Interaction Design and Science Discovery Learning in the Future Classroom

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English abstract

This article reflects on theories of interaction design as they relate to science discovery learning. Media analysis, inquiry structure and relations between the generation of hypothesis and experimentation in theories of science discovery learning are considered in relation to approaches in interaction design. Two examples from use of interactive models for inquiry learning illustrate the discussion. The studies show that students require time to experiment with models to use them as resources, and that experimentation needs some structure elements to be productive. The interactive models need to invite action and allow for different kinds of use.

Keywords: user experience design, interactive objects, technology-enhanced learning
Introduction

In Norway, the classroom is increasingly technology dense, particularly in upper secondary schools (ITU Monitor, 2009). Personal computers are made available to students on the first day of upper secondary school\(^1\), an indication of their importance. The technology is presented as a partial replacement for the textbook, not as a supplement\(^2\). Equipped with easy and stable networks and increasingly powerful computers, the classroom of the future will be equipped to integrate advanced interactive models in learning and may add a new dimension to experiments traditionally conducted at schools. In science in particular, simulations, animations, and other interactive graphics can be an effective way to represent complicated relationships (Bravo, 2005; Furberg 2009; Holzinger et al., 2009; Lowe, 2003), and equally important, can activate and motivate students (Merrick & Maher, 2007; Yaman et al., 2008).

Science discovery learning is frequently employed as a pedagogical structure in which simulations and interactive models can be used (Abdullah & Shariff, 2008; Chang et al., 2008; Kluge & Bakken, 2010; Lindgren & Schwartz, 2009; Quintana et al., 2004; Raybourn, 2007; Reid et al., 2003; Rieber et al., 2004). In general, scientific discovery learning has ‘research’ as an ideal for the learning process (Bodemer et al., 2005), with a well-defined model of doing experimental research serving as the structure for learning in science. In line with constructivist theory (Piaget, 1955), the learner builds knowledge through productive activities that follow the scientific steps of a particular investigation (de Jong, 2006b). In each step, the construction of knowledge is related to constructive processes accompanied by material production (Papert, 1980).

This article studies the constructive use of technology in learning processes, and the ways in which students use models in interactive\(^3\) meaning-making in a relatively open science discovery structure. The data are taken from a field trial that pursues the following research questions: How do students make the interactive models relevant for use as resources in science discovery? How can interactive models be designed to stimulate discovery?

To investigate these questions, the role of technology in science discovery from a learning perspective is first outlined, focusing on technology as expressive tools and as a way to structure the process of discovery. A more dialogical approach to learning is then considered in relation to the design of technology for interactive meaning making. The empirical material gives examples from two different trials of science discovery learning using two different interactive models. The article concludes by discussing the potential for interactive meaning making when using models in science discovery.

The role of structure and technology in science discovery learning

Science discovery (also termed inquiry learning) is here studied in relation to technology use. In the literature on science discovery and technology-enhanced learning, the emphasis on design and use of technology varies. One important design focus in the research is media oriented. These studies concentrate on how different media types (text, animations, graphics, video) achieve a desired effect on learners. Schnotz and Kürshner (2008) found that combining text and animations provides better results in retention and comprehension than learning by text alone, also termed the ‘multimedia effect’ (Reiman, 2003). Lowe (2003) turns this issue around and argues that the ‘perceptual salience’ makes the students ascribe disproportionate relevance to the animations, making them counter-
productive to learning compared with other media types. In their study of physics learning with various interactive simulations, textual explanations and animations, Rieber et al. (2004) show that students who had access to the most varied sources of content in terms of media types and information clearly outperformed the other students. They observed that interactive simulations can lead to meaning making by personal discovery and exploration, and recommend more qualitative studies to explain students’ processes of exploring and making discoveries (Rieber et al., 2004).

A different role is given to the technology for inquiry when viewed as scaffolds for science discoveries (de Jong, 2006b). Emphasizing the need for support to achieve an inquiry process that is productive for students, de Jong and van Joolingen (1998) identified critical points in the inquiry process. The inquiry is thus divided into specific steps: generating hypothesis, experimentation, concluding on the basis of the experiment and reflecting on the gained knowledge (de Jong, 2006a). Based on a broad review of the literature, de Jong and van Joolingen (1998) found that the learners in each of these steps have problems proceeding with the inquiry in a productive way. In general, students have limited knowledge of the inquiry process as such, e.g., they do not know the requirements for making an hypothesis and have difficulties formulating one. In the experiment phase, students design experiments that cannot be used to confirm or reject the hypothesis, and they are found to have a bias towards confirming the hypothesis. Interpretation of unfamiliar types of data, such as graphs or multimodal representations, is difficult for them and far from the familiar binary right/wrong options.

Quintana et al. (2004) suggest a taxonomy for science discovery learning that is open for parallel processes rather than emphasizing the sequential. It consists of three main building blocks: sense making, process management, and articulation and reflection. The elements are accompanied by design guidelines for the scaffolds needed, which are derived from the obstacles learners are confronted with while engaged in that particular point in the inquiry. In an elaborated study, 20 scaffolding strategies arising from seven guidelines of three inquiry elements are formulated. Focusing on sense-making, they explore ‘how tools can help learners connect their intuitions and situational understanding with manipulation of scientific formalisms’ (Quintana et al., 2004, p. 346). In addition to designs that link and activate previous knowledge, there is sensitivity to the semantics of the particular discipline in which the study is done, or the ‘language’ of the discipline. Therefore, the design opens for a tighter coupling between competence required to conduct the inquiry and the discipline, i.e. the format of work and the content.

An important sense-making guideline in this study is the emphasis on representations. Quintana et al. (2004) recommend malleability, having representations open for inspection from different angles, multiple views, and directly manipulative models. To provide a scaffold for the inquiry process as such, the researchers suggest restricting and breaking down the task, and constraining the space of activities.

Similarly investigating ways to open up the scientific reasoning process in a learning situation that uses empirical data, Klahr and Dunbar (1988) consider how the processes can be broken down into smaller units. Studying a simple programming task, they find great variations in how students work in inquiries generating hypotheses and doing experiments. Developing an integrated model for inquiry, they define the main processes as searches in two spaces in the technological tool: (1) hypothesis space for theoretical investigations, and (2) experiment space for performing the practical trials. A main conclusion from this work is that the two spaces are interrelated in a complex and multi-directional way, and that there is considerable variation in individual approaches to inquiry.
work within and in between the two spaces. The study also shows how experimentation plays multiple roles during inquiry. The students do experiments without any hypothesis at all and use experimental operations with scientific models and results to change their understanding of the inquiry they are engaged in. A major function of the experimentation is to reframe the problem they are dealing with: ‘Insight is not merely change of values in slots of a pre-existing frame, rather it is the instantiation of a new frame – this is what is meant by a restructuring of the representation. Interaction between the experiment space and the hypothesis space plays a crucial role in such restructuring’ (Klahr & Dunbar, 1988, p. 41). The study concludes by opening up the inquiry process towards a continuous reframing by the students of the issue at hand, driven by the experimentation process – sometimes led and sometimes not led by different hypotheses. The data show that this reframing was a necessary component, in that none of the more than 100 students initially had what was defined to be the right frame (Klahr & Dunbar, 1988).

Although there is some variation, the approaches above are examples of a systemic approach to science discovery (Arnseth & Ludvigsen, 2006). This approach entails a pre-defined ideal model for inquiry-based learning, and design recommendations for technology in the form of scaffolds that provide optimal support for the particularities of a specific task. The result of this practice is the formulation of structures for inquiry, or the readjustment of previous structures, and the specification of correlations between parameters in such structures. Hypothesis generation, design of experiments and interpretation of data are supported by well-defined sub-operations, requirements at the start of each activity, and criteria for completion. The sequence of activities may be loosened up by presenting them as more parallel (Quintana et al., 2004), or a network model may be used to introduce experimentation and hypothesis development activities (Klahr & Dunbar, 1988), but a more or less pre-defined structure prevails.

Arnseth and Ludvigsen (2006) provide a dialogic approach that is an alternative to the system-analytic view presented above. Rather than presupposing an ideal model for learning (inquiry or other), studies investigate learning processes where they occur. In the context of Computer-Supported Collaborative Learning (CSCL) they propose an alternative dialogic perspective in which learning processes are not reduced to studies of variations within a pre-defined system but conceptualized and studied as ‘different elements mutually shape one another, and their meaning and functions are results of local negotiations and sense-making’ (Arnseth & Ludvigsen, 2006, p. 171). This position has consequences in terms of how ‘learning as use’ is studied in technology-enhanced inquiry learning research. In this article, the dialogic approach is applied to study the use of interactive models, as they are made relevant as resources in the students’ learning activities.

One way to interpret the results from Klahr and Dunbar (1988) in the context of technology-enhanced inquiry learning is by analysing how students use interactive models as experimentation spaces. How can interactive models be opportunities for experimentation, generating hypotheses for the students by framing and reframing their inquiry, and enhancing the opportunity for discoveries productive for learning processes? This question concerns the potential of technology as meaning-making tools. To investigate this issue further we turn to the field of interaction design.

**Interaction design and its contribution to learning**

Interaction design, with focus on design and user experience, has in the past 15 years gradually grown out of Human-Computer Interaction (HCI) field. The emergence of interaction design as a field emphasizing situated meaning-making processes opens up for phenomenological perspectives.
Dourish (2001) puts forth the notion of *embodied interaction*, characterized as ‘the creation, manipulation and sharing of meaning through engaged interaction with artefacts’ and a ‘property of our engagement with the world that allows us to make it meaningful’ (p. 126). Important in his view on design is that meaning arises for the user/learner as interaction develops. Meaning cannot be deduced by analysing artifacts, but are dynamically produced and developed through use, in a fundamental way that cannot be pre-determined. Meaning emerges on multiple levels in the transforming quality of the relationship between humans and interactive model.

This is in line with Schön (1992), who is concerned with how dynamics in the material (interactive models in this case) requires reframing of the issue at hand as the artifact is changing, whether in parts or in the whole. The potential reframing is a result of what Schön refers to as ‘design experiments’, resembling the experiments needed for doing inquiry and discoveries for learning purposes. Meaning and action fuse in a conversation with the material in the process of inquiry (Schön, 1992). This is clearly in line with the framing and reframing to which Klahr and Dunbar (1988) refer. Schön similarly views inquiry as investigating a space, and more importantly, both theories see the need to acknowledge action as experiments in structuring space in which new and gradually more relevant experiments are made to support discovery.

Studying learning as interactive meaning making introduces a perspective on learning in use, enabling a focus on discoveries as they happen or fail to happen. The studies concern the space between potential of meaning embedded in the technology – partly acknowledged by the designers and partly not – and the meaning making taking place as the process unfolds (Linell, 2009). These issues are tested on two different interactive models, related to climate change and the design of elements in a house, respectively.

**Method**

This study employs qualitative and interpretative methods (Walsham, 1995). The study is organized as a field trial with video observations, combining talk and observation of use (Jordan & Henderson, 1995; Kluge 2005). Two separate studies are used to exemplify use of interactive models, and some sequences are selected from the larger corpus to illustrate characteristic use situations (Derry et al., 2010).

In both studies the students were encouraged to talk within their group as they were working, as this gave access to the reasoning they were employing at a given point in time. Our analytical focus is on the students’ interactions with the technology and the discussions that emerge as they work together. These instances of talk and interaction in the groups are the units on which the analysis is based (Fjuk & Ludvigsen, 2001). Characteristic situations where the students make productive discoveries, and characteristic situations where discoveries were expected to happen but did not come about, are reported and analysed in the empirical section below.

**Two interactive models**

The empirical material used to discuss the issues presented above originates from two different studies with some common characteristics. In both studies the students were in the first grade in upper secondary school, 16 – 17 years old. They were engaged in a longer inquiry process, respectively 16 (for the interactive climate model) and 20 (for the CO₂-friendly house) 45-minute lessons each. Although the students worked in different group structures, dyads were the dominating
form of collaboration in front of the computer. In the house trial, the dyads emerged from a group of four students. The empirical data are examples of the variation that occur in the different dyads, and illustration of the theoretical propositions developed above.

**First trial: Use of a model of the future climate**

In the first trial the students study climate models in general, and a model of the future climate until the year 2100 in particular (Figure 1). The ‘story’ framing the activity is that the students should prepare themselves to act as youth representatives at a simulated conference as part of the Intergovernmental Panel on Climate Change (IPCC). The future climate model was integrated in the Viten website (www.viten.no), including a workbook containing questions. The questions begin with fact-based issues, and move into a more explorative form, inviting the students to investigate relationships.

**Figure 1: The future climate model**

The left hand graph (graph A) gives the driving forces for the three curves in the right hand graph (graph B). The curves in graph A represent (1) world population in billions, (2 – below) world wealth in GNP/inhabitant, (3) fossil fuel use as a percentage of total fuel use, and (4 – below) energy efficiency as a percentage of the efficiency in the year 2000. The curves in graph B represent CO$_2$ emissions (without number in endpoint), rise in temperature (here: 2.84°C) and increase in the sea level (here: 21cm).

The general learning goals for using the model and answering the questions were that the students should be able to discover the relationships between the four driving forces (see text figure 1) and their impact on climate (temperature) and sea level. In particular, we looked for their understanding of the latency effect of CO$_2$ emissions, and the fact that CO$_2$ emitted today stays in the atmosphere for decades, influencing temperature and increasing sea levels.
The students could interact with the simulator by choosing between the four tabs representing the four main scenarios developed by IPCC. They could also alter the graphs. In graph A the curves could be dragged up or down, resulting in changes also in graph B as a direct consequence.

As the coordinate systems both had several graphs, the axis could not be used to show the values. This issue was solved using a mouse-over interaction technique. When the user placed the mouse pointer on a point in the graph, the corresponding denomination would become visible at the axis, and the value pair at the point would appear next to the mouse pointer. This was done in both coordinate systems. In addition, the two curves representing rise in temperature and increase in sea level (graph B) had values of 2100 continually present in the right-hand end of the curves (see Figure 1). The rationale for this was that the values represented a kind of end result for the simulator, answering the question of how much can climate, and its subsequent sea level, change in 100 years.

The excerpt below is from Mark and Morten’s initial use of the model. They have not seen the questions, as the workbook has not been opened. Instead they examine the climate model thoroughly, by looking through each of the four scenarios:

| Mark: "It changes a little, doesn’t it?!" |
| Morten: "Yes, it does. You can see the degrees [temperature] and … more I think" |
| Mark: "Increase in temperature … Yes, of course! Because, that is the result, then" |

| He browses through the 4 scenarios |

Here the dyad makes an important discovery that frames their study. Even before they discovered that they could alter the curves directly, they switched between the four scenarios and observed that increase in temperature (as the other curves in the right-hand graphs) is a consequence of the level of the four driving forces. This is a crucial framing of the issue they are working with and the basis for the coming inquiry. The discovery arises from the activity of selecting different scenarios as they see the temperature change depending on the level of the driving forces.

The dyad continues their study on the simulator, now with the workbook and questions present. Inspired by the question where they are invited to vary the different parameters they put together an experiment:
Mark: "Drag everything down to zero"

Morten: If we drag everything down -- but really, it shouldn’t it have become colder then?"

Mark: "Have to take it from the start. And the population also. It is still something left."

Mark: "It does not have much influence now, because we do not have any … but we do not have any [energy] use, it is no more fossil energy .. maybe it means .."

Morten: "… can’t mean anything …"

Mark: "… probably does not mean anything either. The only thing left now is the result of what has been done in advance. Before [the year] 2000.

Here, the dyad drags all the driving forces to zero. This results in zero CO₂-emission, but the increase in temperature and rise of sea level continues for decades. They see this and conclude that the continued increase is a result of what has been emitted until and including the year 2000, and that they cannot change that emission in the model because emissions in the year 2000 is an established fact and not a prediction.

The open exploration in which the dyad engages includes several other exploratory investigations similar to those in excerpt 2. At times the students work with a formulated question, while at other times there is no concrete aim expressed and they seem to explore the model to see what it had to offer. This was the only group of the four studied that discovered the latency effect of CO₂-emissions, that is, effect in the atmosphere decades after emission.

Below is an excerpt of a dyad that has started the simulator for the first time. As with the group Mark and Martin above, these students are high achievers and regularly receive top grades. The excerpt shows how they are hesitant to operate the model.

Hilde: "What are we supposed to do here?"

Per: "I don’t think we are supposed to do anything, I think we shall study it"

Per opens the future climate simulator

He clicks cautious in the graphs, and uses mouseover occasionally and in a controlled way to get information about what the different graphs symbolize, and the amount.

The excerpt illustrates how the dyad applies a rather passive approach to the simulator. Reluctant to manipulate the model throughout the trial, they do not become familiar with it as the material of investigation, which seems to obstruct the process of meaning making. As the questions become their focus of attention, they answer correctly for the specific ones, but are not able to answer the more open questions as they consistently are looking for not only ‘the right’ question, but also ‘the right way’ to interact with the model. They become frustrated, talking about the difficulties of writing and that they do not know what is expected of them, rather than explore possibilities.
The interactive model of the climate is a representation with the potential to make meaning for the students. The latency effect is one such meaning, which the first group discovered, but the variance in driving power of the four forces, and the relations between CO₂ emissions, increase in temperature, and sea level could also have been explored. There is a sharp contrast between how the two groups make use of the model. Mark and Martin’s way of working, with a loose coupling to a scaffolding structure of questions that inspires them, keeps inquiry of the model on track while exploring the model in a productive drive toward discovery. The second group maintained a very strong bond to the questions and task, not understanding the relation in several instances between the questions and the mode. Since exploring questions were up to them to define, they did not manage to use the model productively for discovery.

Only the last part of the question set qualifies as inquiries. The first questions were more about positioning the model and reading data from it in that position. The last part of the task was explorative, and it was also possible to explore the model as such, to investigate what it could illustrate. This was what the first dyad of Mark and Martin did with success. They investigated the model for relations, exploring what it could tell them. As previously reported (Kluge & Bakken, 2010), their engagement was high as they discovered the possibilities of manipulating the curves directly. They palpated the model for meaning in mouse-over interaction and they looked for relationships in sustained interaction that also enabled reflection. The other group, reluctant to interact with the model and resisting an inquiry mode, did not discover the latency effect. Their interaction with the environment was limited to reading out specific values as results, rather than to understand relationships, or indeed make discoveries.

**Second trial: Using the house thermal model**

The empirical material below is from an integrated project named SCY (Science Created by You). The project has science discovery learning as the overall structure for the students’ work. Through the use of tools and scaffolds, the students are challenged to work as scientists, formulating hypotheses, carrying out experiments, drawing conclusions, and reflecting on what they have done. The students use a special-purpose digital environment called SCY-Lab to conduct their inquiry. For the purpose of this article, use of the ‘Thermal simulation’ is studied in particular. This is a tool to select the different features of a house that is relevant for heat loss: building structure, insulation, windows, ventilation and size are the most important parameters. In the 20 hours of schoolwork the students did during the project, this was the main tool in the inquiry of how to design a CO₂-friendly house.
One central feature of the simulation is a bar chart that is always present and which the students use to fill in different attributes of material type and sizes of the house (Figure 2). One expectation before the trial was that the students would only be looking at optimizing heat loss, forgetting about the practical consequences of their choices, due to the accentuated bar chart measuring elements that were directly relevant for CO₂ emissions. However, the empirical material shows the opposite. Overall, the students took practical considerations into account even when external to the simulator, discussing the cost of building the house, the availability of the materials, inner climate consequences, how it ought to look good and be practical, and be made of environment-friendly material. They did not, for instance, increase the insulation indiscriminately to make the house energy friendly or make any other one-dimensional optimization.

In the excerpt below, three students (one dyad and one student from another dyad) sit and work together to find out the structure of the house walls and the insulations, discussing and occasionally looking at each other’s screens. The model allows them to select between several options in two pop-up menus.
Jack: "What do we have for choices again – let's see ...
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Lisa: "Because, if you see, so, like, one of them [materials for insulation and wall structure] is better than the other"

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Jane: "Look, look, look, look. Look at how much lower we can get it"

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Jane: "Then it will be straw bail house"

Lisa: "Straw house"

Jane: "Yes, that's cool. But a bit to flammable"

Lisa: "Yes"

Jack: But – but there are these modern straw bale house where you can mix in some cement-like things"

Jane: "Yes, we can say that we have done that"

Jack: "We should check that out then, in stead of just guessing"

Opens the pop-up menu where the different materials are listed

Referring to the bar chart

Lisa points at the bar representing the walls

Jane changes the numbers as she talks -- simultaneously reading the bar chart

In the excerpt above, the students use the thermal simulator to understand building structure and the relevance of the different components. They discover that one type of insulation and one type of structure is better with regard to heat loss than the other. At the same time, they are engaged by how the consequences of changes in thickness of the structure and insulation have immediate consequences for the heat loss bar chart. The use of the model becomes their way of discovering what the house consists of, and the importance of insulation thickness. The elements of the house are present in the simulator, and the students can make use of the interactive entity to explore the elements of a house relevant for energy use.

As the simulator contains a list of possible insulations, this becomes a way to constrain the inquiry. The group begins to discuss the different types of insulations and their properties. They search information on houses built of straw bale, and they view some pictures, but do not go deeper into the information they retrieve. They rely on their beliefs, and on their aesthetic assessment of the house examples they see in pictures. However, a problem is explicitly acknowledged in the last utterance, as it is clear to them that they do not know the basics about the building material, and should further investigate the issue of using straw bale as building material.

The next group has had a session very similar to the group above when the next excerpt begins. They have studied different materials popping up in the menus, and searched the web for information. They decided on a straw-bale house after a more thorough study than the group above. In the excerpt below, the students begin to discuss what is more effective at decreasing heat loss: increasing the thickness of the structure or increasing the thickness of the insulation. They do not manage to agree on this, and Tina suggests that Nora does a small experiment by use of the thermal simulator:
In the beginning of this excerpt, Tina verbalizes a problem that no one in the group can answer. They seek the house simulator for answers. Kathrine suggests a way of doing it and they explore the simulator for a while without a clear result. Then Tina sketches an experiment. She instructs Nora, who is using the thermal simulator, alternately to set the same thickness on structure and insulation and to read the values of the bar chart. The experiment is well put together for the purpose, and leads to a clear and undisputed conclusion at the end of the excerpt. The students move from an initially unclear state of discussion to resolving the issue by using the simulator.

This experiment by the students was unexpected for the researchers and designers of the model. Looking for ways for the model to make meaning for them, the students did not understand the significance of wall structure versus insulations. Their interaction with the models reveals a question they needed to answer before they could proceed with their design work. The experiment they put together shows how they are looking for meaning, to understand the model and its logic as a representation of house design. In the language of inquiry, the interaction with the model reveals a hypothesis they need to answer – insulation has better impact on reducing heat loss than structure if thickness is identical – and they put together an experiment based on the knowledge they had gained about the potential of the model. This knowledge is about what the interactive model is capable of doing (altering thickness, selecting insulation, comparing by using the graph) and an understanding of the need to select good material in the walls to reduce heat loss and make the house CO₂ friendly.
The house design model did not offer direct interaction in the same way as the climate model. This led the students to less exploration and more emphasis on hypothesis-driven activities. As an interactive object, the house design model has a scaffolding structure integrated in the form of lists of possible selections, and elements to be filled out to complete the task. The representation of the list as a pop-up menu works as a trigger for investigating the different building structures and insulations, and the house model can provide the students with answers regarding heat loss for each building element. It could be expected that the students optimize within the model and leave out elements not covered by the model, e.g., environmental issues regarding production and destruction, price, and aesthetics. Yet, they see their responsibility of the house design as taking a reasonable totality into consideration, although the work invested in such reflections varied across the student groups. The model served as the basis for asking relevant questions. This excerpt illustrates how the inquiry presented to them makes the groups responsible for addressing the overall goals, rather than to optimize within the model. They explore the elements in the model and build knowledge about what a house contains, e.g., how insulation and wall structure are related.

The way the students make use of interactive models as a resource for discovery varies between the two model types and within each model. As students take on the task of inquiry using technology, they enter a world that is doubly unfamiliar, confronted with curricular content they do not know and an interactive model that they do not know how to use. Their challenge is to conduct scientific discovery and to make the interactive model useful for their investigation. Aspects of variation relevant for the research questions are discussed in the next section.

Discussion

To explain how it is possible to understand something you do not already know, can lead to a logical breakdown, as a Meno’s paradox (Solheim et al., 2003). Objects in general, and digital technology in particular, offer an exciting opportunity to bypass this deadlock. By motivating the learner to act, the productive cycle presented by Schön (1992) and others (Hodgkin, 1985; Dourish, 2001) can be set in motion and become instrumental in stimulating discoveries. As learners act by using models, they can at the same time study how models change based on their actions. In interactive models used in science learning these changes are often illustrations of scientific relationships. Using models for playful experiments can lead to productive alterations between investigating use of the model (‘Can we do this?’) by playing with it, developing hypotheses about possible relations, and gradually formulating specific hypotheses to test out and make discoveries.

To make this slightly idealized cycle work, a model is needed that invites action. When students try to make operations – different modes of mouse-over, clicking, or moving – the model should give adequate curricular and also structural response. The students make investigations into the workings of the model, which need to be aligned with the inquiry they are about to engage in.

In this study, as the learners did not initially know what the model could produce for them, exploring by doing more or less structured experiments appears to have been productive. Tentative use to understand the workings of a model, which allows commencement on curricular material, may be likened to exploring the space of experimentation (Klahr & Dunbar, 1988). Through this exploration, the students gradually understand what the model can deliver for them, making more or less explicit hypotheses and thereby also structuring the inquiry. The dyad that looked for the ‘right way’ to operate the climate model, i.e. looked for a precise hypothesis to proceed with the interactive experimentation, became passive and failed to reach an important goal of the
investigation. They were able to get facts as numbers out of the future climate model, but failed to get advanced relationships. The other dyad allowed the material to talk to them and was surprised about interaction possibilities and relationships, in fact, making genuine discoveries on their own (Kluge & Bakken, 2010). Their intense interaction led to discoveries of relationships rather than facts. To some extent, they embodied the interaction (Dourish, 2001) by continuously acting rather than looking up answers as numbers. Rather than moving from hypothesis to experiments, these students stayed in the experiment space (Klahr & Dunbar, 1988) and took occasional detours to make hypotheses about what they in fact already had experienced.

In addition to providing curricular content, the models also structured the discovery process. In the first example, the model of the future climate seemed to work against the sequential set of questions. The questions were taken one at the time, looking for right answers, and the students did not refer to previous answers. The most successful dyad was able to sustain the exploring process as their main activity, opening up for discoveries, whereas the other group relied on the authority of the question structure and remained in a fact-oriented mode.

In the house thermal simulator, the structure was incorporated into the model by lists and implicit sequences of actions. This led to less variation in the inquiry among the students. There were productive results when, as in the future climate model, the students let the model ‘talk to them’ by exploring relationships. Experiments were based on knowledge about the workings of the model that they had acquired through previous interaction, together with an initial understanding of the relations expressed in the model.

Generally, the experiments in which students engage in an inquiry are unpredictable. Mixing insulation with building structure and removing the population from the planet become productive experiments for the students’ further inquiry, yet difficult to plan for. This is an illustration of the need for robust interactive models that implement the logic of the phenomena. The ways in which students choose to investigate an interactive entity cannot be anticipated on a general level, and interaction that may seem meaningless when the model is designed may nonetheless be productive for students’ learning. The need to incorporate a variety of use styles on the one hand, and different levels of previous knowledge on the other, requires flexibility and openness in the design.

Conclusion

The classroom of the future will have the technological prerequisites to make use of interactive models to explore advanced relationships in science and in other domains. This article has investigated how interaction design perspectives can be used to understand the use of interactive models in inquiry learning. Two research questions were posed: How are learners able to make the interactive models relevant and use them as resources for science discovery? How can interactive models be designed to stimulate discovery?

The analysis shows that students need time to experiment with models in order to use them as resources. As novices to the issues being modelled and to the interactive object, students may find it fruitful to operate on it in a variety of less goal-oriented ways. The successful students constructed an intuitive ontology of the phenomena in a world that is new to them, based on interactions. They were intensely interactive, particularly in the early phases of use and inquiry, and the students’ tentative exploring of the model was productive in the sense of making genuine discoveries. This
explorative activity paved the way for the gradually more structured activities to complete the inquiry process.

From a design perspective, successful students familiarize themselves with the interactive model, which needs to invite action and encompass a wide variety of use. The model needs to be robust for the curricular domain and illustrative of the particular relationships in science, and the design should allow for ways of interpreting the totality of the phenomena under investigation. The students’ quest for meaning will assume unexpected forms in the relative openness of an inquiry. Narrow fact-finding can be done with means other than a model, and may hinder discovery.

Choosing between structure and exploration in a model is a question of balancing the two. As this study indicates, incorporating mild structure in a model is productive given that students acknowledge the general goal of the inquiry. A stronger sequencing of the inquiry restrains important movement back and forth between experimentation and posing questions, thereby limiting exploration and science discovery.

This research is done in cooperation with the Norwegian Centre for Science Education and as a part of the SCY projects (Science Created by You) funded by the European Commission

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2 According to e.g. the Norwegian government budget of 2008 http://www.udir.no/Brev/_tilskott/Gratis-laremidler-i-videregående-opplaring/ (In Norwegian)
3 “Interactive” is in this article related to human-computer interaction
4 SCY is financed by the European Commission