

Instrumental genesis as a lens to understand implementation of transdisciplinary modelling work

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What problem is to be addressed?

Models and modelling are important in integrated STEM education. Models mediate complex scientific phenomena and support students' sensemaking (Gouvea & Passmore, 2017). Transdisciplinary modelling work, where scientific, mathematical, and technological perspectives are integrated, enables students to grasp and reason about phenomena that cannot be understood from a single disciplinary lens. However, the concept of "model" is often used inconsistently in educational practice and research. While models are broadly understood as simplifications of reality, there is a lack of clarity about their role when they are integrated in teaching situations. One aspect of this unclarity relates to the fact that a model both is an artefact deployed to support thinking and learning and simultaneously a part of the knowledge to be taught.

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When we first began examining these interdisciplinary teaching situations, our initial assumption was that this ambiguity surrounding the concept of modelling would produce uncertainty and confusion among students. This was not what we observed. Rather than struggling with the indeterminacy of the modelling construct itself, both students and teachers appeared to lack the ability to disentangle the relations between the disciplinary approach adopted, the specific phenomenon under investigation, and the model applied. The difficulty was therefore not confusion about modelling, but a limited capacity to traverse disciplinary boundaries with models. In that sense students tended to treat models as discipline-bound curricular artefacts. Addressing these unclarities requires a conceptual framework that can account for how models function as instruments for learning and classroom practice, as well as an understanding of how this theoretical knowledge travels through adoption, scaling and implementation.

How is it to be addressed?

We present a case study of two teachers engaged in implementing a transdisciplinary modelling curriculum. First, we draw on the notion of instrumental genesis, which allows us to examine how models, initially introduced as epistemic artefacts, are taken up by teachers and students and transformed into instruments for reasoning and inquiry. This perspective presupposes continuity between processes of design and use, simultaneously with a dialectics between artefact and user, in the sense that a user's goal-directed activity is shaped by the use of a tool (this process is often referred to as instrumentation) and simultaneously, the goal-directed activity of the pupil reshapes the tool (this process is often referred to as instrumentalization) (Rabardel & Bourmaud, 2003, p. 673).

Second, we consider implementation as a process of shifting ownership and agency. The curriculum evolves from being a researcher-designed proposal to become enacted by teachers and students (Century & Cassata, 2016). These two perspectives highlight parallel development processes: on the one hand, the transformation of the model from artefact to instrument for thought; on the other, the transformation of the curriculum from externally designed, to locally owned and contextually meaningful.

What is to be implemented?

The case comes from a biology class working on an interdisciplinary activity about the cell membrane and diffusion. Students carried out a lab exercise with alkaline agar blocks in vinegar to simulate how diffusion depends on cell size. They cut the agar into cubes of different volumes, measured diffusion after five minutes, and calculated the rate and

percentage diffused. The results showed that smaller cubes, with a higher surface-to-volume ratio, diffused more. In the process, students developed practical techniques for handling the agar and calculating diffusion, but also epistemic techniques by reflecting on what their results meant for understanding the relation between cell size and diffusion. The agar blocks thus became a model for cell diffusion through what can be described as the students' instrumental genesis. This suggests that students need to interact with a model before they can use it meaningfully, and that the development of a scientific model as a learning tool is a complex process that deserves careful attention in science teaching. Here we move from a situation where the cell model was treated mainly as a biology curriculum, towards it being a tool that could also illuminate physically relevant mechanisms.

What might be the potential importance and significance?

From a theoretical perspective, this study contributes by offering a clear description of models as epistemic artefacts, drawing on research on the adoption of digital tools in mathematics education. By combining the instrumental approach with implementation research, we can conceptualize the developmental processes that occur when new artefacts are introduced into educational practice: on the one hand, their transformation into instruments for students' activity and agency, and on the other, their integration into curricular and institutional structures. The study identifies challenges that arise in the implementation of more complex understandings of models and modelling within integrated STEM education. These challenges concern not only the conceptual clarity of what constitutes a "model," but also the practical conditions under which teachers and students engage with transdisciplinary modelling tasks in upper secondary school.

A further advantage of employing an instrumental approach to analyse how models function in transdisciplinary STEM teaching is that it foregrounds the model's status as an epistemic artefact, meaning an artefact shaped for specific practical and epistemological purposes. This perspective offers several benefits. First, as is well established in research on technology, the integration of new epistemic tools into classroom practice is both demanding and time-consuming (Rabardel & Bourmaud, 2003).

Second, the instrumental framework draws attention to a structural challenge for teachers, often described as double instrumental genesis (Haspekian, 2011). When a model is new, unfamiliar, or framed differently from the models traditionally used within a discipline, teachers themselves must undergo a process of instrumental genesis: they need to explore, understand, and appropriate the model before they can meaningfully design

tasks, scaffolds, and teaching sequences that support students' work. In other words, fostering students' agency with respect to models as epistemic artefacts presupposes that teachers have developed a corresponding form of agency. Teaching for epistemic agency, therefore, entails cultivating teachers' own fluency with the very models they ask students to work with.

Two potential research questions

How do students and teachers develop ownership and agency over a specific model introduced by a teaching sequence? To what extent may we observe the change of ownership through the instrumental genesis?

How does the understanding of models as artefacts and the suggestion of teachers supporting the instrumental genesis with a model travel through the implementation process? In what ways may this framing add value to teachers' and learners' understanding and decision-making in relation to models and modelling?

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