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The impact of the computational inquiry based experiment on metacognitive experiences, modelling indicators and learning performance

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ABSTRACT

Computational experiment approach considers modelling as the essential feature of Inquiry Based Science Education (IBSE), where the model and the computer take the place of the “classical” experimental set-up and simulation replaces the experiment (Landau, Pαez, & Bordeianu, 2008).

Modelling, as a pedagogical tool, involves the model construction, the exploration of model characteristics and the model application to a specific problem, resembling authentic activities of scientists and mathematicians (Herbert, 2003).

Recent developments in strategy instruction research suggest that learning in a particular discipline is enhanced by guiding students through the development of content-relevant metacognitive strategies (Wosnitza & Volet, 2009).

Problem-solving is a complex process, which involves several cognitive operations such as collecting and selecting information, heuristic strategy and metacognition (De Corte, 2003; Garofalo & Lester, 1985; Schoenfeld, 1994).

The purpose of this study was to explore the impact of the Computational Experiment Methodology on learners’ cognitive performance, use of modelling indicators and shift of the metacognitive experiences during problem solving using computational models.

Sixty prospective primary school teachers volunteered to participate in the study.

Students were exposed by the Instructor to a number of computational experiments, while during the course they developed their own models of simulation.

The results of the experiment show that the use of the computational experiment approach has a substantial effect on the metacognitive experiences and the use of modelling indicators.

1. Introduction

1.1. The computational experiment

Over the past decade, increasing importance and attention has been attached to the potential of new technologies of information and communication (ICT) to improve teaching and learning in schools (Barton & Haydn, 2006). Focus on modelling is largely due to the following reasons. One is the recent constructivist attention to conceptions that students bring to the classroom. A second one is the present emphasis on the role of philosophy in science education, which has resulted in stressing the importance of attention for the nature of scientific models. Directly connected to that approach, is that proposed by Sloot (1994) as Computational Physics (CP). One of the crucial components of CP is the abstraction of a physical phenomenon to a conceptual model and its translation into a computational model that can be validated. This leads us to the notion of a computational experiment where the model and the computer take the place

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of the 'classical' experimental set-up, and simulation replaces the experiment as such. Sloot (1994) identifies three major phases in the process of the development of a computer experiment:

a. The modelling phase: the first step to simulation is the development of an abstract model of the physical system under study, b. The simulation phase: this refers to methods that make the underlying physical models discrete in time or stochastic using methods from numerical analysis and c. The computational phase: in this phase we concentrate on the mapping of the simulation techniques to source code including algorithms and the implementation using software or a programming language.

Landau et al. (2008) suggests an approach similar to Sloot's approach, which takes the form:

a. Problem (from science), b. Modelling (mathematical relations between selected entities and variables), c. Simulation Method (time driven, event driven, stochastic), d. Development of algorithm, e. Implementation of the algorithm (using Java, Mathematica, Fortran etc) and f. Assessment and Visualization exploration of the results and comparison with real data.

According to Landau et al. (2008), Computational Physics (CP) and Computational Experiment (CE) provide a broader, more balanced, and more flexible education than a traditional physics major. Moreover, presenting physics within a scientific problem solving paradigm is a more effective and efficient way to teach physics than the traditional approach. In this framework, being able to transform a theory into an algorithm requires significant theoretical insight, detailed physical and mathematical understanding and a mastery of the art of programming and the actual debugging and testing. The organization of scientific programs is analogous to experimentation, with the numerical simulations of nature being essentially virtual experiments. The scientific paradigm should include modelling and simulation as an additional dimension in order to create computational experiments.

Tobochnik and Gould (2008) argue that CP should be incorporated into the curriculum because it can elucidate the physics. Computation is both a language and a tool and, in analogy to models expressed in mathematical statements, CP models are expressed as algorithms which in many cases are explicit implementations of mathematics. An advantage of the computational approach is that it is necessary to be explicit about which symbols represent variables and which represent initial conditions and parameters, boundary conditions, restrictions of the solutions etc.

According to Hestenes (1999), traditional physics courses lay heavy emphasis on problem solving and these results on the undesirable consequence of directing student attention to problems and their solutions as units of scientific knowledge. Modelling theory indicates us that these are the wrong units; the correct units are the models. Problem solving is important, but it should be subservient to modelling. Hestenes (1999) states that most physics and generally science/engineering problems are solved by constructing or selecting a model, from which the answer to the problem is extracted by model-based inference. In a profound sense the model provides the solution to the problem. Thus, an emphasis on models and modelling simplifies the problem and organizes a physics course into understandable units.

According to Hestenes (1999), model specification is composed by a model which describes (or specifies) four types of structure, each with internal and external components, considered as modelling indicators:

1. systemic structure which specifies composition (internal parts of the system), environment (external agents linked to the system), connections (external and internal causal links)
2. geometric structure which specifies position with respect to a reference frame (external geometry), configuration (geometric relations among the parts)
3. temporal structure which specifies change in state variables (system properties), descriptive models represent change by explicit functions of time, causal models specify change by differential equations with interaction laws
4. interaction structure which specifies interaction laws expressing interactions among causal links, usually as function of state variables

Shunn and Klahr (1995) and (Klahr & Dunbar, 1998) in order to describe discovery learning as a search process, introduced spaces in scientific discovery learning which include the hypothesis space and the experimental space. In their model the hypothesis space contains all rules and variables describing the specific domain, while the experiment space consists of all experiments that can be implemented within this domain. Psycharis (2011) extended these spaces in order to include the computational experiment approach and suggested three spaces for the computational experiment, namely:

1. The hypotheses space, where the students in cooperation with the teacher, decide, clarify and state the hypotheses of the problem to be studied, as well as the variables and concepts to be used and the relations between these.
2. The experimental space, where the computational experiment actually takes place and includes modelling-simulation-based on discovery/inquiry learning activities for the problems under study, replaces the classical experimental and learners are engaged in the scientific method.
3. The prediction space, where the results, conclusions or solutions formulated in the experiments space, are checked with the analytical (mathematical) solution as well as with data from the real world and help learners towards predictions for other phenomena.

1.2. The computational experiment (CE) and inquiry based science education (IBSE)

The publication of the "Science Education Now: A renewed Pedagogy for the Future of Europe" report (Rocard, 2007), once again brought science as inquiry to the top of educational goals. The field of science education research is concerned – among other issues – with the development of high-level skills, like concept formation, modelling, problem solving, meta-cognitive skills and scientific procedures.

Inquiry based learning has been officially promoted as a pedagogy for improving science learning in many countries (Bybee, Trowbridge, & Powell, 2008; National Research Council, 2000). Inquiry can be defined as "the intentional process of diagnosing problems, critiquing experiments, distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments" (Bell, Hoadley, & Linn, 2004) and is often considered as a way to implement in schools the scientific method (Levy, Little, McKinney, Nibbs, & Wood, 2010). Inquiry is referred to the science education literature to