DESIGN BASED RESEARCH AND THE MODEL OF EDUCATIONAL RECONSTRUCTION – A COMBINED APPROACH TO DESIGN SUCCESSFUL SCIENCE INSTRUCTION

Floor Kamphorst [1], Magdalena Kersting[2]
[1] Freudenthal Institute, Utrecht University, the Netherlands
[2] Department of Physics, University of Oslo, Oslo, Norway

One of the main challenges that science educators face is to develop teaching-learning sequences that both engage students and convey the science content successfully. In particular, new curriculum topics such as topics of modern physics pose challenges for teachers and educators because of a scarcity of teaching experience and learning resources. What is needed is a powerful and flexible methodological framework that can guide the design of new instructional material. We argue that a combination of Design Based Research and the Model of Educational Reconstruction provides such a framework. To exemplify the efficacy of such a combined approach, we present two educational projects that have combined the Model of Educational Reconstruction and Design Based Research successfully to bring topics of modern physics to science classrooms.

Keywords: Design Based Research, Secondary Education, Educational Reconstruction

INTRODUCTION

Developing teaching-learning sequences that engage students and that convey science content successfully is one of the main challenges that science educators face in their research and practice. This challenge has become more urgent as new learning domains such as modern physics, nano-science, or climate change have started to enter science curricula (Henriksen et al., 2014; Laherto, 2012; Niebert & Gropengießer, 2013). To guide educational design processes, researchers routinely draw on frameworks and methodological support structures. Often, these frameworks integrate perspectives of scientists, practitioners, and students to develop research-based instructional activities (Méheut & Psillos, 2004).

This work seeks to support educators in the gradual process of synthesizing perspectives and designing successful science instruction by showing how two well-established methodological frameworks, the Model of Educational Reconstruction (MER) and Design-Based Research (DBR), can be fruitfully combined. While MER serves as an overarching framework to reconstruct novel scientific topics from an educational perspective (Duit, Gropengießer, Kattmann, Komorek, & Parchmann, 2012), it does not explicitly specify the research methods to do so. However, the framework offers a design-oriented research approach. Thus, we argue that it is natural to complement a research design based on MER with methods of DBR (Anderson & Shattuck, 2012). To guide our explorations, we ask: **How does a combination of DBR and MER offer new opportunities to design teaching and learning sequences?**

In the following, we present MER and DBR in more detail before turning to two case studies that illustrate the merits of combining both frameworks in the learning domain of modern physics. We use these two cases to show how a combined approach MER-DBR allows bridging the gap between theoretical perspectives on teaching and learning and the actual science classroom practices.

METHODOLOGICAL FRAMEWORK

In this section, we briefly outline Design Based Research and the Model of Educational Reconstruction as two methodological approaches to develop solutions to educational problems. In the next section, we present two cases that exemplify how both approaches can fruitfully be combined to design successful science instruction.

Design Based Research

Design Based Research (DBR, Figure 1) aims to solve educational problems by designing new educational solutions that work in the ‘messy’ setting in which day to day education takes place. To this end, educators who use this framework not only want to know if an educational solution works but also why it works (Bakker, 2018, pp. 3-18). In DBR, the design is guided by certain design principles or design hypotheses (provided by a learning or design theory) to generate certain learning outcomes in a certain context. The design is then tested in real educational settings and practitioners contribute to the design over multiple design cycles (Plomp, 2013, pp. 20-25). Eventually, methods of DBR result in new learning resources (the design) and a local theory that describes if and how the design works. These local theories are humble in the sense that they cannot be generalized over populations per se, but usually they are general enough to be also applicable in other classrooms settings.

Model of Educational Reconstruction

The Model of Educational Reconstruction (MER, Figure 2) aims to make novel learning domains accessible to students by offering a methodological framework that integrates three strands of educational research: curriculum development, design of learning environments, and assessment of learning processes. To this end, MER provides guidance for science educators on how to integrate empirical research on teaching and learning in the development of learning resources. MER comprises the basic idea that “science subject matter issues as well as student learning needs and capabilities have to be given equal attention in attempts to improve the quality of teaching and learning” (Duit et al., 2012, p. 13). The holistic approach of MER serves as a useful and flexible tool to scrutinize the educational relevance of learning domains that have not entered mainstream science education yet. Eventually, methods of MER result in an educational reconstruction of a learning domain that contains a content structure for instruction, learning resources, and findings on student perspectives.

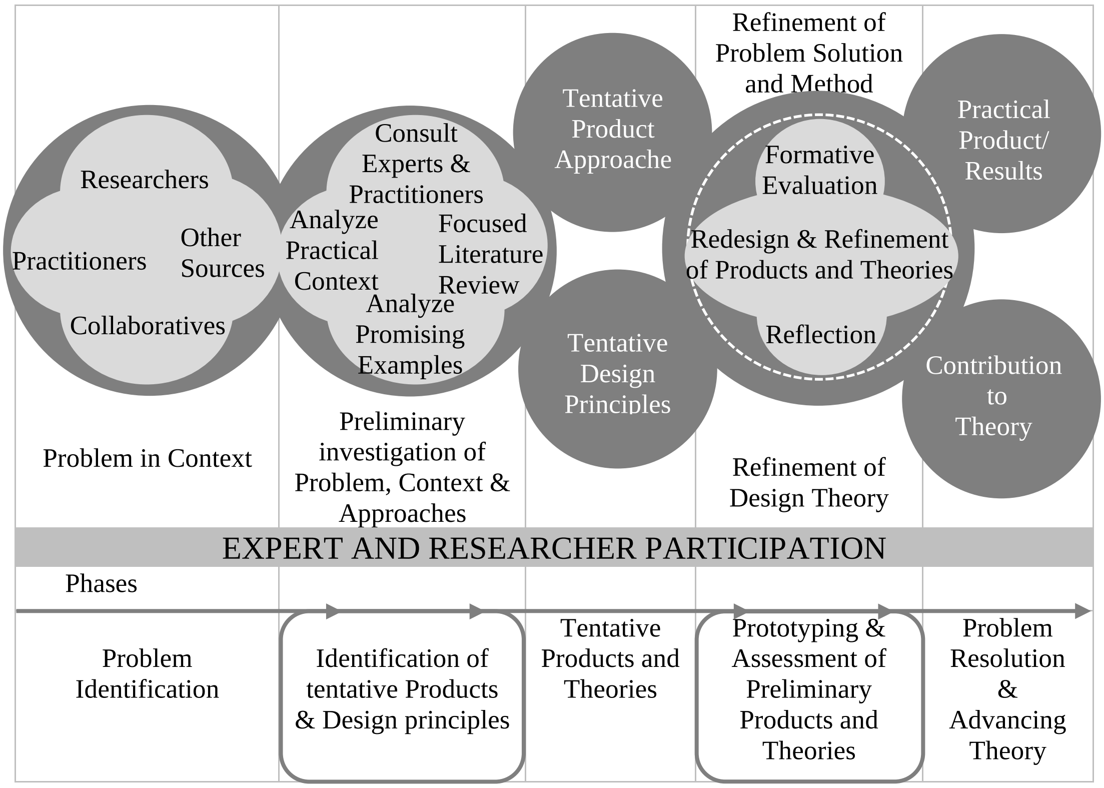

Figure 1. Design Based Research combines input from practitioners, users, experts and researchers to inform and improve educational design and theory.

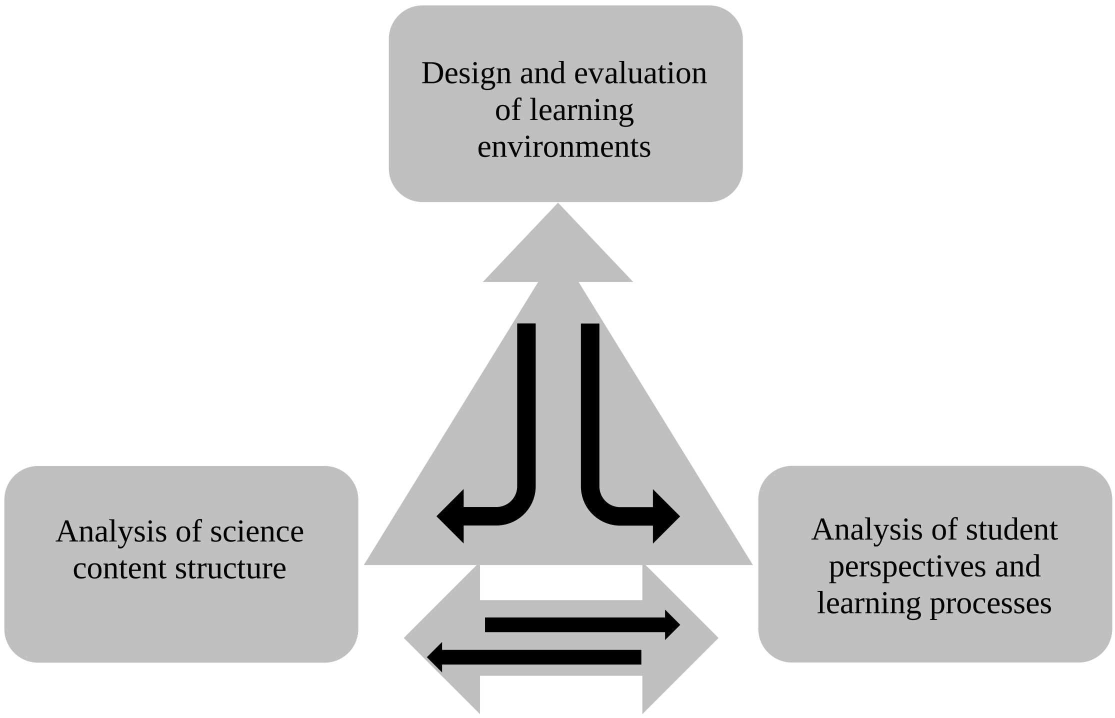

Figure 2 - The Model of Educational Reconstruction integrates three strands of educational research.

CASE STUDIES

In the previous section, we introduced DBR and MER as two frameworks to develop design solutions in educational settings. Both Special Relativity (SR) and General Relativity (GR) are new physics topics that have found their way to secondary school curricula in many countries (Blair & Kersting, in preparation; Kamphorst, Vollebregt, Savelsbergh, & van Joolingen, 2019; Kersting, Henriksen, Bøe, & Angell, 2018; Kim & Lee, 2018) . Yet, field-tested and research-based educational material is rare in this emerging learning domain of relativity education. In this section, we present two specific cases from the Netherlands and Norway in which we have combined the frameworks of MER and DBR to design teaching-learning sequences for secondary school students.

Relativity Education

Our modern scientific understanding of the universe rests on the special and the general theory of relativity. These theories present Albert Einstein's revolutionary description of space, time, light, and gravity. According to Einstein, space and time are dynamic entities that dynamically interact with matter and light. In contrast to classical physics where space and time are absolute and separate from the laws of physics, SR and GR thus ask us to let go of absolute space and universal time, concepts that seem integral to our experiential understanding of the world (Woodhouse, 2014). The abstract character of these physical insights seem counter-intuitive or even contradictory to the common-sense understanding of students (Kamphorst et al., 2019; Kersting et al., 2018). Moreover, the formulation of SR and GR necessitated philosophical changes in the world view of many scientists (Kersting & Steier, 2018). Consequently, there is potential to design learning resources that have a specific emphasis on the history and philosophy of science (Levrini, 2014).

In response to the conceptual challenges of SR and GR and acknowledging the need to convey historical and philosophical perspectives as well as content knowledge, the following two case-studies combined methods of MER and DBR to develop research-based learning resources.

Example 1 – Special Relativity

Special relativity was introduced in the Dutch upper level secondary physics curriculum in 2013. This curriculum reform placed a bigger emphasis on scientific literacy and the process of knowledge formation in physics as well. The curriculum goal of SR reflects this change: "The candidate can explain the phenomena of time dilation and length contraction in thought experiments and applications, using the concepts of lightspeed, simultaneity and reference frame." (Dutch College for Exams, 2014) Although the 'big ideas' in this goal are clear, it is not clear how they can be achieved.

Drawing on the model of educational reconstruction we were able to design a teaching and learning sequence in which students can experience the prototypical thinking and reasoning that introduces the concepts of SR for themselves. The teaching and learning sequences take students' spontaneous reasoning with light propagation (Kamphorst, Vollebregt, Savelsbergh and van Joolingen, 2019) as a starting point. Through subsequent reasoning activities students introduce and explain new relativistic concepts and phenomena. A first experimental exploration in small groups with multiple versions of the design offered a proof of principle and insights to improve the task design (Kamphorst, Vollebregt, Savelsbergh and van Joolingen, 2018). However, the design was not yet suitable to use directly in the classroom. To that end we involved teachers as co-designers, informed by the DBR framework. The teachers offered deeper insights into students' difficulties with some aspects of the initial designs. The teachers also adapted the task design to foster the proposed learning in the classroom context. Furthermore, this close collaboration with teachers ensured the intended performance of the educational design.

Combining the frameworks of MER and DBR stimulated us to create a detailed view on student learning processes and the content structure of SR on the one hand and look for design guidelines that can inform future educational design on the other hand. The result is an educational design that takes both students' conceptual difficulties and the classroom reality into account.

Example 2 – General Relativity

As part of the school reform introduced in 2006, GR became part of the Norwegian curriculum for upper secondary physics. However, the specific curriculum goal for GR remained vague: "The aims of the studies are to enable pupils to give an account of the postulates that form the basis for the special theory of relativity, discuss qualitatively some of the consequences of this theory for time, momentum and energy, and give a qualitative description of the general theory of relativity" (The Norwegian Directorate for Education and Training, 2006). This broad curriculum goal left scope for different interpretations of what a qualitative description of GR might look like.

Using MER as overarching framework, the Norwegian project ReleQuant unpacked the curriculum goal by attempting an educational reconstruction of GR (Kersting et al., 2018). This reconstruction entailed the development of a content structure for instruction, the development of a digital learning environment that is freely available in English and Norwegian (www.viten.no/relativity), and in-depths studies of students' conceptual understanding of key ideas in GR (Kersting, 2019; Kersting & Steier, 2018). This proposed educational reconstruction of GR suggests that students can obtain a qualitative understanding of relativistic concepts when provided with appropriately designed learning resources and sufficient scaffolding of learning through interaction with teacher and peers. A key feature of the design process related to the methodological issue of combining MER and DBR. To develop the content structure of instruction, which characterises MER, we drew on DBR methods to supplement this content structure with design hypotheses. We tested these hypotheses in iterative rounds and eventually formulated design principles that encapsulate successful ways of teaching relativistic concepts based on the empirical evidence from the classrooms. The design principles encompass overarching themes that characterise appropriately designed learning resources and specific recommendations that promote successful instruction in GR (Kersting et al., 2018).

CONCLUSION - DBR & MER COMBINED

We live in a fast-changing world where science educators are continuously invited to integrate new domains to the curriculum. The task of integrating new science topics is particularly difficult for two reasons. First, teachers lack practical experience teaching these topics. Furthermore, there is little known about student learning processes in these domains. Therefore, science educators face not only the question what to teach but also how to teach. The combined framework of MER&DBR offers a practical guide to answer these questions.

DBR and MER are two complementary methodological frameworks. MER provides a framework that includes a broad perspective on theory, teaching and learning perspectives. DBR provides a structure to include practitioners and design hypotheses. The common denominator in both frameworks is the iterative approach in which field testing informs the improvement of the design. We have added features of both frameworks to this common iterative approach. From the MER framework, we incorporated the analysis of the theory and student perspective to create a content structure for instruction. DBR added design hypotheses and involved practitioners as co-designers to the framework. The combination of these two frameworks has shown its benefits for the subjects of SR and GR.

Although this combined framework offers guidance in the design process, it still remains an open process in regard to two features: first, science educators can freely choose which aspects of MER and DBR they want to integrate into the design process. Second, the design process itself is open because it offers and reveals many possible choices in regards to different perspectives on teaching and learning. Despite these different choices we expect that structuring the design with the combined framework of DBR and MER is likely to result in common features in the final teaching-learning sequences. These features, together with the design hypotheses or design principles and the content structure, make up the outcomes of design research.

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