THE DEVELOPMENT OF MODELING SKILLS THROUGH COMPUTER BASED SIMULATION OF AN ANT COLONY

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ABSTRACT

Learning in science can be analyzed into a number of constituent components: the acquisition of experiences with natural phenomena provides the basis for the subsequent development of concepts; the mental representation of the structure and organization of scientific knowledge that is needed to avoid knowledge fragmentation and meaningless use of jargon comes with the development of epistemological awareness; scientific and reasoning skills provide the strategies and procedures for making operational use of one's conceptual understanding in order to analyze and understand every day phenomena but also to undertake critical evaluation of evidence in decision making situations. Finally, positive attitudes towards inquiry feed students motivation and safeguard sustainable engagement with the learning process. Traditional instruction has failed to explicitly take into account many of these components. This has severely constrained the ability of traditional teaching approaches to promote real learning. Effective instructional programs need to promote all these components in unison in a manner that enhances situated learning and promotes awareness of the significance of coherent operational understanding and its power in shaping decisions, both public and personal. At the level of the individual student, modeling can provide a theme that runs through the whole of science learning and through appropriate instructional design can be used to continuously focus in on all the components mentioned above in a systematic and constructive way. The Learning in Physics Group has a program to explore the way modeling can shape the teaching and learning process in science and the extent to which computer-based modeling tools can support this process. We have designed and implemented an intervention to develop the modeling skills of students in upper elementary grades in the context of division of labour in an ant colony. In this paper, we present the design of our ant colony simulation environment and the learning outcomes of one classroom trial of our intervention.

KEYWORDS

modeling skills, ant colony, simulation, epistemological analysis

1. INTRODUCTION

Physical science can be characterized as a complex network of models interrelated by a system of theoretical principles. Models are units of structured knowledge used to represent observable patterns in physical phenomena. Accordingly, *physical understanding* can be perceived as a complex set of modeling skills, that is, cognitive skills for making and using models [1]. The development of modeling skills enables students to make sense of their own physical experiences and to evaluate information reported by others.

Modeling can potentially provide a backbone structure for constructing meaning in physical science. In this approach, students are guided to develop a set of generic modeling skills in one domain and to transfer those same skills in other domains, further elaborating an developing them with experience and practice. The modeling approach to learning is iterative in that it involves continuous comparison of the model with the reference physical system with the express purpose of gaining feedback for improving the model so that it accurately represents as many aspects of the system as possible. It is also cyclical in that it involves the generation of models of various forms until one can be found that successfully emulates the observable behaviour of the system [2].

The main purpose of this paper is to present the results of evaluation of research-based curriculum aiming to use this model-based approach in constructing division of labour concepts in the context of investigating an ant colony.

2. BACKGROUND

A model is primarily a conceptual representation of the structure of a physical phenomenon or procedure. According to Constantinou [2], a model may consist of one or more material objects or massless entities. The capability to construct models relies on a combination of a number of skills, such as extracting information from the physical phenomenon and the models, comparing models to corresponding physical phenomena, comparing models with other models and inventing new, more refined models that are in better correspondence with observed phenomena.

Glynn and Duit [3] suggest that, in order to achieve substantial knowledge in physical science, children must construct conceptual models consisting of interrelated concepts. Models are simplifications of reality that help us to better understand a system, especially large and complex systems. Particularly, models help us to visualize a system and specify its structure or behavior. Moreover, the modeling process usually simplifies a phenomenon thereby revealing its more fundamental concepts and downgrading any secondary information that is not directly relevant to those aspects of the system that are of interest for investigation purposes.

3. DESIGN OF THE CURRICULUM

3.1 DESIGN PRINCIPLES

We have developed curriculum that seeks to promote student understanding of the division of labour in an ant colony. The curriculum is suitable for children aged 10 upwards. By the age of 10, many children have extensive direct experience with ant colonies. We have found that modeling an ant colony can be both interesting and motivating for these children.

The design of curriculum needs to take into account several principles. Firstly, the structure, organization and content of an effective instructional program needs to take into consideration the learners' mental age and their developmental constrains so that formulated objectives will be realizable. Besides conceptual understanding, instructional programs should aim to develop scientific and reasoning skills, such as formulating hypotheses, modeling physical phenomena, predicting future behaviour and experimenting with isolated aspects. Scientific skills, reasoning skills and epistemological awareness facilitate the operational use of one's

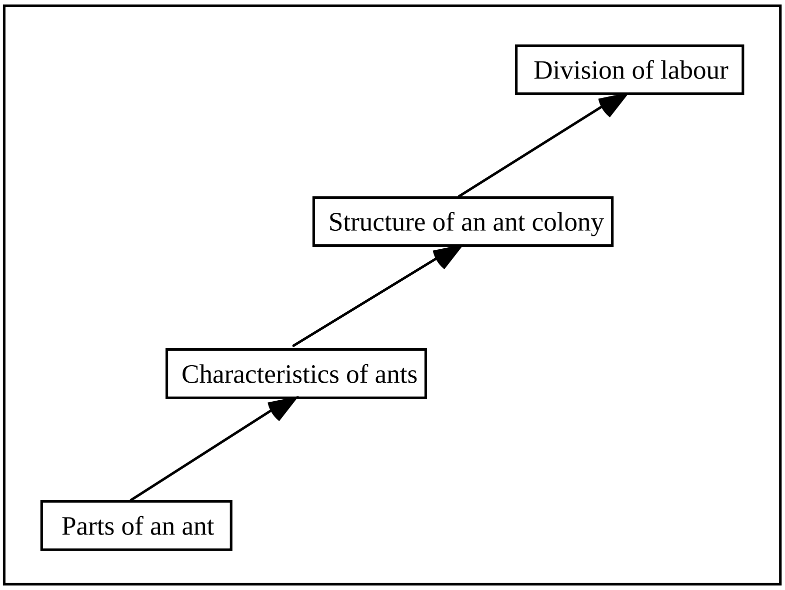

Figure1: Epistemological analysis of the concept of *division of labour*

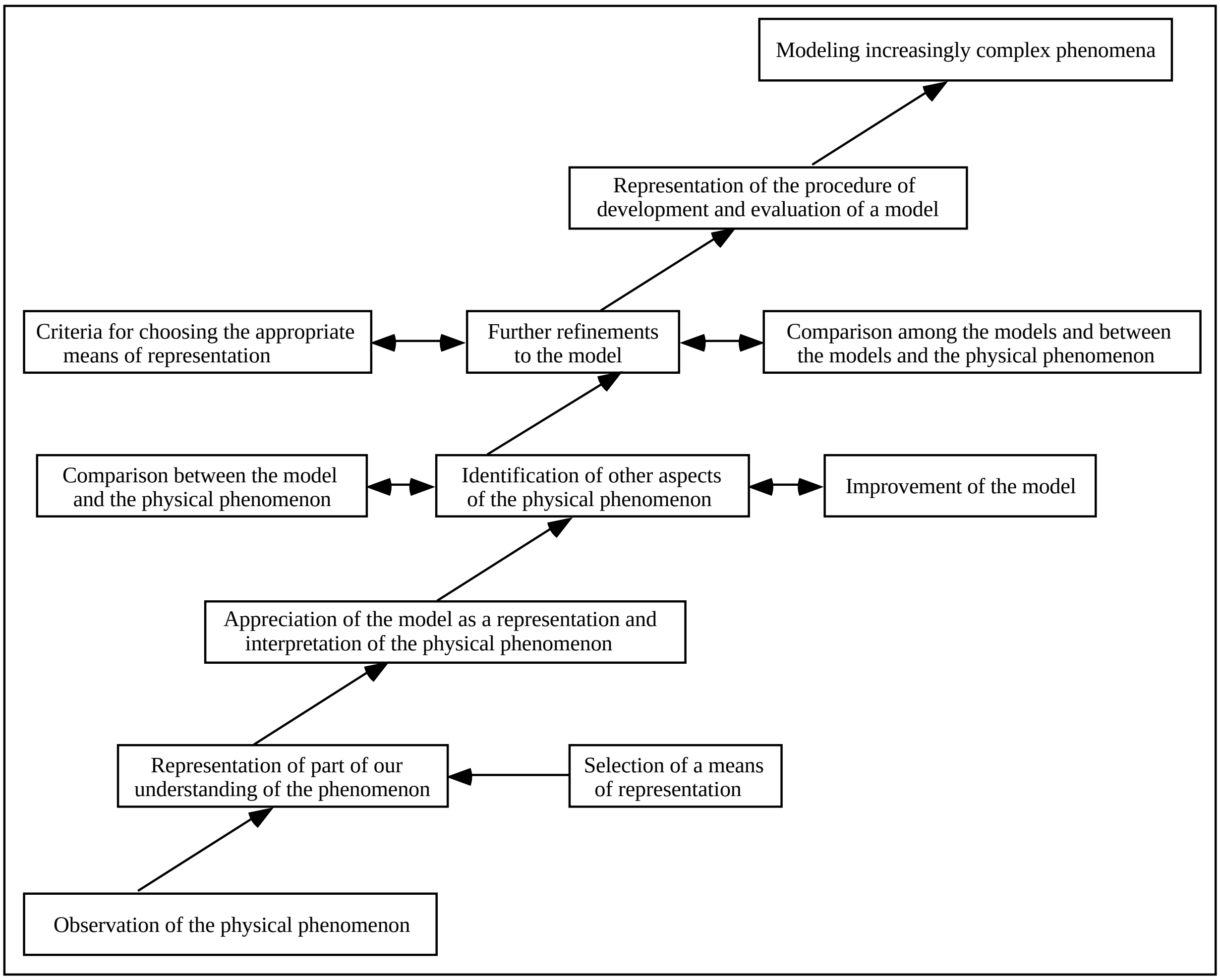

Figure 2: Epistemological analysis of *modeling skills*

conceptual understanding in order to analyze and understand everyday phenomena, but also to undertake critical evaluation of evidence in decision-making situations.

Secondly, the content of the curriculum needs to satisfy basic constraints set by the epistemological structure of the domain. In order to adhere to the latter principle, we undertook epistemological analysis of *modeling skills* and the concept of *division of labour* during the design of our intervention. This analysis is shown in figures 1 and 2. The result of epistemological analysis is, in each case, a sequence of pre-requisite concepts and skills for each of the two objectives.

3.2 THE SOFTWARE APPLICATION

The software application is a movie created in Macromedia Flash, which is a tool for building internet animations. The movie presents a realistic representation of a vertical cross section of an ant colony. One can observe ten quarters and the corridors ants use to move either from one quarter to another, or in and out of the colony.

Every quarter presents ants performing a specific type of work. In two of the chambers, one is able to watch the *suppliers* bringing into the colony and storing seeds and grasshoppers, whereas other ants suck juice from plants' roots. Another group of ants *cultivate* mushrooms, which are also used for feeding. A special kind of ants *produces juice*, which is used for feeding other ants. *Constructors* are expanding the colony creating new chambers. *Cleaners* undertake the carriage of useless materials out of the colony. *Male ants* can be observed walking around in one of the quarters. A larger quarter is used entirely by the *queen*, which is responsible for laying eggs. *Eggs* are moved to another chamber where they are hatched.

The application provides the user with the capability to zoom in and out, thereby allowing learners to observe what is happening in each quarter in great detail. They can also get more information on each quarter by placing the cursor above it.

3.3 THE TEACHING INTERVENTION

The structure of the intervention follows closely our epistemological analysis as presented in Figures 1 and 2. Constantinou [2] proposes that the development of modeling skills should proceed in two phases: *model development* and *refinement*. Originally, one describes the physical phenomenon in a phenomenological way. As soon as the original model is created, one makes continuous comparisons between the physical phenomenon and the models that arise. This iterative procedure leads to a refined model that approaches closely some aspect of the physical phenomenon. Every model, including the final one, in an isolated learning process, is open to evaluation and further refinement and modification. The development of modeling skills also involves practice of the above procedure in many different contexts so that the learner can extract general rules for creating models and can actively modify the details during application of the process.

In the present study, students were first asked to sketch an ant colony on a piece of paper, in order to create their first model. This activity also aimed to identify the children's initial ideas about an ant colony and potentially their conceptions of the role of division of labour in shaping the structure and organization of the colony. Subsequently, the students observed the actual physical phenomenon through an artificial ant colony, made with real ants. Afterwards, the students were encouraged to compare their model to the actual colony and to make suggestions for improving the first one. So, they made a second drawing, which they also compared to the physical phenomenon. The latter discussion concerned the division of labour in the colony, the conclusions of which led to the need for a more realistic model. The model created in Macromedia Flash was then presented to the students and further discussion ensued. At the end, students were asked to make a conceptual map of the intervention structure, so as to realize the procedure through which an effective model arises. Meta-cognitive familiarity with the procedure gives the students the opportunity to apply it in new contexts for developing models of other physical phenomena.

4. EVALUATION OF THE CURRICULUM

4.1 CONTEXT

The research described in this paper took place in a fourth grade classroom of a small suburban elementary school. The 10 children participants ranged in age from 9 years and 6 months to 10 years and 6 months. All children had well developed basic computer literacy skills prior to our intervention. Both the teaching intervention and pre-test and post-test administration were carried out by the researchers over a three week period.

4.2 METHODOLOGY

For the evaluation of the instructional program a pretest and a post-test were designed.

The pretest was organized into two parts and was administered prior to the intervention. The first part of the pre-test was designed as a baseline assessment with respect to modeling skills in the context of city traffic. The second part of the pretest was designed to evaluate children's understanding of the internal structure of an ant colony. Children's ideas on the conceptual part of the intervention were extracted during the lesson. This part of the lesson coincided with the development of the children's first model, which was a paper-based drawing.

The post-test was used to assess the children's conceptual understanding of division of labour in an ant colony and any improvement in their modeling skills, as well as their capability to apply these skills in a new context (forest ecosystem and food chains).

4.3 RESULTS

The intervention described here constitutes only a part of a whole unit of lessons that aim to promote development of modeling skills among elementary school children. Since this instructional program is only the first part of the unit, it was not expected that the children would succeed in developing all parameters of modeling physical phenomena to the same level. Despite this fact, the learning objectives were realized to a more than satisfactory extent.

Modeling skills were evaluated (in different contexts) both before and after the intervention. The first part of the pre-test and the first part of the post-test each involved a series of conditions evaluating different aspects of modeling as a skill. Both tasks were analyzed with respect to five criteria. Table 1 presents these criteria. Each criterion corresponded to a number of conditions and each condition corresponded to only one criterion as shown in Table 1.

In this part of the pre-test, we first asked children to make a drawing of the traffic system in a small city based on their knowledge of traffic in their area (condition E1). They had to label every item on their drawing and to explain its function. They then had to compare their drawing with another drawing that was provided (E2), they had to identify similarities (E3) and differences (E4), state information provided by one and not the other (E5, E6) and, finally, suggest an alternative way to represent the traffic system that did not rely on a drawing (E7).

In the corresponding part of the post-test, we asked children to draw a pyramid with different levels representing the interacting populations of a series of forest species (eagles, sparrows, worms and plants) (condition O1). They were then asked to explain their drawing in detail (O2), to play a modified chase and run game with different groups representing different species, to state what information can be extracted from the game (O3), to identify similarities and differences between the game and the drawing (O4) and to evaluate the two as models of the forest species (O5). Finally, they were asked to find a single name for both the game and the drawing (O6) and to come up with an alternative representation of the interaction between the different forest species (O7).

The conditions that corresponded to the same criterion were treated as a group. The children's answers to each group were analyzed phenomenographically [4] and a grading score was assigned to the categories that emerged based on their degree of appropriateness. These scores were normalized to a maximum of 100 and these scaled scores were used to calculate an average performance for all children participants on each criterion.

Table 1 presents the criteria and the children's performance on each criterion. The results presented in Table 1 can be taken as a measure of the children's ability to apply their modeling skills in an unfamiliar context. It can be inferred from the tasks, and it is also apparent from the data, that the post-test task is noticeably more difficult than the pre-test task. The post-test task is more complete in that it covers all five criteria, whereas the pre-test task only relates to three of the criteria and is therefore more useful for use prior to an intervention.

Table 1. A measure of modeling as a skill prior to and after the intervention. The conditions on the pre-test (E) and on the post-test (O) that correspond to each criterion are shown in parentheses.

Criteria	**Pretest average score %**	**Post-test average score %**
Extraction of information from a model (E1, E2, O2, O3)	70	55
Comparing models and real phenomena (O4)	–	65
Comparing one model to another (E3, E4, E5, E6, O5)	70	90
Formulation of new models (E7, O7)	45	90
Appreciation of a model as a representation of a physical phenomenon (O6A, O6B)	–	65

The skill of *extracting information* from a model appears to have weakened after the intervention. Baring in mind that the difficulty level of the pretest is lower than that of the post-test, the results are not disappointing. In pretest the children were asked to extract information from a model that concerned a phenomenon from their every-day experiences (traffic in the city), whereas in post-test they were asked to extract information on a phenomenon that is not so familiar (forest ecosystem).

Although there are no results in *comparison between model and real phenomenon* prior the intervention and no comparison can be made, the level of success in the post-test (65%) is satisfactory.

The capability to compare models appears to be well improved as a result of the intervention. The post-test recorded a 20% increase in average performance as compared to the pre-test. This is considered an important result. The ability to make comparisons between models helps learners to develop more refined and gradually more advanced models. Likewise, average performance in tasks requiring the development of new models doubled from 45% to 91%.

At the end of the intervention 64% of the children were able to identify models and appreciate their importance in better understanding physical phenomena. In comparison, from informal observations during initial concept extraction, it appeared that prior to the intervention the children were not able to name the concept or recognize its usefulness.

The second part of the pre-test and post-test concerned children's understanding of the internal structure of an ant colony. In the pre-test, we asked children to draw the inner part of an ant colony and we evaluated their understanding based on this drawing. In the post-test, we asked children to describe an ant colony and to state as many items as could be found inside. The children's answers were assigned a grade out of a maximum of 10 based on whether they showed internal tracks (5 points) and chambers (5 points). Table 2 presents a comparison of the results prior to and after the intervention. The average grades are normalized to a maximum possible of 100.

Table 2. Average success rate in tasks related to children's understanding of the internal structure of an ant colony

	Pre-test %	**Post-test %**
Total average grade	65	100

Additionally, children's responses on the post-test were graded for their ability to mention different items that can be found inside the ant colony. We looked for a name for each of three types of ants (queen, workers, males) and different types of food (leaves, fungi, seeds, eggs and different types of insects). This part was also graded out of a maximum of 10 and the class average grade was 6.

As is clearly shown by these results, by the end of the intervention, the children were able to better appreciate an internal structure to the ant colony.

Finally, in the post-test we also asked children to explain the term *division of labour* and describe how it applies to the organisation of an ant colony. 50% of the children could define *division of labour* as the assignment of different kinds of work to different individuals based on some criteria *and* could explain the different roles usually undertaken by the queen, the males and the workers in a typical ant colony.

Although informal observations during the lesson showed that more children understood the concept of division of labour, a formal definition for the term was not emphasized, since more emphasis was given to the development of modeling skills. Consequently, the children found this final task difficult. Despite this, 50% of the children performing successfully on a definitional task is an indication of the effectiveness of the intervention in promoting conceptual understanding.

5. DISCUSSION

There are two issues that are worth emphasizing based on the results reported here.

Effective curriculum development needs to rely on research in two distinct aspects: firstly, it needs to take into account the available research literature on the various types of difficulties encountered by students in their effort to construct meaning. Epistemological analysis (figures 1 and 2) is a technique that systematically enables us to do this as well as map out a strategy to enable students to overcome such difficulties. Secondly, effective curriculum only emerges as a result of iterative refinements achieved through carefully researched classroom trials such as we have described here. In particular, many of our post-test results remain below 85% success rate and would be open to improvement by further refinements in the curriculum and in our software tools.

The second issue that is worth emphasizing is the importance of declaring carefully formulated *integrated* learning objectives that include the simultaneous development of reasoning skills and real conceptual understanding. Only in this manner will science education become relevant to the needs of learners in a modern society and will be able to justify the increased time and emphasis that it enjoys in school curricula worldwide.

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