Modeling and Simulation in an Educational Context: Teaching and Learning Sciences

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Abstract

In science education, there is a need to evaluate the behavior of dynamic systems. Representing and explaining processes through educational models or simulations enables students to perform activities where it is easier to understand these processes and discover the essential properties of a system. Performing modeling or simulation activities that promote interpretation and understanding of systems are learning activities in which students have the ability to create and test their own perceptions of a given phenomenon. Although such activities enhance the development of skills such as reflection, decision making, creativity and generalization, the use of these activities in educational contexts is very sporadic. The difficulties teachers experience in using this type of activity relate to the types of models that are usually used to represent a system, the specificities needed to represent them, the degree of complexity of modeling and simulation tools to do so, and the lack of preparedness to implement practical research activities. In this research, we present the Modeling for Kids methodology to support the development of georeferenced multisensory modeling and simulation activities for the first cycle of Basic Education. This methodology lists a set of norms that aim to advise the teacher and the student in the accomplishment of these activities. The methodology identifies the strategies, contexts of use, and curriculum areas where these activities can be inserted. It also identifies the processes of analysis and representation of dynamic systems. Due to the importance and advantages of georeferenced multisensory information in learning, the methodology also prescribes that teachers and students use this type of information in modeling and simulation activities.

Keywords: Science education**,** Modeling and simulation, Elementary education

Introduction

In science education, there is a need to evaluate the behavior of dynamic systems. The analysis of these systems by elementary school students is usually a complex process that requires a great cognitive effort. The traditional teaching of science impels children to memorize processes, not privileging the understanding of which entities, processes, and relationships are

present in a system. Its purpose is for the teacher to pass on to the student's mind his or her knowledge of the scientific content and for the student to consolidate it through memorization processes. The current and more traditional model is based on the following premises: What can be taught can be provided to the student in the form of information; information can be verified by the student through observation, which will be applied in answering questions and solving exercises.

In contrast, the use of models and simulations in an educational context can provide alternative collaborative and interactive environments that foster personal discovery and help students to act and think, assuming the role of researcher, allowing them to build their own knowledge. Representing and explaining processes through educational models or simulations enables students to perform activities where it is easier to understand these processes and discover the essential properties of a system. Performing modeling or simulation activities that promote interpretation and understanding of systems are learning activities in which students have the ability to create and test their own perceptions of a given phenomenon. Although such activities enhance the development of skills such as reflection, decision making, creativity and generalization, the use of these activities in educational contexts is very sporadic.

The difficulties teachers experience in using this type of activity relate to the types of models that are usually used to represent a system, the specificities needed to represent them, the degree of complexity of modeling and simulation tools, and the lack of preparedness to implement practical research activities.

Why use modeling and simulation in an educational context?

The traditional teaching model of science impels children to memorize processes, not privileging the understanding of which entities, processes, and relationships are present in a system. Its purpose is for the teacher to pass on to the student's mind his or her knowledge of the scientific content and for the student to consolidate it through memorization processes. The current and traditional model is based on the following premises: What can be taught can be provided to the student in the form of information; information can be verified by the student through observation, which will be applied in answering questions and solving exercises (Cosgrove & Osborne, 1991).

Papert (1993) states that the best research and experimentation activities are those in which children are involved in their development and that result in meaningful things for them and all those who share the same interests. Osborne (1991) states that children act as scientists, are curious about the world around them, and constantly question themselves about the functioning of systems and objects. They elaborate explanations based on everyday experiences in order to build a vision of the world in which they live. In making their own explanations, children reuse their knowledge to construct new concepts about a particular system.

The acquisition of skills that promote the understanding and interpretation of complex systems has progressively assumed an important role in education (Jacobson & Wilensky, 2006). Several researchers claim that the best learning activities are those in which students, in addition to interacting with their own material, have the ability to create and invent systems where these materials are reused (Papert, 1980; Resnick, 2002).

Driver (1985) states that activities should be valued where students have the opportunity to present their ideas, in groups or individually. Students should also be encouraged to share their conceptions of the world around them and be exposed to unexpected, "counterintuitive" situations, as they are compelled to generate new explanations. The construction of several explanations about the same phenomenon will allow students to confront different explanations, in order to give consistency to the elaborate thought and to understand that it is possible to have several explanations for a given phenomenon or dynamic system. The explanations developed by the students to understand a particular phenomenon are limited to this phenomenon. But their reuse, when exposed to other situations, will allow children to increase or develop their knowledge (Repenning, Ioannidou, & Ambach, 1998).

The diversity of the content taught in the classroom motivates teachers to implement modeling and simulation activities in educational environments more frequently (Lunce, 2006). In these activities, programs are used to represent systems, usually through a mathematical description. Schwarz et al. (2007) indicate that modeling or simulation tools allow students to graphically represent a phenomenon, entities, and relationships for the purpose of analyzing, predicting behavior, and understanding (Cherry, Ioannidou, Rader, Brand, & Repenning, 1999). The use of these tools has been steadily increasing due to the need on the part of teachers and content writers to produce interactive content that enables them to create more enriching, motivating, and meaningful environments for students (Hung & Chen, 2002). Their use will also allow the introduction of research methods, which is crucial for students to develop the critical thinking and skills needed to understand the dynamic systems and processes that surround them.

Modeling and simulation in an educational context

Humans have had, since ancient times, models to understand or represent systems or phenomena, and several authors claim that models are a technique that can be used to study the behavior of phenomena and dynamic systems (Banks & Carson, 1984; Bennet 1995; Cherry, Ioannidou, Rader, Brand, & Repenning, 1999; Law & Kelton, 1991; Watson & Blackstone, 1989). The representation of a small part of a real complex system through a model can be aimed at understanding and discussing the complex phenomena that are part of the system (Kuipers, 1994). In an educational context, its use may aim to motivate the student to test hypotheses about reality, to represent systems through schemas, or to develop mental models, among others (Duffy & Cunningham, 1996; Repenning, Ioannidou, & Ambach, 1998; Winn & Synder, 1996).

In this context, a modeling activity is based on the use of a model that represents a phenomenon or system more simply and where certain aspects have been suppressed in order

to make it easier to understand (Cherry, Ioannidou, Rader, Brand, & Repenning, 1999; Lunce, 2006; Kuipers, 1986). The same system can be represented by several models that represent it in part or in full. In any case, the level of detail and fidelity with which a model represents the real system are important factors, even if the model does not represent all elements of the system (Alessi & Trollip, 2001).

Several authors indicate that in implementing these activities, teachers may use two distinct methodologies or modes: the exploratory mode and the expressive mode (Gomes, Ferracioli, & Marques, 2008; Marcelino, 1998). In exploratory mode, students manipulate the parameters of a model and cannot modify its structure. Templates are generally provided by the teacher (Bliss & Ogborn, 1989; Bliss et al., 1992). In expressive mode, students have to identify which model can represent the phenomenon and build it, which can then be expressed using a modeling tool. A modeling tool is specially designed and built to facilitate the construction and calculation, or simulation, of models.

As Marcelino (1998) indicates, the use of each of these methodologies is related to the type of application that the teacher and students are using. In the case of a modeling tool, students can build or execute a model, which allows the teacher to use the two methodologies described above.

Another way to use models in education, albeit indirectly, is through simulation programs. Evagorou et al. (2009) state that, through simulation, students can verify the dynamic behavior of systems or phenomena present in most systems studied by children, whether energy transfer between systems, heat transfer, phases of the moon, or plant growth.

In a simulation activity, students run the program that allows them to identify the meaning and influence of variables in the system, unaware of the underlying model structure. In simulation programs, students can only explore a model that was previously implemented when building the program.

Marcelino (1998) identified yet another way of using modeling tools and simulation programs in an educational context, which he designated as a demonstrative mode. In this case, the teacher uses the tool or program to demonstrate a phenomenon or system. The teacher's choice of the methodology to be used depends on the objectives to be achieved, the students' prior knowledge, the time available for the activity, and the degree to which the teacher wants the students to analyze the phenomenon or system.

There are several types of simulation models that can be used in educational contexts. They can be grouped in quantitative models and qualitative models. Quantitative models are composed of entities represented by numerical values, and the relationships between entities are described through mathematical relations. They provide their authors or users with numerical data that reflects their evolution and behavior (Fritzson, 2004). Another type of model we can use is qualitative. In this case, the entities that make up the model are represented by a finite set of qualitative states (Fritzson, 2004).

Qualitative modeling allows the representation of complex and dynamic systems with only the essential characteristics of their structure and behavior (Neumann & Bredeweg, 2004) and about which there is little information. Thus, it is possible to represent a system where, although not having all the data necessary for a quantitative representation, this representation has the ability to reproduce the essential characteristics of the system in question, neglecting a large amount of information that is not relevant to its execution (Neumann & Bredeweg, 2004). In these models, the state of variables is commonly identified through a finite and ordered set of qualitative values such as small, medium, and large.

Regarding simulation programs, Lunce (2006) identifies four different ways to classify them: physical, iterative, situational, and procedural simulations.

- Physical simulations represent a certain phenomenon and allow students to manipulate some of the variables represented in the simulation. In this type of simulation, the system is already represented and the student has only the possibility to change the variables and verify the impact of these changes on the system behavior.
- In iterative simulations, students have the possibility to test and represent hypotheses and verify the results and thus learn about the phenomenon represented.
- Situational simulations allow students to deal with different environments or situations in order to play a certain role and thus acquire knowledge about the system represented.
- Procedural simulations allow, for example, to learn how to operate equipment.

Advantages of using modeling and simulation activities in educational contexts

According to Leite (2001), we can classify modeling and simulation activities as practical activities. Their implementation allows teachers to create interactive environments where students can design, create, and test alternative ideas and models that represent a system they observe (Papert, 1980; Resnick, 2002). The execution of the models allows students to compare the results with their previous perceptions. Resnick (2002) classifies this action as cyclical and iterative, where new ideas generate new creations and new creations generate new ideas.

Performing modeling and simulation activities in educational contexts can bring a diverse set of advantages. For Parush et al. (2002), they are an efficient and effective tool for teaching and learning complex and dynamic systems. Several authors report that these activities enable more dynamic, interactive, and motivating learning that can enhance the development of skills such as reflection, decision making, creativity, and generalization (Hansmann, Scholz, Francke, & Weymann, 2005; Mills , 2004; Ramasundaram, Grunwald, Mangeot, Comerford, & Bliss, 2004; Schwarz, Meyer, & Sharma, 2007; Tarman & Tarman, 2011). They also enable learning by discovery (Passmore & Stewart, 2002; Schwarz & White, 2005).

Alessi and Trollip (2001) state that these activities have additional advantages compared to other methodologies because they enable students to take an active role in their realization and, in the opinion of the students themselves, are more interesting, motivating, and

meaningful. They facilitate the understanding of systems because they focus the student's attention on the aspects considered by the teacher as essential, preventing the student from being distracted by analysis of other elements or entities (Alessi & Trollip, 2001).

We can also affirm that the use of models and/or simulations, if designed well, can facilitate learning where the student is stimulated to develop a scientific attitude, because they allow for creating research environments "of real or experimental situations. In this case, students are usually called to 'invest' in determined roles, observing the variables at play and taking responsibility for the development of a given process" (Brito, Duarte, Torres, Bahia, Figueiredo, & Alves, 2002, p. 18).

Other studies indicate that the realization of these activities shows that students get better results, that there is a better transfer of acquired knowledge to real-world situations (Leemkuil, de Jong, de Hoog, & Christoph, 2003), which allows the analysis and the representation of phenomena that could be expensive to represent or impossible to visualize in reality (Alessi & Trollip, 2001). Wilson et al. (1996) also point out that they allow for changing the time scale by compressing it or selecting a part of the time in which a phenomenon occurs. Thomas and Milligan (2004) point out that they enable students to create stimulating and rich learning environments by providing access to certain concepts that might otherwise be dangerous and impractical. They also allow for the customization of the pace of learning and repeating experiences as needed (Kang, 1995).

Despite the potential that exists in introducing these activities in an educational context, teachers and students find it difficult to perform modeling and simulation activities. Proof of this is the small number of projects or initiatives that use modeling and simulation as an educational tool. These difficulties of use are due to, among other reasons:

- The specificities of educational modeling and/or simulation authoring tools, which oblige their users, teachers, and students to have time to adapt to their interface and to have higher-level scientific and technological knowledge than may be the case.
- The forms of model representation are usually based on quantitative modeling, which compromises their use at educational levels where the fundamental thing is not to know the system in detail but only to have part of it or to have an idea of its functioning.
- The absence of methodologies that help the teacher implement modeling and simulation activities.

Methodology to support the development of modeling and simulation activities

When implementing modeling or simulation activities in educational contexts, there are key issues to consider when planning the development of such activities. Defining the context of use, the strategies to be used, the forms of analysis, and representation of the systems is crucial for such an activity to be fruitful.

The presented methodology aims to provide a set of specifications to support the use and development of modeling and simulation authoring tools for Basic Education. The methodology

will define the objectives that can be achieved with the accomplishment of this type of activity, the contexts and strategies of use, the curricular areas where they can be implemented, the methods of analysis, and representation of dynamic systems, among others. The methodology aims to provide teachers with a set of norms that allow them to engage, motivate, and assist students in carrying out research activities that model or simulate common phenomena, issues that concern them, and experiences lived in field work.

The Modeling for Kids (M4K) methodology is intended to assist teachers and students in the development of modeling and simulation activities for primary school. The methodology has:
- A set of standards that will assist the teacher in planning and implementing such activities.
- A process for the analysis and representation of dynamic systems, based on qualitative modeling and causal reasoning, which will allow students and teachers at this level to build their own models.
- A set of specifications for the development of modeling and simulation authoring tools for this level of education.

The planning and implementation phase is intended to provide teachers with an indication of the purpose of modeling and simulation activities, the curriculum areas and the contexts in which these activities can be used, and their use strategies. In this phase, the role of the teacher is also described, an activity planning model is presented, and the phases of support for its implementation are identified.

The realization of modeling and simulation activities involves analysis, in the case of both, and may involve the representation of dynamic systems, in the case of the former. The difficulty inherent in identifying all the elements and relationships present in a system and all state combinations can restrict the use of these activities in the first cycle of Basic Education. Hence the need, in our opinion, for a methodology that can assist in these processes. The M4K systems analysis and representation phase provides teachers and students with methodologies that facilitate the analysis and representation of dynamic systems. This phase also has a set of standards that:
- Define the types of models that can be used in modeling and simulation activities.
- Describe the process of analysis and model representation.
- Identify the stages of development of a modeling activity.

A modeling and simulation authoring tool should share the characteristics that Papert (Resnick, et al., 2010) has identified in the programming languages developed for this age level: Low Floor, High Ceiling, and Wide Halls. Papert says that child-oriented applications should be easy-to-use, accessible applications, so that their users can enjoy these applications without taking too much time to understand: Low Floor. However, they should enable more experienced users to perform activities according to their level of knowledge: High Ceiling. The success of these types of applications also depends on their curriculum coverage, i.e., they should, as far as possible, cover a wide range of curricular areas: Wide Halls.

Conclusion

In everyday life, children naturally act as scientists, are curious, and seek explanations for the phenomena surrounding them. Conducting practical research activities in Basic Education allows students to be involved in carrying out these activities and in achieving results that have meaning for them. In this work, we aimed to demonstrate the importance of practical research activities and the use of simulation and modeling in the construction of knowledge. We highlighted the relevance that the use of simulation and modeling can have in the development of students' critical thinking.

ICT enables teachers to create more motivating, enriching educational environments and access to content and activities that would otherwise be difficult or impossible to do. The combination of ICT with modeling and simulation enables the creation of integrated educational environments that are highly accessible and facilitate the development of learning environments that can foster action and reflection. Performing modeling and simulation activities in educational environments is an effective tool for learning complex and dynamic systems, as it allows for more active, motivating learning at the pace of each student, in which he or she is induced to develop important skills such as understanding, reflection, intuition, and generalization.

We analyzed different ways of using modeling and simulation in education and the advantages of this use in the educational process. We refer to the various types of models we can find, which we have classified as quantitative models and qualitative models, and how the use of qualitative models can enable more students and teachers to design and perform modeling and simulation activities across educational levels, with special emphasis on Basic Education. Qualitative modeling allows teachers and students who do not have the mathematical knowledge or information needed to represent quantitative models a way to model phenomena that they observe in the real world, about which they only have the fundamental characteristics.

The lack of a methodology that facilitated and normalized the integration of modeling and simulation activities in Basic Education led this research team to identify a set of procedures that are of relevant importance in carrying out these activities.

The Modeling for Kids methodology has a set of standards that help the teacher and the student to perform modeling and simulation activities. M4K intends, through the presented norms, to provide a methodology that values the conceptions that students have and that they build when they analyze a certain system, providing procedures that promote an attitude of active and scientific analysis. The methodology presents schemes of representation of dynamic systems through qualitative modeling and defines the roles of teachers and students and the steps to follow in carrying out these activities. M4K also describes the specifications that modeling and simulation authoring tools should have in order to enable these students to perform modeling and simulation activities with them.

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