schools, and in those cases the researchers had a strong influence on the way the implementation was done. This influence was especially strong in the areas of testing and the evaluation. We define *educational settings* (as opposed to laboratory settings) to be situations in schools where teachers are fully in charge of the arrangement of the learning environment, including evaluation and testing.

The main question of our paper is whether simulation courseware that is shown to be effective in the laboratory can also be shown to work in educational settings such as schools, colleges and universities. We distinguish two sub-questions with respect to this problem:

1. First, we have the question of *implementation*: do teachers and students adopt the courseware, do they consider it as a suitable extension to their approved learning practices and do they feel

comfortable using it? To answer this question we have reviewed recent literature and interviewed some experienced teachers.

2. Secondly, evidence should exist showing that simulations work in an educational setting and that the learning results are at least as good as those obtained via traditional instruction. We searched for this evidence in the literature and we discuss what kind of evaluative research will be needed to get such evidence. Most of our own experiences are in the field of physics, but we shall also make use of findings from other sciences.

In recent years a large number of simulations have become available in the form of *applets.* Many of these are written in *Java*, which enables the simulations to be distributed easily and cross-platform via the world-wide web. Almost all publications describing such simulations are, however, of the *engineering* type, and only few of them discuss implementation issues. We shall describe two studies (one unpublished as yet), in which a more extensive evaluation has been carried out to identify learning effects by using simulations in a practical context.

Our study will first give an overview of the results of former evaluation studies in laboratory settings and then discuss the implementation question: under what conditions do teachers and students adopt simulation programs for scientific discovery learning? We shall then treat the problem of evaluating simulation packages in educational settings, including the use of applets. In the final discussion we shall give some recommendations for further research

METHOD

In a review paper by De Jong and van Joolingen (1998) a large set of studies about simulations and their learning effects were summarized. Their overall conclusion is that better learning by simulations is accomplished only when the students are guided in their discovery. Without guidance or structuring the task, many learners exhibit unstructured behavior, driven by local decisions instead of planning or working towards a goal. We regard this article as a guiding document for our study, summarizing what has been reported until 1998. The studies that were analyzed by De Jong and Van Joolingen were all of the laboratory type, according to the definition in the introduction: The researchers, not the teachers, were in charge of evaluation and testing.

To get information about reported findings from 1998 until 2002 we performed three searches in two databases. After inspection this yielded six articles, containing information related to our questions. We added to this information (1) the findings of the second and third author evaluating their MAP-project (Martin et al., 2001) and (2) findings from some other studies that we knew and did not yield from the literature search (mainly form CBLIS conferences). At last we conducted a study, on the basis of a short questionnaire, among physics teachers in Canada and the Netherlands, to get answers on the issue of courseware adoption by teachers.

RESULTS

Literature searches

Two searches were made on the *ERIC* database, with restriction in publication date ‘after 1997’, first with keywords *science, simulation* and *education*, afterwards with *physics, simulation* and *education*, in titles and abstracts of documents. The first search yielded 24 ‘hits’, the second search only two. With replacement of the keyword *education* by *applet* not a single document appeared. A search, with the same restriction in publication year, in the *Science Direct* search space, with keywords *simulation* and *applet* yielded12 hits.

From the resulting documents (38) first contemplating and summarizing documents were excluded, not mentioning new studies, leaving 16 documents. At last we excluded 10 documents that only described the design of courseware, without experiences on learners; the articles by Reed and Afjeh (1998) were in this class and will be mentioned as example. Six articles resulted that contained relevant information with respect to our questions: Bayraktar (2002); Dwyer & Lopez (2001); Hmelo & Day (1999); Kelly (1998); Scanlon et al.(1998) and Windschitl & Andre(1998).

Simulations with various types of learning outcomes

Papadouris and Constantinou (2001) stress the importance of a careful analysis of the potential contribution of ICT materials to the development of learners' competencies and the capabilities of 'tools' to add to the learning environment. Following this recommendation we shall first make a distinction between three types of simulations, depending on the expected learning outcomes.

First we notice a type of learning activities by ICT-driven simulations, where students work with models and try to extract regularities by careful experimentation. Typically the simulation obeys rules from a 'hidden model'. The task for the learner is to discover these rules and other characteristics of the model, by inferring them from data obtained by experiments in the simulation. It is often supposed that this activity gives rise to an induction process, which is also the basis for acquiring conceptual knowledge. In terms of learning psychology, this should lead to the formation and tuning of schemas, a kind of network in long term memory where concepts function as nodes and relations are connections between nodes. Tuning of schemas, then, makes the connections stronger and the entire schematic matrix more interconnected. We shall confine ourselves in the remainder of this article to this kind of learning.

Secondly we distinguish a kind of learning as described by Papadouris and Constantinou (2001), which refers to model phenomena in physics by means of modeling courseware. Here the objective is to grasp the essentials of the phenomena and reflect them in a model of that phenomenon. This, it is thought, contributes to growth in cognitive skills for making and using models. Accumulation of those models could lead to a more in-depth view of physics and on the coherence of physical models. Van Heuvelen (2000), who takes the position that knowledge about the physical world becomes more abstract, through generalization of rules over different contexts, also describes this. Psychologically the focus is on integrating schemas, as described above, into macroschemas, covering a greater part of the physical world. The difference with the first type of learning is in the status of the model: in the first type the model is pre-constructed whereas in the second type the model has to be constructed by the learner. Both types are meant as an environment for self directed and 'constructivistic' learning.

There exists a third type of learning, which can be described the acquisition of proficiency in running a process and making decisions in critical situations. This objective occurs in the study by Reed & Afjeh (1998), where the working principles of an apparatus, a gas turbine, are contained in an applet. The student could not only discover those principles, but also be in control of that apparatus. This is an *engineering* study: only the package is described but no results with learners are reported.

Effects of simulations on conceptual learning

The review by De Jong and van Joolingen (1998) yields some instructional measures that yield better learning effects. First, access to domain information helps, but only if it is offered just in time (JIT-information) and not when the instruction begins with supplying this information. Secondly, providing assignments (questions, exercises, games) that focus on the relevant variables shows improvement of learning. One recent study from our literature search, to be treated later on, gives new confirmation to this point (Hmelo & Day, 1999). Next, model progression in complex simulations makes a difference: it has been shown that introducing complex models step-by-step is beneficial for understanding. Finally, the actual structuring of the learning environment can also aid or inhibit learning, but this factor is less well understood. Two studies from our literature search (Windschitl & Andre, 1998; Dwyer & Lopez, 2001) give additional evidence, we shall come back later on this point.

Another conclusion by De Jong en Van Joolingen is that working with simulations often produces learning outcomes not always measured with conventional tests, but results in what is called *intuitive knowledge*. This is a kind of implicit conceptual knowledge which becomes evident in predicting the progress of a simulation after changing one of the parameters; it seems to be valuable as long as the simulation occupies the student.

From the literature search resulted a study by Bayrakter (2002), containing a meta-evaluation of experimental effects with CAI-based instruction in secondary and college science education. The overall positive effect size turns out to be .273, which can be interpreted as: an average student in an experimental CAI group exceeds the achievement of 62% of the students getting traditional instruction. This effect is small but consistent. For studies where the CAI was in the form of simulations the effect size was .391. Indications are found that the effectiveness is better when CAI is used as a supplement to traditional instruction (CAI-alone settings are less effective) and when the student-computer ratio is higher (one student per computer is most effective). It is not sure that all studies in the meta-evaluation measured growth of conceptual knowledge, but most examples give an indication that this is the case.

Implementation and adoption of simulations by teachers

In field applications, the beliefs and educational worldviews of teachers and tutors play a role. Steinberg (2000) describes the use of simulations in physics at college level, but he also makes a restriction with respect to the exclusive use of those packages. There is an opinion among science teachers that the discovery process should reflect in some sense scientific reality, which calls for authentic experiments instead of simulated experiments.

> "....are we encouraging students to think that the process of doing science consists only of extracting the right answer from some all-knowing source?..."
> (Steinberg, 2000, p. S40.)

To understand this better, we performed a study on the acceptance of simulation programs among physics teachers, in Canada and in the Netherlands. We asked if they would be willing to take part in a –hypothetical– educational experiment, involving their 10^{th} or 11^{th} grade class. The experiment would occupy 75% of lesson time with a package of simulations devoted to the study of *mechanics.* Instructions on how to use the simulations, worksheets and tests would be supplied by the researchers; hardware considerations and support in installation would not be a problem and the content of the package would be in line with the textbook. Students results would be handed in (anonymously), together with log-files and results on a questionnaire, which would require another 15 minutes.

As well, teachers were asked additional questions that may influence or cause them to revise their answers. These were: Would their answers be altered if:

(1) the conditions are such that no other experiments than the simulated ones would be allowed, or
(2) if results from a laboratory study indicated that the simulation approach yielded superior learning, or
(3) the testing could be done by the teachers themselves, or
(4) the simulations are in the form of applets which are also available at internet so student could work on them at home.

In the Netherlands five experienced teachers were interviewed. Two of them were willing to take part in the experiment, even with option 1: no real experiments allowed; one of them made the restriction that he would have a try-out with a small group. The third teacher would take part, but not under option 1: he liked to be free to fill in the rest of the time in his own manner. The fourth teacher would hesitate to take part, because he had bad experiences with using simulations and learning effects from it: he would participate, however, under option 2: results available from laboratory studies about good learning effects. The fifth teacher rejected the proposal, because he needed more than 25% of lesson time for other things to do with students, especially in teaching mechanics (this argument was also mentioned by the fourth teacher). If the time for the simulation package were 50% or less, he would possibly participate, after inspection of the material by himself, but certainly not under condition 1. Four of the five teachers indicated that the availability of simulations as applets on the internet would positively influence their viewpoint. Three of them mentioned serious problems in doing the tests, unless the appointments were made about one year before when the testing and examination plan was not yet fixed. In conclusion, all kinds of answered were registered in the Netherlands, with 3 of 5 teachers showing a disinclination to use the simulations if real experiments were excluded from the study.

In Canada six teachers responded to the questionnaire. Three of them would participate in the project, one teacher would probably refuse because too much time would be devoted to it and he would definitely do the testing himself. Two respondents hesitated, one of them would come in under condition 2 (laboratory studies point out a good learning effect), the other one would let it depend on the view of the nature of science as reflected in the package. Four of the six Canadian teachers would certainly not participate if there were constraints in doing real experiments (option 1), for one teacher that would be a problem in one course but not so much in another course. Most teachers consider it as an advantage when the materials are published on the web as applets, one even required the availibility of the materials.

Canadian teachers often mentioned constraints in their situation, concerning shortage of hardware (4) or commitment to central examinations or curriculum (3); one respondent (who would participate) feared that students would not perform well on the central examination. Excluding those constraints, the answers by Canadian teachers match very well with their Dutch colleages. Canadian teachers put somewhat more emphasis on doing real experiments.

Simulations by applets

There are a few examples where the implementation of applets in teaching has been reported. Most of the reports are of the engineering type, containing no information about learning effects. From the description, however, the impression remains that the teachers are quite satisfied with the materials and that the implementation in school practice has been successful. Dancy et al. (2002) describe a case in which a student is offered a range of optics problems, using modifyable applets. The package gives rise to enthusiastic classroom activity, so the adoption by students seems to be good. A similar study (un-published, spring 2002) by Anderson and Martin was conducted during the collaborative development of applets for use in Canadian high schools. The collaboration was between the Modular Approach to Physics project (Martin et al , 2001) and Alberta Learning – the provincial ministry of education for the Province of Alberta. This project was a unique blend of developer (MAP) and implementers (Alberta Learning) working within a school environment. The study involved 11th grade students (N= 35, 16-17 years of age) and the use of an applet to investigate 2-dimensional accelerated motion. Some student comments are given in Table 1.

Table 1. Student comments while working with a simulation applet investigating 2-dimensional accelerated motion

- "This gadget really helps visualize it!"
- "I can see it happening."
- "It was nice to see the ball moving so we can picture the skateboarder or whatever we are looking at"
- "… good assignment …"
- "The assignment was good, but it would be better if it did not take 10 minutes to get into the program. I could probably do it from home much faster"
- "It would have been okay, except for the problems with the computer"
- "This program is interesting, but not for a very long time"
- "I thought learning this way was extremely difficult and hard to understand. I prefer note taking and chances to ask you questions when they arise."
- "I'm not good with the computer - too slow of a connection"
- "This was awesome and fun"

It is clear from this study that, while not all learners enjoy the use of applet-based simulations, there is a strong sense of approval by most learners. The study's principal investigator (Anderson) concluded his report by stating:

> "Overall, I was personally very pleased with the lesson/applet and feel that students now have another very powerful technological resource to help them visualize a

dynamic physical concept. However, in order to deliver the full potential of the resource many factors (some technical, others not) need to be taken into account. The lessons/applets will have the most impact when they are used to supplement and enrich a multimedia course that includes a variety of teacher and student centered activities. Furthermore, the instructor and pupils will need to be confident in the delivery system and be willing to take some risks in order to obtain the full potential of the resources."

Both reports mention the need to have well crafted instructions to shape student activities.
From these reports, and from the reactions of teachers in response to our questionnaire, we conclude that simulations by applets are as effective as other simulations, with an additional value because they can be made available for students on the Internet. We believe that all indications on how to design instructions around simulations also apply to the design of the instructions around applets.

Learning results in school situations
In the introduction we developed the position that learning effects by using simulations should be established in schools by using teachers' evaluation instruments. Now we should, however, weaken this point, as we found not a single study in the literature where this kind of evaluation instrument was used. Taking this new position we can mention five studies where an evaluation is made of the learning effect of simulations in a school situation.

Windschitl and Andre (1998) used simulations of the cardiovascular system in a course on human anatomy and physiology for non-biology majors among university students. They had two experimental conditions, both with simulations: an exploratory group getting so called *constructivistic* instruction and a confirmatory group. The confirmatory group followed prescribed steps to confirm information from lectures and written materials, whereas the exploratory group was stimulated to create and test their own hypotheses. Windschitl and Andre conclude that the *constructivistic* instruction yields better learning results, in particular on questions reflecting misconceptions about the cardiovascular system (conceptual change). This effect was far more pronounced for students having more advanced epistemological beliefs then for students with less advanced beliefs. By using students from a pilot study as a control group, they established an increased learning effect for both 'simulation groups'.

Hmelo and Day (1999) report on the use of a simulation in a case study for medical education (first year university). In one form of the simulation, questions were incorporated to get students focussed to bridge the gap between the problem situation and conceptual science knowledge. The control group was given the same simulation without questions. Both groups learned from the simulation, but the experimental group gave more complex and higher level formulations in a task to summarize the evidence from the case. It was concluded that good questions promote conceptual learning.

Dwyer and Lopez (2001) investigated the effects of simulations in various phases of the learning cycle in earth science education for upper elementary and middle school science students. Simulations appeared to be most effective in preinstructional and exploratory phases, especially when students got specific guidance from their teacher. It is hypothesized that the activities elicit and challenge students' alternative conceptions.

Zhou, Brouwer and Martin (2003) report on the outcomes of the MAP-project (Martin et al. 2001, Austen et al., 2001) in particular in attaining goals of enhancing conceptual learning through the use of applets. They used a test derived from the well-known Force Concept Inventory or FCI-test for conceptual knowledge in mechanics (Hestenes et al., 1992). Experimental groups and control groups are instructed by regular instructors, in the experimental groups applets are used. The aim of applets is to confront alternative conceptions about physics phenomena with clearly conceptually challenging experiments. In most cases experimental groups show a significant better growth in conceptual understanding. For some experimental groups the effect was less pronounced, a fact that could be explained in retrospect by the sequencing of the simulations and learning activities in the lessons. It became clear that the use of simulations during the introduction of a new topic was more useful and motivating than using the simulation applets as verification instances of the concepts developed in the lesson. As one instructor put it (Zhou et al., 2003): " If I used applets after the theory, students did not pay any attention to them. They already knew what would happen….In the fall I used applets most often in the beginning of the class." The discussion with the instructor indicated that there was a need to teach instructors when and how to introduce these constructivist applets into the lessons. The advice is in line with the findings by Dwyer and Lopez (2001) cited above.

Scanlon et al. (1998) evaluate three courses in the Open University science curricula containing computer tools, one of them consisting of a simulation; in fact it is not a classroom application but an example of distance learning. The authors point to the difficulties in evaluating in a such a setting, they use evaluation techniques like questionnaires, interviews, a computer conference and delayed post-tests. These techniques are laborious and expansive but considered irreplaceble. Nevertheless they can not point out learning effects from the simulation, those are only 'defendable' or 'probable'. The arguments about evaluation techniques could be applicable to the testing of learning effects in classrooms.

DISCUSSION AND CONCLUSIONS

In writing this article we had to change our definition of what we considered as a *school situation* when considering the learning effects of a simulation package. In the introduction we mentioned that the instructor should set up the testing, but in the description of indicative studies we dropped that condition. This argument is inspired by the conclusions in the study by Scanlon et al.(1998), stating that sophisticated and laborious evaluation techniques are needed to prove special learning effects in computer-based courses. We have to admit that good research in the educational field can hardly rely only on teacher made tests and we now advocate that the test for learning effects in a practical situation should be designed and prepared by researchers (perhaps in an action-research model with experienced instructors). Of course, it is wise to have instructors cooperate in devising the test and it would be hard to insert test items that they do not support. If there is a connection between the test to be used and the examinations, the test should be appointed long before the actual implementation to give room for adaption of the examination schedule.

Our second conclusion is that simulation applets do not appear to raise any unique problems in the instructional process. In fact, not a single teacher, in our interviews, pointed out any major problems with the use of these applets. Rather, they saw only an advantage when applets were made available on the internet to work with outside of school.

Another remark results from our teacher survey: instructors differ quite strongly in their opinions about what should be contained in good instruction and many of them insist on leaving room in the curriculum for real experiments alongside the simulations. Designers of learning packages should have a clear picture of the opinions among the instructors they plan to deliver it. Some instructors can be persuaded if there are laboratory studies confirming the learning effects. In some cases instructors should be teached how to use the simulation package in order to obtain good learning results.

In constructing the learning sequences which should 'surround' simulations, several considerations are of interest. From laboratory studies a set of recommendations emerge for what type of instruction will give good learning effects. These recommendations include (1) access to domain information just in time (JIT-information), (2) providing assignments (questions, exercises, games) that focus on the relevant variables, (3) model progression in complex simulations and (4) structuring of the learning environment in some way. From our review of some recent studies, conducted in educational settings, we found confirmation for the first principle: domain information should be given after presentation of a simulation, in order to keep learners interested. The positive effect of guiding students with questions is found again by Hmelo and Day (1999). With respect to the fourth recommendation we found an indication that a *constructivistic* structure for the instruction, where learners have to formulate hypotheses themselves, yields more learning effect (Dwyer and Lopez, 2001; Zhou, Martin & Brouwer, 2003); there is an interaction effect in the sense that learning is even better for students with more scientific epistemological beliefs (Windschitl & Andre, 1998). Student motivation seems to be better when a simulation is used as an introduction to a topic.

There remains one point for which the solution is not so easy to find. Research indicates that learning effects from simulations are often in the field of intuitive, or conceptual, knowledge. Few school and college curricula thus far have sufficiently valued conceptual learning enough to focus on it in the classroom and in the examinations. The technique for testing intuitive knowledge is yet more uncommon in schools. It is suggested by Scanlon et al. (1998) that the assessment of special learning effects, provoked by computer based tools like simulations, need specialized and laborious evaluation techniques, in particular in situations where part of the learning process takes place outside the school or institute. Much more research and development will be needed to bring school evaluation practices in line with laboratory settings, where the learning effects of a simulation environment are evaluated in a more sophisticated way.

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Dr. Imme de Bruijn (corresponding author)
University of Twente,
PB 217 7500 AE Enschede,
the Netherlands
Email : I.deBruijn@tn.utwente.nl

Dr. Brian E. Martin
Kings College University,
Edmonton, Canada
Email : bmartin@kingsu.ab.ca

Dr. Wytze Brouwer
University of Alberta, Edmonton, Canada
Email : wytze.brouwer@ualberta.ca