

Teaching and learning in the STEM domain

Research Program 2020-2024 of the Eindhoven School of Education¹

Abstract

ESoE aims to advance education in Science, Technology, Engineering and Mathematics (STEM) in response to new societal challenges. To contribute to this aim, we conduct scientific research on education and professional development of teachers and on the design and evaluation of educational innovations. In a recent update of our research program, the successful research strand on preparing and supporting teachers for innovative STEM learning and teaching in secondary education has been continued. This research has been extended with two new developments. First, teachers in higher education have been included as a focus of our research. Innovations in higher STEM education like challenge-based learning raise many questions about the new expertise teachers need and how they can develop this expertise. Second, questions about the optimal pedagogy of innovative STEM teaching and learning in secondary and higher education have been included. Answering these questions requires systematic design and evaluation research to provide evidence for successful practices. In these endeavors, research and development go hand in hand, aligned with ESoE's mission to contribute to both scholarly advancement as well as to improvement of educational practice.

ESoE's mission

The Eindhoven School of Education (ESoE) is the expertise center of Eindhoven University of Technology (TU/e) with regard to the education and professional development of teachers, scientific research in STEM education and educational innovation, all with a focus on secondary and higher education of STEM (Science, Technology, Engineering, and Mathematics). More specifically, ESoE

- offers a Master program in Science Education and Communication, in which teachers are educated to become so-called first-degree (“eerstegraads”) teachers in Mathematics, Physics, Chemistry, Research and design, and Computer science. ESoE also offers an educational minor (for bachelor students) and an educational module for master students) that lead to a second-degree teaching qualification;

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- conducts scientific research in education and professional development of teachers, and on the design and evaluation of educational innovations, in particular with regard to STEM education;
- supports and promotes educational innovations through professional development, consultancy and applied research, both at the TU/e and at educational institutions / schools in the region.

Leading is ESoE's vision on professional STEM teachers: innovative experts in their subject domain who design and develop (technologically) rich contexts for learning. They systematically reflect on their teaching, including their own role, and demonstrate an inquiring and learning attitude towards their subject and work as teachers. As such they are a role model for their students. In innovative contexts they act as agents of change, together with colleagues inside and outside their schools, and they demonstrate the professional leadership needed for this. ESoE strives to educate these academic professionals in close cooperation with schools and academic departments.

ESoE aims to advance STEM teacher education in response to new societal challenges, such as interdisciplinarity, language-responsive teaching for equal access, and the urgent global challenges prioritized by the United Nations. Secondly, ESoE aims for innovating and supporting the innovation of engineering education.

Recent developments in ESoE's research strategy

The ultimate goal of ESoE's research program is to contribute to the education of more and better STEM teachers and to educational innovation. The focus of ESoE's research program is on secondary and higher STEM education, both as object and as context. In line with their three-fold mission, ESoE's scientific research is practice-oriented. Their research program starts from and connects with issues, problems and questions in educational practice. Consequently, ESoE researchers strive for high quality research with strong societal impact on teaching, teacher education and educational innovation in the STEM domain.

The research focus on both teacher professional development and innovative STEM education aligns very well with ESoE's teacher education program, the research interests and expertise of the scientific staff, and the mission and vision of TU/e (Strategy 2030; TU/e 2018). The recent overall research evaluation (Qanu, 2020) was very positive about the continuous development of ESoE's research strategy and program. In addition, they added further recommendations, for example to connect school and university STEM education research more closely (e.g., teacher professional development and rewarding excellence in teaching; transition studies school - university STEM education), and to increase engineering education

research in digital learning environments and digital curriculum resources, in line with TU/e's focus on digitalization and blended learning.

In line with this recent research evaluation, in the current research period from 2020 onward the successful research strand on preparing and supporting teachers for innovative STEM learning has been continued. This research has been extended with two new developments. First, responding to an increasing interest from our research environment, teachers in higher education have been included as a focus of our research. Innovations in higher STEM education like challenge-based learning raise many questions about the expertise university teachers need to be able to fulfil new roles in novel educational models and environments (Vermunt, Den Brok, et al., 2020). Second, questions about the optimal pedagogy of innovative STEM teaching and learning in secondary and higher education have been included more prominently in the renewed ESoE research program (e.g. Gallagher & Savage, 2020). Answering these questions requires systematic design and evaluation research to provide evidence for successful practices. Good funding opportunities exist in both new directions. In these endeavors, research and development go hand in hand, aligned with ESoE's mission to contribute to both scholarly advancement as well as to improvement of educational practice. Such an dual approach resonates very well with the engineering education environment of ESoE.

Characteristics of ESoE's research approach

The aim of ESoE's research is to contribute to the advancement of knowledge about teaching and learning in the STEM domain. The approach we take to realize that aim has a number of specific characteristics:

1. The research is both scientifically rigorous and highly practice-oriented in nature. This implies for example that research outcomes are disseminated in both high impact international scientific outlets and in practice-oriented outlets for teachers, policy makers and educational practitioners.
2. The aim of the research program is to improve student and teacher learning through innovative teaching and learning approaches, in other words, to contribute to research-informed educational innovation.
3. Studies are focused on teaching and learning in the STEM domain, with digital (or analogue) curriculum resources and educational technology. When occasionally a broader disciplinary perspective is helpful to achieve our goals, we will take that broader perspective.
4. Studies are focused on secondary and higher education, or on the transition from secondary to higher education. When helpful, we may occasionally extend this focus to professional lifelong learning in a variety of learning and working environments.

Research strands

In line with the recent developments in ESoE's research strategy outlined above, ESoE's research program has been organized into two interconnected research strands:

1. Innovative pedagogies and students' learning and thinking in STEM education
2. Teachers' teaching and professional learning in STEM education.

Research in the *first strand* focuses on understanding and improving students' learning and thinking in and across STEM-disciplines. Cognitive reasoning, critical thinking, deep learning, self-regulation, motivation, affect and wellbeing are some examples of research topics within this strand (e.g. Dinsmore & Zoellner, 2018). We study the outcomes of existing learning environments and pedagogies on students' learning processes and outcomes. More importantly, we use knowledge gained in this way to help design innovative learning environments and pedagogies to help improve students' learning, thinking and motivation, and study the impact of those innovative STEM-pedagogies on students' learning processes and outcomes (e.g. Gallagher & Savage, 2020). We intend to examine and understand the quality of students' learning and thinking skills and their capacity to self-regulate their thinking and learning both as a prerequisite for and as an outcome of learning processes.

Research in the *second strand* focuses on teachers and their teaching and professional learning (e.g. Beijaard, 2019). A first way to do this is to translate the findings of research on student learning into strategies for teaching. For example, how can teachers support effective strategy use by students to solve everyday science problems? How can teachers use principles of inclusive pedagogy in their classroom teaching, and how can they deal with growing student diversity (e.g. Schüler-Meyer et al., 2019)? How can teachers foster active, meaningful, self-regulated and collaborative student learning (Järvenoja et al., 2020)? How can teachers assess students' problem-solving skills in physics and individual participation in collaborative group work?

This kind of research yields important new insights to improve teaching and student learning in the STEM domain. Such innovative practices may be new to many teachers and they need to learn to understand and use them in their daily teaching (Mesutoglu & Baran, 2020). Therefore, research in the second strand aims to understand and improve teacher professional learning, both in teacher education and in the context of educational innovations (Beijaard, 2019; Thurlings & Den Brok, 2017, 2018).

Connecting teacher learning and student learning

Research on students' learning and instruction and research on teachers' teaching and professional development are hardly connected in the international literature. In our view, this disconnection severely limits the impact of educational research on classroom practices. Figure 1 conceptualizes the relations between teachers' learning, teachers' teaching and students' learning (Vermunt et al., 2017). Teacher education or professional development (PD) programs may initiate teacher learning processes. These learning processes lead to teacher learning outcomes, which may become manifest in many different forms, including changed knowledge, beliefs, motives, attitudes, skills and professional identity. When teachers use these learning outcomes to change their teaching practices, they become part of the student learning environment. This may then initiate student learning processes, leading to student learning outcomes, which can be conceptualized as changed knowledge, beliefs, identity, motives, attitudes, skills, and grades.

These interrelations are dynamic, and the influences may well move in other directions as described above as well. Therefore, the arrows between the elements of the model are represented as bidirectional. For example, teachers may observe the learning processes of their students and through reflection learn how their students' understanding is fostered or hampered by the way they taught a particular topic. Educational innovations may demand novel teaching practices and hence give rise to changes in teacher education programs. Moreover, students may learn a lot by observing their teachers struggling to understand new and difficult problems in their subject domain.

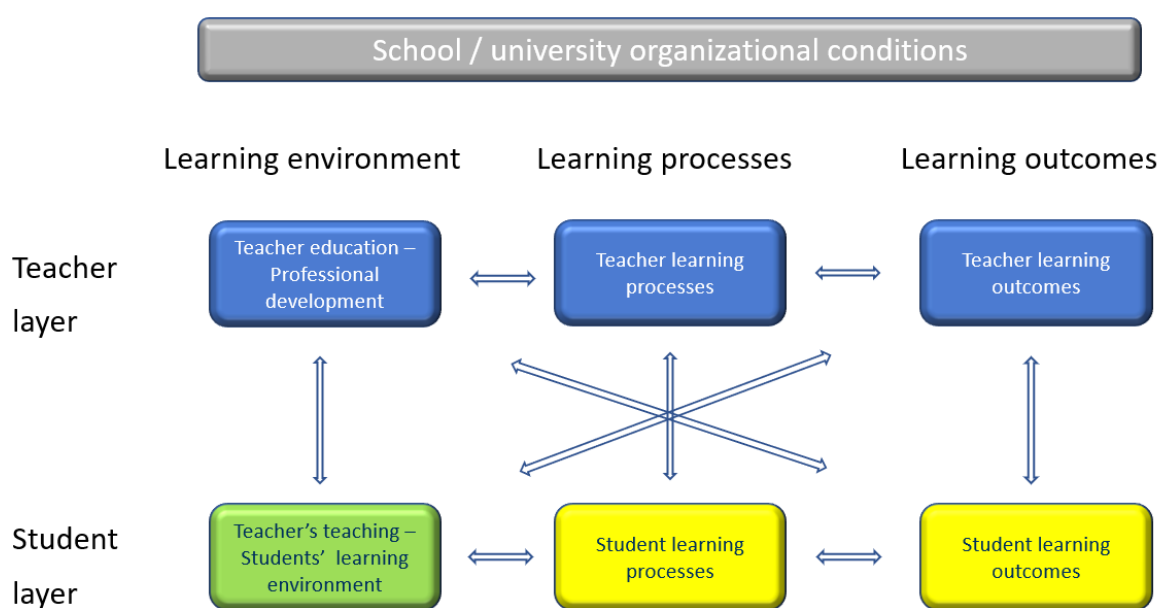


Figure 1. A multi-layer model of teacher learning and student learning (from Vermunt, Vrikki, Warwick & Mercer, 2017).

Since the ultimate purpose of teacher learning is to have an impact on students, we try to connect the two layers of teacher and student learning whenever possible in our research. Studying the whole chain of evidence from teacher professional development to student learning outcomes requires long time research projects and may often not be feasible. Therefore, we need to develop creative research designs that cross the boundaries between student learning and teacher learning and bridge the two research fields.

Student learning and teacher teaching and learning are for example linked in the (digital) curriculum resources that both are using, as the socio-didactical tetrahedron model in Figure 2 below shows. This shows that artifacts/resources are fundamental constituents of the didactical situation, and can thus be used as a lens through which to view both teaching and learning. The question is how to design, appropriate, orchestrate, etc. these resources, so that they become 'teaching or learning resources' (or educative resources for teacher learning). Trouche, Gueudet and Pepin (2019) have developed a whole theory around 'resources' for mathematics education and teacher and student interaction with resources. In their view it is through the interaction with resources, may they be analogue or digital, social, or cognitive, that learning emerges. Hence, the resource approach as a theory/lens for viewing and designing teaching and learning. In other words, it is not only about teachers' or students' use of technology/digital resources, but about their learning with and through the resource.

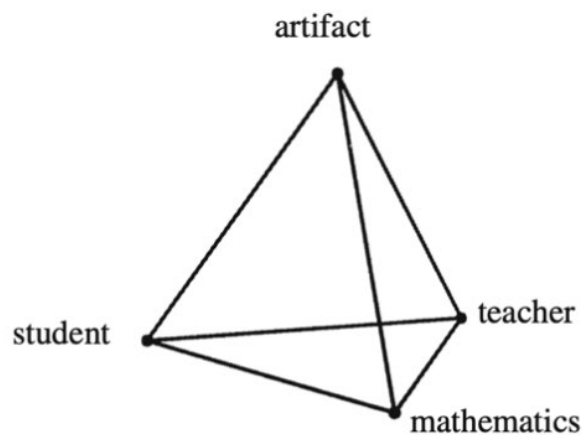


Figure 2: Socio-didactical tetrahedron for mathematics (from Trouche, Gueudet and Pepin, 2019)

ESoE research group

The members of the ESoE research group represent a variety of disciplinary backgrounds (e.g. Mathematics, Physics, Chemistry, Technology and Engineering education, Educational sciences, Learning sciences) and they investigate learning and teaching from different disciplinary and theoretical perspectives. Moreover, they aim to take an interdisciplinary

stance and collaborate with researchers from other disciplines within and beyond the research group to gain a better understanding of the nature and enhancement of learning and teaching in the STEM domain.

This multiplicity in perspectives on education and pedagogies makes the ESoE research group ideally suited to tackle the above objectives through collaborative research. Accordingly, ESoE aims to make an impact by tackling the issue of connecting student learning and teacher learning in a wholistic way. The two Figures presented above give two examples of how ESoE aims to research learning at the intersection of teachers, students, learning environments, resources and historical practices of the domain.

Some examples of recent studies in the research program

As stated above, ESoE's research program is developing continuously. This research program 2020 – 2024 continues the successful research on teacher learning and development in secondary education from the previous program, and introduces new research lines on higher education teachers and innovative pedagogies in STEM teaching and learning. However, these new developments have not been launched suddenly, but have originated on a small scale in previous years and grown since then. To illustrate this continuous development, we will give some examples here of recent studies by members of the research group which can be viewed as early precursors of the current program.

The research in the *first strand* focuses on understanding and improving students' learning and thinking in and across STEM-disciplines. Recent examples of studies in secondary education are the design and study of pedagogies to improve students' mathematical reasoning, socio-scientific thinking, modelling skills in physics, and students' STEM identities development (e.g., Bayram-Jacobs et al., 2019; Taconis, in press). Schüler-Meyer et al. (2019) studied how mathematics education can be developed towards becoming more responsive to linguistic diversity. Pepin & Kock (2021) examined the quality, design and integration of innovative (digital) curriculum resources for teaching and learning, and how students learn with and from these resources. Bouchée et al. (2019) studied the use of widely available digital technology for learning in the learning and teaching of STEM subjects. Another example is the study of Hendrickx et al. (2017) who looked into the extent to which everyday classroom interactions in the STEM subjects in secondary school are associated with students' aspirations to pursue a study and eventually a career in STEM.

ESoE's research strategy has been extended to include innovations in higher education. We intend to systematically design Challenge-Based Learning (CBL) as a pedagogy to educate engineers of the future, and then study the effects of a variety of design characteristics on

students' self-regulation, motivation, collaboration, and interdisciplinary thinking skills (e.g., Doulougeri et al., 2021; Kiliç & Pepin, 2020; Van den Beemt, McLeod, Van der Veen et al., 2020). Another example of research in higher engineering education is how teaching and learning can be supported with ICT and learning analytics (e.g., Van den Beemt et al., 2018). MacLeod and Van der Veen's (2020) study on the effects of scaffolding interdisciplinary project-based learning is also a nice example of this kind of research.

Research in the *second strand* focuses on teachers and their teaching and professional learning. This includes studies on how and what teachers learn through PD initiatives in the context of the introduction of new STEM-curricula in schools and universities (e.g., Bayram-Jacobs et al., 2019). In *secondary* education, for example, Schellings (2020) and Vermunt et al. (2019) examined student teachers and in-service teachers' interactions in Lesson Study groups, trying to understand how they develop their pedagogical (content) knowledge and where and how this knowledge development may be improved. Stollman et al. (2019) addressed the question how (STEM) teachers can be supported in their professional development (PD) towards more innovative and diverse teaching approaches in order to maximize each student's learning. Hendrickx et al. (2020) studied teacher interactions in professional learning communities and how these are related to teachers' professional knowledge development.

In a large ongoing national research project, Vermunt, Den Brok and colleagues (2020) from 20 research universities and universities for applied sciences are investigating teacher professional learning and development in higher education in the context of educational innovations. Also in higher education, Ping et al. (2018) conducted a literature review on the professional learning of teacher educators. De Putter-Smits et al. (2020) tried to understand the development and needs of career changing teachers and teachers learning to teach in context-based science classes. And Schellings et al. (2019) studied student teachers' and experienced teachers' formation of professional identity since it is so closely linked to their pedagogy and support of innovations.

We should also note here the research on 'teachers as co-designers of their curriculum' and the use of digital (curriculum) resources for teacher learning. This research addresses questions as: What does teachers as co-designers mean (in different contexts)? How do teachers develop design capacity? What (digital) resources or technology do they use to collaborate with colleagues (e.g. in school, online)? How do resources support (or hinder) the enactment of innovative curricula? These questions refer to both school education and higher education, where students become 'co-designers of their own curriculum' (e.g. Pepin & Kock, 2021; Pepin et al, 2019; Guedet, Pepin, & Lebaud, 2021).

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