Educational Research Review 13 (2014) 52–73

Contents lists available at ScienceDirect

Educational Research Review

journal homepage: www.elsevier.com/locate/EDUREV

Review

Assessment of the modeling competence: A systematic review and synthesis of empirical research

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ARTICLE INFO

Article history:
Received 8 February 2014
Revised 11 October 2014
Accepted 13 October 2014
Available online 22 October 2014

Keywords:
Science education
Modeling competence
Assessment approaches

ABSTRACT

We provide an analysis of the existing literature on the assessment of modeling as a scientific competence focusing on empirical research findings. Out of 802 searched citations, a total of 23 publications from science teaching and learning met the inclusion criteria. The analysis was based on the types of instruments used (interviews, questionnaires, videos) to assess the different aspects of scientific modeling (e.g. modeling practices; modeling product; meta-knowledge; cognitive processes during modeling). The results indicate that specific aspects of the modeling competence tend to be evaluated by specific types of assessment instruments and that assessment of other important aspects of the modeling competence is scarce. We suggest that this may be occurring due to the lack of a unifying framework for conceptualizing the modeling competence. In addition, these findings provide insights into certain challenges and confounding factors involved in designing new assessment instruments for each aspect of the modeling competence.

Contents

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http://dx.doi.org/10.1016/j.edurev.2014.10.001
1747-938X/

1. Introduction

Modeling, the process of constructing and deploying scientific models, has received widespread attention as a competence whose development also facilitates student learning of science concepts, methodological processes and the development of an awareness of how science operates (Hodson, 1993). Modeling natural phenomena is known to be challenging for both students and teachers (Schwarz et al., 2009; Sins, Savelsbergh, & van Joolingen, 2005). However, its potential benefits are thought to make it a worthwhile activity to include in science education, particularly as a context for developing an awareness of the value of epistemological objects that lead to evidence-based predictions, as a means of understanding complex dynamic systems, as well as a process of acquisition of conceptual knowledge and learning of scientific reasoning processes.

Efforts to design modeling-based learning instruction have relied on a theoretical framework about the modeling competence, which analyzes the constituent components into two broad categories, namely *modeling practices and meta-knowledge* (Nicolaou, 2010; Papaevripidou, 2012; Papaevripidou, Nicolaou, & Constantinou, 2014) (Fig. 1). Attempts to validate such designs have led to the claim that student modeling competence can emerge as a result of active participation in specific modeling practices, and is shaped by meta-knowledge about models and modeling. Model construction (Stratford, Krajcik, & Soloway, 1998); model use (NRC, 2012); comparison between models (Penner, Giles, Lehrer, & Schauble, 1997); model revision (Schwarz & White, 2005) and model validation have been identified as the main *practices* in which students are engaged during modeling. *Meta-knowledge* is analyzed into the *metacognitive knowledge* about the modeling process, which refers to student ability to explicitly describe and reflect on the actual process of modeling, and *meta-modeling knowledge* (Schwarz & White, 2005), i.e. the epistemological awareness about the nature and the purpose of models.

Assessment is considered, along with curriculum, instruction and teacher development, as one of the key components of science education (NRC, 2012). It is a vital part of classroom life and as such it should be at the focus of any educational effort (Pellegrino, 2012). Despite the growing research interest in modeling-based learning, research on possible approaches for assessing the modeling competence would appear, from a first glance, somehow fragmented in that they typically focus on student meta-modeling knowledge, or on specific constituent components of modeling ability (e.g. model construction or model comparison) without presenting a comprehensive perspective of modeling. Evaluation of the cognitive processes enacted during modeling and evaluation of the constructed models is particularly scarce (Louca, Zacharia, Michael, & Constantinou, 2011).

This fragmented view of modeling assessment and the need for additional modeling implementations in teaching practice highlight the need for a systematic review of the assessment of the modeling competence in science teaching and learning. To our knowledge, such a review has not been conducted so far. Most of the relevant research is composed of single empirical or design studies investigating learners understanding of epistemological aspects of models and modeling prior to or after the implementation of interventions and seeking to analyze the process or the end product of modeling. We identified only two extensive reports on modeling (Louca & Zacharia, 2011; Stratford, 1997). Stratford's review covered research conducted on the topic of using computer models to aid science instruction at the precollege level. The review investigated research about students (a) running simulations, (b) creating dynamic models using modeling environments, and (c) using program-