Assessing students' understanding of computational modelling in physics

Roeland BOOT, Kim KRIJTENBURG-LEWERISSA, Wouter van JOOLINGEN

Freudenthal Institute, Utrecht University, Princetonplein 5, 3584 CC, Utrecht, The Netherlands

Abstract. In secondary physics education, integrating computer modelling offers diverse benefits for students, such as enhancing realism in understanding physics principles, familiarization with scientific inquiry methods and exploration of complex phenomena. Assessing metamodelling competences is crucial for effective implementation. We present an adaptation of the existing Framework for Modelling Competence (FMC) towards physics computational modelling. A interview study with Dutch pre-university students indicates strengths in the aspects Nature, Purpose and Testing but gaps in the aspects Multiple and Changing. Further refinement of competences is suggested for optimal utilization of the framework.

Facilitating student involvement in physics computer modelling holds considerable promise for enhancing physics education through numerous potential benefits. 1) Learning with computer models will enable students to develop a realistic view towards modelling outcomes, thereby offering the advantage of forging a clear and direct link with the fundamental principles of physics [1,2]. 2) Engaging with computer models exposes students to the methods employed by physicists in their routine scientific investigations, affording students insights into the formulation of physical theories [1,2]. 3) Computer models enable students to execute more complex calculations than they can do manually, so they can investigate more realistic physics phenomena [2]. 4) Utilizing computer models for physics education offers students an opportunity to acquire proficiency in solving physics orientated problems [3]. To fully achieve these benefits, research is needed into the integration of computer modelling in physics education.

In order to effectively introduce and implement computer modelling in secondary physics education, it is essential to identify the required metamodelling competences that are fundamental for undertaking such initiatives [3]. Identifying these competences necessitates an empirically tested framework for their assessment. An important candidate framework is the Framework for Modelling Competence (FMC) [4]. This framework includes five aspects in the field of general science modeling: *Nature* of models, *Multiple* models, *Purpose* of models, *Testing* models, and *Changing* models.

The *Nature* aspect evaluates the degree to which students grasp the essence of a scientific model, its fidelity to reality, and how it differs from empirical phenomena. The *Multiple* aspect examines students' understanding regarding the existence of different models for a particular scientific phenomenon. The *Purpose* aspect assesses students' understanding of the utility inherent in scientific models. The *Testing* and *Changing* aspect assess the extent to which students understand the reason for testing a model and making changes to the model.

The usefulness of the FMC has been extensively studied for general science modelling [4]. In this study we adapt and explore its applicability for physics computational modelling. For this purpose, we defined the five aspects in specific terms applicable for computational modelling in physics. This transformation was based on a literature review (e.g. [5]) and resulted in an adapted framework, as shown in Table 1.

Table 1. The adapted theoretical framework for students' understandings of physics computer models.

Aspect of physics computer models	Level I	Level II	Level III
Nature	A set of equations describing reality	Presence of parameters and constants, based on assumptions	Resource for theorizing, based on principles and concepts
Multiple	Different computer model properties	Focus on different aspects	Describing phenomena from different physical perspectives
Purpose	Showing the facts	Identifying and explaining relationships	Examining concrete and abstract ideas
Testing	Testing of basic requirements	Investigating characteristics of the computer model	Testing hypothesis with research designs
Changing	Alterations to improve the computer model	Alterations due to new findings of the original	Alterations due to findings from model experiments

To evaluate this framework, pre-university students in the Netherlands (n=36) were interviewed and their understanding of physics computer models was examined. During the interviews, students were asked questions about their metamodelling knowledge of physics computer models. A balanced sample was constructed with a representative cross-section in terms of academic achievement and gender.

The following is a student's response within the *Testing* aspect: "*I think the most effective method is to use a radioactive substance with a known half-life for comparison against a real-world experiment, carried out in a controlled environment where the outcomes are predictable. If your computer model reflects the same, then you know your model works well.*" This response is categorized as level II because this student mentions that testing the computer model can be done by comparing it with controlled experiments with known results.

Another student's answer within the same aspect is as follows: "*You could, for instance, make a new particle by shooting two particles together and calculate its activity at that moment. Once you have that new particle, you can measure how long it takes before it decays and you can use that to see if the output of the computer model is correct.*" This response is categorized as level III because this student gives a method for testing the model by creating new particles, measuring their decay, and comparing relevant results with the computer model.

With the framework, the competences within the *Nature*, *Purpose*, and *Testing* aspects can be determined. Competences within the *Multiple* and *Changing* aspects have lower scores. In a follow-up study, teaching materials will be developed to promote all competences, so that these competences can be identified and further adapted using the framework.

References

[1] S. Löhner, *Computer Based Modeling Tasks, The role of external representation*, doctoral thesis, Universiteit van Amsterdam (Amsterdam University), 2005.

[2] J. Weber and T. Wilhelm, The benefit of computational modeling in physics teaching: a historical review, *European Journal of Physics* **41** (2020) 034003.

[3] C. Schwarz and B. White, Metamodeling Knowledge: Developing Students' Understanding of Scientific Modeling, *Cognition and Instruction* **23**(2) (2005) 165-205.

[4] A. Upmeier zu Belzen, J. van Driel & D. Krüger, Introducing a Framework for Modeling Competence, In: A. Upmeier zu Belzen et al. (eds.), Towards a Competence-Based View on Models and Modeling in Science Education, *Models and Modeling in Science Education* **12** (2019).

[5] D. Fortus, Y. Shwartz, S. Rosenfeld, High School Students' Meta-Modeling Knowledge, *Research in Science Education* **46** (2016) 787–810.