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# Boundary crossing by science teacher researchers in a PhD program

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## HIGHLIGHTS

- Boundaries exist between the community of teachers and the community of educational researchers.
- Teachers doing PhD research might bridge the so-called research-practice gap.
- Sixteen teacher researchers were interviewed as well as their professors and their school principals.
- Two success stories of teacher researchers who seemed successful in crossing boundaries between the two communities.
- Personal and contextual factors influence boundary crossing activities of teacher researchers.

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## ABSTRACT

The boundaries between communities of teaching and educational research are very persistent. Boundaries can be conceptualized as sociocultural differences, leading towards discontinuity in action or interaction. Boundary crossing refers to the efforts made to establish continuity. The purpose of this article is to provide a better understanding of how these boundaries can be crossed by teachers who are also PhD students in a national PhD program for educational research in the context of science education. Sixteen teacher researchers as well as their professors and school principals were interviewed. Additionally, two stories were studied of two teacher researchers who seemed successful in crossing boundaries between the two communities. Many differences were found between the two communities, not all of them being boundaries. Specific personal characteristics - such as communication skills and flexible switching – seemed to facilitate boundary crossing, just like particular contextual factors such as school teams with open learning climates and supportive supervisors. All 16 teacher researchers contributed to better science teaching in their own practices, while eight teacher researchers had been able to share insights from their PhD projects with others.



## 1. Introduction

Findings from educational research can contribute to the improvement and innovation of educational practices. However, there seems to be a lack of productive interaction between academic education research communities and professional practices of teaching, leading to the so-called research-practice gap (Vanderlinde & van Braak, 2010) or a cultural barrier (Carr, 2002). Educational research might lead towards valid and relevant knowledge, but it does not seem to contribute to the improvement of educational practice in a high extent (Bakx, Bakker, & Beijaard, 2014). This may be caused by the fact that outcomes of educational research are not practice-based and often cannot be used by educational practitioners. It might also be that research findings *do not reach* educational practitioners like teachers and therefore are not used to their possible full potential. Also, more alignment between the knowledge building (in the academic community) and insights needed for practice (community of educational practitioners like teachers) is needed in order to bridge the perceived relevance gap (Starkey & Madan, 2001).

The gap might be described in terms of boundaries between two communities of practice, not profiting from one another's expertise because of certain boundaries between the two communities. One possible way for overcoming these boundaries is connecting the

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two communities by teachers conducting educational research. By carrying out educational research, teachers might be able to improve their own practices or those of their colleagues, based on their own research findings and those of others. In turn, teachers doing educational research embedded in an academic community may also emphasize concerns and experiences of practitioners to this academic community. Despite this suggested potential for overcoming boundaries by having teachers conducting research, the literature is scarce on how teacher researchers might contribute towards narrowing the gap between the two communities and improving their educational practice at the same time.

In order to overcome the boundaries experienced between both communities, a Dutch, nation-wide PhD program in educational research was set up for (science) teachers in secondary schools. This program enabled teachers to conduct educational research, aimed at improving their educational practice. The (full time) teachers in this program conducted a PhD project for three days a week during four years, whilst still teaching the other two days a week. This PhD program provided us an opportunity to study teachers doing research, what possible boundaries they experienced and, if so, how they could contribute towards the improvement of educational practice. This PhD program took place within Dutch schools and universities, but is internationally important especially in the light of the current discourse about evidence-informed practice, for example in Western Europe, Australia and USA (Vanderlinde & van Braak, 2010). The aim of our study was to gain more insights into possible boundaries between the academic community of educational researchers and the community of educational practitioners (teachers). More specifically, we were interested in how the teachers doing educational research succeeded (or not) in crossing possible boundaries between these two communities, while aiming at an actual improvement of (their) educational practice.

## 2. Teacher research as strategy for narrowing the research-practice gap

The gap between educational research and practice has been a topic of concern for many years (e.g., Biesta, 2007; Nuthall, 2004). This gap can be seen as a barrier to education reform, because teachers seem to miss out the increasingly enhanced theory required to adequately address teaching and learning processes, for example in the field of science education (Duit & Treagust, 2003). The other way round, from the scientific community it is argued that teachers' practice-oriented expertise is a critical factor in sustainable curriculum reform (e.g., Barab & Luehmann, 2003; van Driel, Beijaard, & Verloop, 2001). Narrowing the research-practice gap in education reform might be realized by establishing more connections between theory based on educational research and the practice-orientation from the perspective of teachers.

It is known that small scale teacher-based action and design research are types of research which can result in insights usable for educational reform (e.g., Feldman & Minstrell, 2000). These types of research can potentially contribute to teachers' professional development and, for example, to a better understanding of particular curricular domains by addressing the complexity of educational settings (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). In research collaborations with academic researchers, it is likely that teachers somehow contribute to narrowing the research-practice gap (Smit & van Eerde, 2011). However, hardly any background or study on this assumption could be found. In this study, we used a conceptual framework on boundary crossing in order to thematically study teacher researchers and their (im) possibilities to contribute towards narrowing this gap, while working in two different communities (Akkerman & Bakker, 2011).

### 2.1. Boundary crossing as a lens to study teacher research

Researchers and teachers work in communities of practice or activity systems with different subjects, goals, tools, division of labor, and rules. Communities of practice can be seen as "shared histories of learning" (Wenger, 2007, p. 3), referring to groups of people going through the same learning experiences. In activity theory (Engeström, 2001), so-called activity systems are not studied in isolation but in relation to each other. Interaction between such communities or activity systems can be challenging, a phenomenon often conceptualized in terms of boundaries (Engeström, Engeström, & Kärkkäinen, 1995; Wenger, 1998). Akkerman and Bakker (2011, p. 139) defined boundaries as "sociocultural differences that give rise to discontinuities in interaction and action." The problems summarized as in the research-practice gap are exemplary for discontinuities in interaction (between researchers and practitioners) and action (e.g., using research findings in practice). In activity theory such boundaries are considered the tensions that may lead to transformation of existing activity systems, and in some cases can even lead to the formation of new systems. For example, biophysics can be seen as a boundary practice, evolving from the interaction between biology and physics.

It is assumable that teachers who combine the profession of teaching and the profession of research might be able to connect both communities in a way that might narrow the research-practice-gap for some extent. People who interact in two different kinds of communities can bring something from one to the other community. People who actually do this, and by doing so connect two communities, are called *brokers* (Wenger, 1998). A combination of two jobs, combining research and education may thus create brokers who can cross the boundaries between research and practice.

The challenges for the teacher researchers in this study are multiple, because the school context in which they work is very different from the university context, often with a lack of research culture in the schools (Anderson & Hogan, 2010). In addition, PhD research needs much time for study and reflection, while working with students as a teacher mostly asks for quick responses and immediate actions (e.g., Korthagen, 2010). Differences between the cultures in schools and universities might actually be boundaries, but could also be seen as differences between two work contexts.

### 2.2. Boundaries, brokers and boundary objects

Thinking in terms of boundaries has been quite common for a long time, but in science education this is more recent (Kisiel, 2014). People move between different communities all the time, often without making any effort. In our study, we wanted to investigate whether and to what extent the teachers made an effort in dealing with differences or in what way they experienced discontinuities, in order to gain more insight into the temporality or partiality of boundaries (Akkerman, 2011).

Once possible boundaries experienced by teacher researchers have been identified, it makes sense to focus on the crossing of these boundaries. Suchman (1994) used the term *boundary crossing* to refer to the challenges when professionals enter unfamiliar territory, being to some extent 'unqualified'. The teachers might "face the challenge of negotiating and combining ingredients from different contexts to achieve hybrid situations" (Engeström et al., 1995, p. 319). From this perspective, boundary crossing can be seen as the efforts made in order to establish action or interaction across different practices. Akkerman and Bakker (2011) described four different mechanisms for doing so: identification, coordination, reflection, and transformation. Identification refers to demarcation of practices (e.g., learning how both practices work

and what is common behavior and what is not). Coordination is looking for means to cooperate effectively (e.g., finding out who of your colleagues you can ask questions about work routines and how). Reflection concerns the explication of differences between practices (e.g., describing for oneself what research meetings are and how this form of content exchange might be used in the educational context). Transformation refers to more fundamental changes in practices and may include the formation of new practices (e.g., introducing working with small research groups in school when encountering educational problems).

More recently, Akkerman and Bruining (2016) have identified how these four mechanisms can also operate at intrapersonal levels (i.e. within a person). Identification then refers to a person defining his/her own participatory positions, in our case that of teacher and researcher. Coordination at the intrapersonal level is about seeking procedures to align these participatory positions in different practices. Intrapersonal reflection is about taking a different perspective on a participatory position (being a teacher) because of the other position (as a researcher). Transformation at the intrapersonal level is developing a hybrid position (integrating teacher and researcher positions).

Which mechanism might be useful for crossing boundaries and connecting communities depends on the contexts in which the teachers operate as well as on the preferences and characteristics of the individual teacher researchers. Useful in this respect is the concept of *boundary objects*, which "both inhabit several intersecting worlds and satisfy the informational requirements of each of them" (Star & Griesemer, 1989, p. 393). Boundary objects are artifacts assisting brokers in bridging different worlds in which they participate (Star, 2010). Examples of boundary objects in the context of this study might be scientific language, transferred from the academic towards the school community, or an educational design developed for the PhD project and tested in the school. The existence of possible or potential boundary objects, the possibilities to conduct boundary crossing activities and acting as brokers and the space provided to do so (or not), are contextual factors. Both communities have their own characteristics with supporting or exhibiting factors for brokering.

The teacher researchers in this study were expected to become brokers: being in the position to give other teachers access to what is known in research communities, whilst also being able to help researchers stay in touch with educational practice and keep having a sense of what is feasible or needed in practice. However, being a broker is challenging, because one needs to be able to switch between expectations from different communities, having a quite ambiguous position. Brokers are members of both communities (both-and) but simultaneously they do not fully belong to either community (neither-nor) (Akkerman & Bakker, 2011). When brokers manage to meet the expectations of different communities, they could make a change in communities by boundary crossing and introducing boundary objects in both communities they participate in (Morse, 2010). Brokers need particular personal traits for this (Wenger, 1998), the so-called boundary-crossing competence (Walker & Nocon, 2007). This competence is the "ability to manage and integrate multiple, divergent discourses and practices across social boundaries" (p. 181). Little is known yet about contextual and personal factors which play a role in (successful) brokering. We wanted to gain more insights into how these factors might contribute towards successful brokering and, in turn, whether or not this helped narrowing the research-practice-gap with and, as the final goal, an improvement of science teaching.

### 2.3. A multi-level perspective

The PhD program in this study not only intended to contribute to bridging the research-practice gap, but also to contribute towards a possible improvement of science teaching in practice. This improvement could take place on micro, meso, and macro levels (cf. Akkerman & Bruining, 2016). The micro level concerns the teacher researchers themselves at the individual levels. For example, their research may lead to the growth of their skills in designing their own education or their awareness of providing 'evidence' of what works in their own teaching practice and why it works (e.g., Cordingley, 2003). Meso level concerns the organisational level of the school or school team, transcending the individual level. For example, sharing insights when working together and interacting in the school team, leading to 'shared outcomes' (e.g., Little, 2003). Macro level concerns systems, like the educational system. On this level, the teacher researchers could contribute to increased knowledge of science (teaching) on a regional or even national level when outcomes of the PhD project could be used by other schools and be fitted into the new national science reform.

### 2.4. Research questions

The following research questions were addressed in this study:

1. Which differences do teacher researchers experience between the academic and the school community, and which of these can be conceptualized as boundaries?
2. Which personal factors facilitate and hinder teacher researchers' boundary crossing between school and academic contexts?
3. Which contextual factors facilitate and hinder teacher researchers' boundary crossing between school and academic contexts?
4. How did the teacher researchers' participation in PhD projects contribute to (a possible improvement of) the practice of science teaching?

The first and second research question concern the micro-level of intrapersonal boundary crossing by teachers. The third predominantly addresses meso-level issues, and the fourth includes the macro-level.

## 3. Method

The research questions were addressed by means of an interview study and two case studies of *success stories*.

### 3.1. Participants

#### 3.1.1. Participants interview study

The PhD program started with 19 teacher researchers, of whom three left before the second year. The other 16 teacher researchers all participated in this study: nine males and seven females, with an average age of 37 years old. They all finished an academic master program as part of their teacher education. When entering the PhD program, none of them had experience with conducting educational research (using methodology from social sciences).

At the time of interviewing, the teacher researchers had been participating in the PhD program for at least two years and maximally three years. All teacher researchers worked in different schools ($n = 16$). Table 1 presents the topics of the PhD studies for the different science domains included.

To answer the first research question on their experiences, we interviewed all sixteen teacher researchers. We additionally interviewed all eleven supervising professors (two females) and sixteen school principals (four females) to obtain a detailed picture of the factors in which we were interested (the second and third research question). To answer the second and third question more in-depth,

**Table 1**
Topics of the PhD projects.

| Subject area/Topic | Research theme | Central research question(s) |
|---|---|---|
| Biology | 1. Designing concept-context[a] education by biology teachers | 1. In what way are biology teachers' practical knowledge and their designs of concept-context materials related? |
| | 2. Evolutionary thinking in the concept-context approach | 2. What is evolutionary thinking and can students learn this by means of concept-context education, exploring authentic practices? |
| | 3. Recontextualizing in the concept-context approach in the domain of biology education | 3. How can an inquiry-based-process, aimed at recontextualizing biological concepts, be structured? |
| | 4. Promoting coherence in students' cognitive networks of biological knowledge learning and teaching activities on the topic of photosynthesis | 4. How can learning-teaching activities within a concept-context module on the topic of photosynthesis be structured? |
| Mathematics | 5. Designing and implementing switch problems for mathematical discussion, reasoning and level raising | 5. What is the effect of the use of appropriate switch problems in a collaborative learning setting on mathematical discussion, reasoning and level raising? |
| | 6. Mathematization as a shackle of the modeling cycle: opportunities and obstacles while creating a mathematical model | 6. Which components are suitable for an effective learning strategy in the domain of algebra? |
| | 7. Understanding differential equations | 7. Which characteristics of a pedagogical approach of differential equations match students' learning processes and result in an easy transition to college education? |
| | 8. Shift-problem lessons: fostering mathematical reasoning in regular classrooms | 8. How can teachers design new statistical lesson series in order to foster students' mathematical reasoning? |
| Physics | 9. Students reinventing the general law of energy conservation | 9. How can the changing relation between context and concept regarding general law of energy conservation be designed in order to help students develop a flexible mindset on the general law of energy conservation? |
| | 10. Development of a professional development program for teachers in the field of mechanics | 10. Which pedagogical approach can be used in order to develop a professional development program for teachers using exemplary materials? |
| Nature, Life and Technology (NLT) | 11. Professional development of teachers in cooperation on a multidisciplinary science | 11. How can multidisciplinary science be introduced and which characteristics should a professional development programme have for teachers in this domain? |
| | 12. Learning correlation and regression within authentic sciences | 12. Which characteristics does a valid and effective teaching strategy have in order to teach students correlation and regression within authentic sciences? |
| Multidisciplinary science and maths | 13. Design principles for summative assessment in context-based science and mathematics curricula | 13. Which design principles for summative assessment can enlarge validity in context-based science and mathematics curricula? |
| Biology and chemistry | 14. Relation of chemistry and biology within a context-concept approach | 14. What are the characteristics of an adequate learning and teaching strategy for upper secondary education inspired by an authentic practice, that enables students to experience coherence between the subjects chemistry and biology? |
| ICT is science education (math) | 15. Use of ICT for acquiring, practising and assessing algebraic expertise | 15. How can ICT be used in acquiring, practicing and assessing students' algebraic expertise? |
| Learning of students in the new science education (multiple science domains) | 16. Knowledge building and designing a curriculum for inquiry based learning for students | 16. What is a usable and effective design of a lesson series on inquiry learning for students aimed at learning about validity, reliability, and accuracy in varying science domains? |
| Professional development of teachers in innovation of science education | 17. Academic reasoning in the highest grade (12) of secondary education | 17. Which characteristics should a teaching strategy on academic reasoning have in the highest grade of secondary education? |
| | 18. Science teachers designing context-based curriculum materials: developing context-based teaching competence | 18. How does the participation of teachers in context-concept-design teams contribute to their professional development towards context-concept-proficiency, and which factors concerning the teams hinder or facilitate this? |
| | 19. Success-driven and outcome-based implementation of concept-context educational innovation | 19. How can teachers' conceptions on their education practice, related to the concept-context method, be assessed? What are the most important perceptions of teachers, which can be used in order to develop a professional development program on the concept-context method? |

[a] Context-based education is generally called the concept-context approach, thus stressing a focus on development of conceptual knowledge connected to specific contexts.

we carried out two case studies of *success stories* to learn more about personal and contextual factors and specific contributions made to science teaching. To address the fourth research question, in addition to the interviews, available documents from the teacher researchers were studied (for each PhD project: a summarized research proposal, an extended research plan and possible publications).

### 3.1.2. Participants for the success stories

To select cases for the *success stories,* a set of criteria was designed, as presented in Table 2. These criteria were developed in an earlier study (Bakx et al., 2014) on success and fail factors of teacher researchers conducting PhD research. The criteria were based on the aims of the PhD program, specifically the contribution to the improvement of science teaching by means of boundary crossing. For scoring the criteria, data on the teacher researchers from interviews with the school principals, professors and the teacher researcher themselves were used. Next to this, we used data on the teacher researchers like drop-out and delays registered by the PhD program manager.

Only two teacher researchers met all ten inclusion criteria. This is why (only) two cases were selected as *success stories*. Both (female) teacher researchers were relatively young (31 and 33 years old). For the reason of triangulation, we decided to interview not only the two teacher researchers, their two school principals and professors, but also teacher-colleagues and students who were able to judge the teacher researcher's work and were familiar with the research project of the teacher researcher. The teacher-colleagues –

**Table 2**
Criteria used for the selection of success stories.

| | |
|---|---|
| | Exclusion criteria |
| 1 | Drop-out of the PhD program |
| 2 | Need of more than an additional period of six months for completing his or her PhD research (more than 4,5 years in total) |
| 3 | No job as a science teacher anymore |
| 4 | Intention to leave education after completion of the PhD project |
| | Inclusion criteria |
| 1 | PhD research is on schedule |
| 2 | Contribution to the body of knowledge on science education by writing articles or presenting on conferences |
| 3 | At least three examples concerning boundary crossing mentioned by the teacher researcher in our previous study |
| 4 | The school principal had been able to illustrate the science teacher's role as a broker with at least one example |
| 5 | The school principal had illustrated the contribution of the PhD research to the practice of science education in his or her school with at least one example |
| 6 | The teacher researcher had developed boundary-objects concerning science education |
| 7 | The professor could illustrate the science teacher's role as a broker with at least one example |
| 8 | The science teacher had created a liaison between people from the academic environment and the school by involving other persons than him- or herself |
| 9 | The science teacher pursued a future connecting role for him- or herself, combining science education and research |
| 10 | The science teacher had mentioned at least three learning points for him- or herself, as learning outcomes from the participation in the PhD program |

two for each case – were three females and one male. Both teacher researchers nominated six students from grade 12 in secondary education (pre-university track, in Dutch: VWO). The students were 18 years old on average. Both groups of students consisted of three girls and three boys. All students and teacher-colleagues participated in the interviews voluntarily.

### 3.2. Instruments

A semi-structured interview was developed for interviewing all 16 teachers, their school principals and supervising professors. Four themes were questioned: (1) differences between work communities; (2) personal factors; (3) contextual factors; and (4) possible impact on the educational practice (of the teacher researcher). In total, the teacher researchers were asked 41 questions (varying from: 'Can you describe differences between working in a school and working in an academic community?' to 'how many articles have you written so far and what are these about?'). The professors were asked 32 questions, like: 'What do you think are important characteristics or qualities for teacher researchers to complete a PhD study successfully?' The school principals were asked 21 questions, like: 'Is the PhD study of your teacher embedded within your school and, if so, how?'

For the case studies of the success stories a semi-structured interview was used for questioning colleagues, students, and teacher researchers. It contained three themes: (1) broker characteristics; (2) boundary-crossing activities; and (3) characteristics of the community of practice in school. The colleagues were asked 19 questions, like: 'Does this teacher differ from other teachers and, if so, could you describe that?' (theme 1). The students were asked 12 questions, like: 'Your teacher works in this school for two days a week and three days a week as a researcher. What can you tell me about her research?' (theme 2).

### 3.3. Procedure

All interviews were conducted by the first author. The teacher researchers were interviewed individually during a face-to-face meeting from 1.5 h on average. The supervising professors (1.5 h each) and school principals (1 h each) were interviewed individually by telephone. All the interviews were audio taped and transcribed. A member check procedure was used to check the correctness of the transcripts (e.g., Hoffart, 1991). Each transcript was e-mailed to each interviewee with the request to reply to the interviewer whether it was recognizable, correct, and accurate. Each interviewee was furthermore asked to give his/her consent, stating that the transcript was indeed the input of the interviewee and 'correct and accurate' for use in the study.

For the interviews regarding the success stories, the two teacher-colleagues per case were interviewed together and the six students per case were interviewed as a group, followed by a short interview with the teacher researcher in that school. Both groups of students each had one volunteer to check the interview description for the entire group, while all four teacher-colleagues received the description of their interview individually. The transcripts were approved by the participants. One student suggested small changes, which we adopted.

### 3.4. Data analysis

#### 3.4.1. Interviews

A grounded theory approach was used for analyzing the interview transcripts, working with sensitizing concepts as used in the thematic questions and based on the theory (see also Bowen, 2006). This analysis was an iterative process of going back and forth between the data and our concepts in order to search for possible subthemes.

We started analyzing the raw data by searching for text fragments having to do with possible subthemes related to our four main themes: (1) differences between the two communities; (2) personal factors (facilitating and hindering brokering); (3) contextual factors (facilitating and hindering brokering); and (4) contribution to (improvements of) the practice of science teaching. Interview fragments with similar meanings were place together in subthemes. This process of data analysis revealed several subthemes for each main theme: five for the differences between the two communities, and three and eight for the personal and contextual factors respectively. For the main theme of contribution to (improvements of) the practice of science teaching, five specific subthemes regarding micro-level were found. No specific themes were found referring to meso or macro level, only examples of individual teacher researchers were found (described in the results section). All the subthemes will be described and further explained in the result section.

The subthemes found came up from our data, but were validated by literature. When labeling the subthemes, we first generally described the subtheme (close to the raw data) and in the next step, we connected it to the theoretical basis of boundary crossing literature. For example, regarding the main team 'personal factors' the teacher researchers often mentioned 'changing perspective', 'seeing things from a different view', 'looking to things from one context but also from the other context'. These kind of descriptions were found in the raw data (transcripts). Theoretically, the so-called boundary-crossing competence refers to the ability to integrate multiple practices across social boundaries and to switch flexibly between perspectives (Walker & Nocon, 2007). Connecting

our findings with theory, we labeled this subtheme as 'flexibility' (in cognitive switching and perspective taking). By doing so, an iterative process of data-analysis was conducted going from data to theory and back, helping us labeling the subthemes in a way theory and practice could be linked in a meaningful way.

For the purpose of reliability a procedure was used inspired by the audit procedure as proposed by Akkerman, Admiraal, Brekelmans, and Oost (2006): first, the data were analyzed by one researcher. Next, two other researchers analyzed a large part of the dataset as well, in the same way, searching for sub themes. The findings of the three researchers were then compared and discussed together. The other two researchers concluded that the analyses of the first researcher were conducted in an accurate way and that the selected fragments and possible subthemes were justified. Additionally, regarding reliability, a selection of quotes was used to illustrate the subthemes found.

#### 3.4.2. Case studies of success stories

The data consisted of (1) materials from the PhD projects of the teacher researchers and (2) interview data. The materials of both PhD projects were studied and a summarized description of the project was made for each PhD project. The two teacher researchers assisted in the final description of their own PhD project.

In total, ten interview transcripts were available for the description of the success stories: four new interview transcripts (two of the teacher colleagues and two of the students) and six interview transcripts, which were already in the database (two of the school principals, two of the professors and two of the teacher researchers themselves with a few additional remarks made after the school visit). These interviews were analyzed when all other data were already analyzed. In this way we could start the analyses from the data from the transcripts using the subthemes found in the analyses we had already conducted. Not all subthemes found in the earlier analyses were found in the two case studies and no new subthemes were found.

## 4. Results

### 4.1. Differences between the school community and the academic community (RQ1)

All teacher researchers indicated that the school community and the academic community differed. Table 3 presents the five subthemes found regarding differences they reported.

The difference between theshort-term and the long-term perspective was mentioned most. Eleven teachers explained that working in the school community needed a high speed modus through switching relatively quickly from one activity to the next. Conversely, in the academic community long-term plans were made, a specific focus of the work was common, and much more time was available to work on one topic or project.

The specific focus versus broad expertise refers to teachers working in a school community practicing their jobs as being broad experts, while in the academic community everyone had a specific focus and expertise. Three teacher researchers added that they perceived more quality-mindedness in the academic community, compared to the school community.

Seven teacher researchers mentioned the embeddedness in society of the two communities: the school community being embedded within society and the academic community being more of a 'spectator of society', not an active participant, but an observer.

Flexibility and output were also put forward by the teacher researchers as differences. Within the schools there was a lack of flexibility, because of the lesson schedules, meetings and fixed tasks and roles, whereas the academic community had more space for flexibility in time and planning as well as structure of the work. Differences regarding output pertained to students' diplomas (main output in schools) and articles (main output of academic performance).

We consider the awareness and formulation of these differences to be intrapersonal *identification*. The teachers had different positions and concerns in the different communities. Whether and how such differences were challenging, and evoked other types of intrapersonal boundary crossing is the focus of the following examples.

Since not every difference needs to create a boundary, differences associated with challenges as experienced by the teacher researchers were of particular interest. Because of the focus here on intrapersonal boundary crossing, we focus on challenges teachers experienced and how they dealt with the different positions they had in different communities. Thirteen teacher researchers reported frictions between the two communities of practice, including time pressure, not being able to be present on specific days in school, lack of understanding by school colleagues and schedule problems for data collection on school days. From our analysis two types of challenges emerged, pointing to the efforts teachers had to make to cross boundaries. A first type is having duties in two communities. As a consequence of the obligations in both communities, seven teacher researchers experienced time pressure. One of them said: "Sometimes so many practical issues need attention that I cannot succeed in writing articles. Then, sometimes, I restart at 10 p.m. and continue working until 2 a.m." This challenge points to the need to *coordinate* their positions in different practices. Time has to be distributed between two communities, and tasks aligned.

A second type of challenge is switching of perspectives between communities, illustrated by the following quote: "You constantly have two ways of thinking and reacting in mind: ad hoc, quick response versus in-depth, investigating etc. (…) Cognitive switching, our changing perspectives, is hard." This challenge also points to the need to coordinate their positions as teachers and researchers. The quote illustrates that these teachers had not yet integrated previously distinctive ways of thinking or doing, but were challenged to do so. Intrapersonal transformation had thus not yet taken place for these teachers at the time of being interviewed. However, some teachers described how they changed over time, feeling more and more at ease with their academic researcher positions. They started to consider their school work from an academic perspective, which is an example of intrapersonal reflection. We have anecdotal evidence from the end of the project that a few teachers had transformed to researchers and did not want to work at school anymore but had the desire to be and even became good teacher educators because of their experience with both teaching and educational research. This is a form of intrapersonal transformation into a new hybridized position.

### 4.2. Personal factors facilitating and hindering boundary crossing (RQ2)

Three personal factors contributing to the deployment or inhibition of boundary-crossing activities were found: flexible switching, personality-related qualities, and communication and interaction. The teacher researchers mentioned flexible switching and seeing things from another point of view as most important factors, enabling them to cross boundaries between both communities. Additionally, twelve teacher researchers stated that they operated well in both environments because of their 'personality-related qualities or skills'. The following quote of a teacher researcher illustrates this perception: "I can organize and plan well (…). I am very autonomous. When I do not have the experts needed

**Table 3**
Subthemes regarding differences between the school community and the academic community.

| Subthemes | Description |
|---|---|
| 1. Short-term or long-term perspective | 1. Period of time taken for (main) activities; short-term concerns minutes, hours, up to one week while long-term concerns a duration of weeks or months. |
| 2. Specific focus or broad expertise | 2. Difference between expertise of a specific content area versus a broad range of knowledge varying from a broad content area like 'biology' towards pedagogy and communication with teenagers. |
| 3. Embeddedness in society | 3. The main activities concern society directly, like working.with students every day as a teacher or may be more reflective towards societal issues like studying educational processes while not being involved. |
| 4. Flexibility | 4. Ability to plan activities, sequences and priorities versus working with fixed time-schedules (time and content) like teaching specific subjects. |
| 5. Output | 5. Output refers to the main aims of the work processes, like academic articles or students' diploma's or certificates. |

around me, then I will find a new expert myself. I think it has to do with a person's character whether you can or can't do this." This quote is a clear example of intrapersonal coordination. Communication and interaction skills were mentioned nine times as very important for boundary crossing, because boundary crossing cannot be successfully done by one individual; it requires interaction with others. The teacher researchers specifically mentioned getting along with people, knowing everyone and be known, being easily accessible as a person, having convincing skills, and investing time in coffee breaks and informal trips. The following quote illustrates some one of these aspects of intrapersonal and interpersonal boundary crossing: "Being accessible as a person, honest and communicating openly. Authenticity. Showing enthusiasm and drive and reflecting this to others. Communicative skills in a social way, not necessarily in a strategic way." Interpersonal reflection in terms of coming to value and taking up another's perspective seems to underlie what this teacher researcher pointed to.

According to the teacher researchers, pro-activity as interaction skill was important for being able to successfully cross boundaries from one community to another. Taking notice of opportunities for boundary crossing was mentioned as a chance to come forward and put in extra effort to realize boundary crossing. The next quote illustrates this: "I have the guts to say what people need, according to my point of view (giving input). I take the initiative. I can translate aspects from the one to the other community." Such translation is an example of the coordination mechanism identified in the boundary-crossing literature at the interpersonal level.

### *4.3. Contextual factors facilitating and hindering boundary crossing (RQ3)*

Boundary crossing is not just an individual endeavor at the micro-level; it depends on a successful broker possessing boundary crossing skills and receivers who are willing to listen or get involved, thus interpersonal boundary crossing at the meso-level.

Features of the practices the teacher researchers are involved in probably also play a role. We identified eight factors which were classified as facilitating boundary crossing. These factors relate to the context of the school community, the research community and the home-context (see Table 4).

Team membership was mentioned as a first factor that could help brokering (from bottom up) and gaining cooperation within the school for the research project, or, for example, for replacement when not being able to teach (because of research activities). Ten school principals stated that their teacher researchers still had the same stable position within the school team as before, because they had already been part of the team for quite some years. Some teacher researchers themselves stated that being a respected team member helped them to introduce new materials (boundary objects) and lessons learned from their PhD project.

The second factor found to facilitate boundary crossing was an open school climate with, for example, room for experiments and a policy stimulating teachers' professional development. Schools with an open climate seemed to enable the teacher researchers to work on their PhD research successfully and to transfer results to the school practice. Additionally, the professors stated that cooperation and interest in the PhD project are the most important aspects for a school to be stimulating for teachers conducting PhD research.

A third factor refers to the availability of time for conducting the PhD research and for enabling to bring in lessons learned and materials developed. Also the professors stated that giving time (not tying teacher researchers up to fixed schedules with lessons) was an important condition for successfully conducting PhD research and brokering by teacher researchers.

The fourth factor was mostly mentioned as a hindering factor regarding boundary crossing: absence of research-mindedness in a school team. Most teacher researchers stated that their team was not *research-minded*, except for four teacher researchers. One of the teacher researchers who experienced this absence of research-mindedness in his school stated:

> "My school is doing nothing at all with research. They spend as little time as possible on the professional development of teachers. The (…) hours for each teacher for professional development are not really used. Nothing is done with research data."

The fifth factor regarded 'role changing'. The teacher researchers had to get used to the new community of practice of research. In this community they were seen as starters, while they were seen as experts within their school community. The professors emphasized the importance of the role change from teachers towards teacher researchers, and that this change process should be supported by the supervisor. This points to the need for support to allow for intrapersonal transformation in terms of integrating new ways of thinking and doing into the ways they were used to as teachers.

The professors mentioned two additional factors: (1) work-life circumstances and (2) academic support. Work-life-circumstances referred to sufficient time to spend on PhD research, either afforded by the school or the teachers' home situation. Through a lack of time a PhD project could not be conducted well and boundary crossing activities would not be undertaken at all.

Academic support was reported to be a crucial factor for success in a PhD program for teachers. Effective supervision can help conducting the PhD project successfully, preventing large mistakes and seeing possibilities for brokering. Consequently, time could be used efficiently and there might be time left for brokering activities. A quote of a teacher researcher illustrates that interpersonal reflection (valuing and taking up other perspectives) and brokering can be performed in both directions, from school to university and vice versa:

> "When I talk to my supervisors about my progress and from which backgrounds and experiences I design educational

**Table 4**
Contextual factors facilitating or hindering or boundary crossing activities.

| Contextual factors | Description |
|---|---|
| 1. Membership in the school team | 1. Being seen as member of the school team, who takes responsibility for his or her tasks |
| 2. Open school climate | 2. Culture with much room for experiments, exchange of (ne) ideas and innovation |
| 3. Facilitation in space and time | 3. Getting appointed school tasks which can be planned flexibly (not a fixed scheme) and enough time for conducting research |
| 4. School team's research-mindedness | 4. School team members being open to examine school practice, having a positive attitude towards doing research in schools |
| 5. Support in role changing | 5. Role modeling or coaching of the transition from teacher towards teacher-researcher |
| 6. Work-life circumstances | 6. Demandingness of work-related activities versus demandingness of home-related activities |
| 7. Academic support | 7. Support and coaching regarding the design of and execution of the educational research |
| 8. Relatedness of PhD research to school needs | 8. Extend in which the research theme connects towards needs or priorities of the school mission and team goals |

materials, I introduce the practical component in the discussion (…) Methodological, analytical thinking is what I have learned and what I introduce in my school and that is difficult sometimes. I have learned things in the field of pedagogical content knowledge and education and that is what I take with me to school. I try to bring this into my school in a bottom up way."

The eighth and last factor was additionally brought in by the school principals. They stated that the more the PhD project was aligned to the school needs, the more cooperation, interest and possibilities were visible. This was especially so when materials developed for the PhD project, such as lesson series or professional development activities for teachers, could be used within the school team. These materials could then function as boundary objects, thus fulfil particular needs in different practices.

Personal and contextual factors in-depth: success stories (RQ2 and 3).

Two *success stories* were investigated to study the role brokers can have in schools and academic contexts more in detail. Tables 5 and 6 give a short description of what the two PhD projects aimed at and in which ways the projects were executed. Both PhD projects aligned with the school needs.

The facilitation by contextual factors for boundary crossing were found in both success stories. The two teacher researchers were team players with a visible role in the school team, they both worked in a school with an open school climate and a research-minded school team offering sufficient space and time for the PhD project.

The colleagues stated that the PhD projects and especially the materials developed (instrumental checklists, rubrics, research lessons for students, series of lessons) led to better teaching by teacher researchers and themselves because of the materials developed (boundary objects) and expertise gained. The next quote from one of the colleagues is illustrative for this (*transformation at interpersonal level)*:

"The workshop for students aimed at making a research paper is entirely new. Within our school we worked already on many new initiatives. (…) New terminology like 'validity, reliability, accuracy'. She distinguishes these concepts well for our students. We also saw that in small science experiments, where students were instructed on accuracy etc.. (…) It is important that we, as her colleagues, also want to work with the materials and are open to them. Within the science team that works well."

All twelve students stated that their teacher was a very good teacher, but they were not certain whether this was due to the PhD research or not. This refers to *interpersonal reflection*, valuing someone else's perspective or contribution (with origin in university practice). The following quote of a student is illustrative:

"PhD research is good for our school, because we get teachers with higher qualifications from whom we can benefit. Our teacher teaches us how we can make a report. We could present our paper and received a lot of valuable feedback from our teacher. She is more critical than other teachers and she really wants the best for us. She can substantiate very well why she states something and how we can improve our work."

All students and colleagues mentioned an increase of the teacher researchers' knowledge of students' learning regarding their domain of the PhD research. There seemed actual brokering beyond the teachers themselves. By the boundary objects (educational materials) and inspiring talks, their colleagues could also benefit from the research outcomes and the expertise acquired. One teacher colleague explained this as follows (*reflection*):

"She developed a method for research and design. She did this in her spare time. I can work with this method very well. When you are able to develop something like that, you must be a really good teacher. She can predict in a good way how students might respond to lessons and so on."

Next to the supportive, research-minded school community, in both success stories the personal qualities of the two teacher researchers also played a role in the boundary crossing activities. Both teacher researchers brought knowledge to their schools and talked a lot with their colleagues about materials, their acquired

**Table 5**
Description of the teacher Researcher's project 1.

| Teacher researcher's project 1: Development of a student's curriculum for inquiry |
|---|
| The PhD project of teacher researcher 1 aimed at gaining insights into how students can learn how to investigate multiple science domains in coherence. The emphasis was on evaluation of concepts of accuracy, reliability and validity in different science domains. Educational materials were developed (1) a self-assessment-instrument (memo letter, checklist and rubrics), (2) a series of lessons presented in a book with worksheets and (3) a teacher guideline for using the materials. |
| The researcher explicated the resemblances and differences between evaluating accuracy, reliability and validity in different research contexts for students. In this PhD project the way students and teachers used Concepts of Evidence (CoE) was studied during science research (van der Jagt, Schalk, & van Rens, 2011). In total, three research modules were developed together with other science teachers (colleagues) and tested in two cycles. Investigation of students' learning outcomes showed that students had learned to evaluate the accuracy, reliability and validity of their own research by using the materials developed. Some of these materials are also available in English: http://hdl.handle.net/1871/47924. |

**Table 6**
Description of the teacher Researcher's project 2.

| Teacher researcher's project 2: Design of a model for a professional development program for a multidisciplinary science subject |
|---|
| In 2006 the Dutch government assigned a commission for developing a new subject in the science domain for secondary education: Nature, Life and Technology (NLT). The teacher researcher developed a professional development program for teachers in secondary education who had to work with the new NLT-materials in their classes. This program was based on literature on effective curriculum implementation, features of the NLT-subject and on interviews with teachers (Visser, 2012). |
| The teacher researcher examined the effectiveness of her program for NLT-teachers. This program was conducted in two cycles with the subjects 'brains and learning' and 'a hydrogen car inside out'. Eleven teachers participated in the professionalization program. Also, design principles were formulated for multidisciplinary professionalization programs, teachers' as well as students' outcomes were studied and conditions for using the skills and knowledge learning in the professionalization program were studied. During the PhD project the teacher researcher worked as an NLT-teacher herself and she tested the materials developed for students and the professionalization program in her our classes as well (Visser, Coenders, Terlouw, & Pieters, 2012). |

knowledge, and theoretical backgrounds of their new insights (using their communication and interaction skills). The teacher researchers were viewed as role models for students and colleagues.

Summarizing, in both success stories the personal-related facilitating factors seemed present in both teacher researchers. Also all eight contextual factors facilitating boundary crossing activities (as presented in Table 4) seemed to be present. Finally, both teacher researchers received supportive academic supervision helping them to conduct the PhD project successfully and to change their role towards teacher researchers.

### 4.4. Contribution to teaching (RQ4)

The two success stories revealed ways in which the two teacher researchers were able to contribute towards the teaching practice in their schools. Combining the interview data with an analysis of the products of the PhD projects revealed some more insights into such contributions to the teaching practice, especially on the micro level (see Table 7).

On the micro level, all teacher researchers reported examples of how they improved their own science teaching. All teacher researchers, except two, reported having designed concept-context lessons and/or assessment tools for their students as part of their PhD projects. These products can be considered boundary objects. Scientific reasoning and inquiry-based learning were reported by the teacher researchers as ways in which they improved or changed their science teaching. Deepened or new insights into specific concepts were mentioned by seven teacher researchers as input for their improvement of science teaching.

On the meso level, eight teacher researchers shared insights from the PhD project with others as a part of the PhD project; in most cases, they designed science lessons or professional development programs for other teachers as well. Seven teacher researchers shared insights from the PhD project with their colleagues on their own initiative, outside their PhD project; for example, concerning how to practice scientific reasoning and inquiry-based learning with students. In total, 13 teacher researchers reported examples of contributions to science teaching on the meso level; most of the times this was part of the PhD projects (Appendix A shows for each teacher researcher the contribution to science teaching on micro and meso levels.).

We found one contribution at the macro level: one teacher researcher (from the first *success story*) mentioned that she developed tools, which she tested together with other teachers as part of her PhD project and which she shared with colleagues within her own school as well as in other schools.

## 5. Discussion

Almost all teacher researchers reported challenges of participating in the two communities of practice. The more the PhD projects seemed to be aligned with school's needs or aims, the more boundary crossing activities seemed to be able and the less frictions were experienced. Below we discuss these and other findings in more detail.

### 5.1. Personal and contextual factors facilitating and hindering boundary crossing

Especially (cognitive) flexible switching seemed to be an important personal factor for enabling boundary crossing. Communication and interaction skills were also important factors: teacher researchers who liked to interact with others and to share their lessons learned from their PhD work, seemed to have an advantage regarding boundary crossing as we noticed studying the two teacher researchers studied in the success stories. Regardless of participating in the PhD program, the dispositions of these two teacher researchers might have made them embrace a theoretical perspective and develop shared resources anyway. However, the opportunity to become teacher researchers turned them into successful brokers (Wenger, 2007). The fact that – next to facilitating contextual factors - the deployment of boundary crossing activities seems to depend on specific personal qualities or skills is in line with Walker and Nocon's finding of the 'boundary crossing competence' as "the ability to manage and integrate multiple,

**Table 7**
Contributions from the PhD-projects to science teaching on the micro-level.

| Contributions from PhD-projects | Examples |
|---|---|
| Pedagogical content knowledge, used in concept-context lessons | - Photosynthesis, evolutionary thinking, recontextualisation of cellular respiration<br>- General law of energy conservation<br>- Basic algebraic expertise and symbol sense |
| Content knowledge | - Insights into differential equations<br>- Insights into a coherent cognitive structure (relation between chemistry and biology) |
| Scientific reasoning | - Showing how biological concepts work and scientific reasoning using scientific language<br>- Scientific reasoning by reading scientific articles by students |
| Inquiry-based learning | - Questioning students on concepts<br>- Investigating concepts with students |
| Assessment tools | - Evaluation tools of concepts of accuracy, reliability and validity in science education contexts<br>- Rubrics for research assignments |

divergent discourses and practices across social boundaries" (2007, p. 181).

Regarding the school community, cultural aspects appeared to be important for brokering, such as research-mindedness, interest and cooperation, importance acknowledged of professional development of teachers, facilitation, an open climate and feeling 'at home' within the schools. The focus of the teacher researcher's project made an important difference regarding boundary crossing opportunities: alignment of the subject studied in the PhD project with the school goals seems to work positively for brokering. This is in line with studies in comparable areas; for example, Starkey and Madan (2001) studied the so-called relevance gap in the field of management (research and practice), concluding that alignment of stakeholders was one of the most important factors helping to bridge the research-practice gap. This also seems to be the case in the two success stories: much alignment of the PhD project with the school goals led towards involvement of the school team, support of the school principal and time and space to bring in materials developed for the PhD project.

### 5.2. Contributions towards the practice of science teaching

Contributions of the PhD projects to the improvement of the teaching practice were especially found on the micro level: all teacher researchers improved their (knowledge about their) own teaching by insights gained from their PhD projects, for example, by designing concept-context lessons and/or assessment tools for their students. These lessons and assessment tools often functioned as boundary objects (Bakker & Akkerman, 2014; Wenger, 2007). Also, scientific reasoning and inquiry-based learning were reported by the teacher researchers as ways in which they had improved or changed their science lessons, based on deepened and new insights into science concepts. On the meso level, two activities could be distinguished: (1) sharing insights from the PhD project with other teachers or students as part of the PhD project, and (2) sharing insights from the PhD project with colleagues in the school. Regarding this latter, boundary objects seemed to work as bridges between theory and practice, especially when there was alignment between the PhD theme and the school goals (see also Starkey & Madan, 2001). Only one teacher researcher had been able to contribute towards the improvement of science teaching on a more macro level, meaning outside the own PhD and school context (nationally). This teacher researcher disseminated her educational materials (boundary objects) in other Dutch schools.

### 5.3. Narrowing the research practice-gap by using boundary crossing mechanisms

Most teacher researchers showed some aspects of 'brokering' by crossing boundaries between the two communities of practice, for example, by improving their own teaching and sharing their findings or insights with colleagues. Especially personal factors like cognitive switching, interaction skills, and being able to see things from different perspectives helped the teacher researchers to accommodate and function in both communities more easily. Being able to take perspectives flexibly can be seen as reflection (e.g., Boland & Tenkasi, 1995), one of the key learning mechanisms distinguished in the boundary-crossing literature by Akkerman and Bakker (2011). However, in order to 'make a change' in one or even both communities, more is needed than the ability to cope with two different and demanding communities; successful interaction with others in the community at the right time seems necessary. On the one hand, successful interactions depend on the skills of the teacher researchers, while on the other hand some communities seem to be more open or accessible for brokers than others. As Starkey and Madan (2001) concluded, alignment may play a crucial role in connecting research to practice.

We found that contextual factors played a role in facilitating as well as hindering boundary crossing activities. School teams open to their teacher researcher, offering possibilities for experiments and being interested, created most opportunities for brokering. When the theme of the PhD project aligns with school's needs, the way seems free for all kinds of boundary crossing activities. This might explain why the so-called artifacts, the boundary objects, play a major role in brokering (Bakker & Akkerman, 2014): the introduction of new materials, terminology or methods appear to be effective strategies for brokering (Star & Griesemer, 1989; Star, 2010). When school teams can use 'products' from the PhD projects, boundaries almost seem to disappear.

### 5.4. Implications, limitations and future research

Educational materials as part of the PhD project can stimulate involvement of colleagues and result in usable tools for schools and teaching professionals. A dissertation topic which aligns with school needs seems to make boundary crossing easier. For future PhD programs for teachers such as the one we studied, we recommend to involve school principals or teams when choosing research themes. The more alignment, the smaller the relevance gap will be perceived (Starkey & Madan, 2001).

Understanding how doctoral students negotiate their programs of study helps supervisors to support their PhD students more efficiently and to help them in boundary crossing activities. Departments of Education at universities might also need to reconsider their programs of study for their PhD students in educational research.

It might be argued that design research, as used in both success stories, enables boundary crossing. In design research, researchers make use of design cycles in which, for example, educational materials are developed, tested and improved for practice, mostly together with colleagues (Cobb et al., 2003). When this is done in partnerships between educational researchers and teachers, opportunities for brokering will be plenty and, when intensively cooperating, the gap might even not exist anymore (Starkey & Madan, 2001).

A limitation of our study was the moment of data collection. Data were collected when the teacher researchers had spent at least two years and at most three years of their four-year PhD project. Some of them had only conducted a first study and planned to do more. In future research, data might be collected in the last phase of the PhD project or shortly after completion of the PhD project. More brokering activities might have taken place then.

Our findings can be enriched by observational studies of boundary crossing in practice to gain richer images of the activities involved. We have further focused on success stories, but case studies of less successful teacher researchers may add information about the factors hindering boundary crossing. Finally, longitudinal research may follow teacher researchers after they completed their PhD projects in order to see if and how they continue their career as teacher researchers and continue to contributing to bridging the educational research-practice gap. Such research would provide knowledge about the sustainability of the human capital in which the PhD program invested.

## 6. Conclusion

Teachers conducting educational PhD research can indeed contribute to narrowing the gap by acting as brokers between school-based and university-based communities of practice. Additional clarification for the perceived relevance gap could be found

in different purposes and micro-politics of schools and universities. This cannot be resolved by simply having all teachers become PhD students. However, it might be possible to combine the impact of PhD research, small-scale teacher-based research and the different purposes of schools and universities by establishing partnerships between educational scientists and teachers and alignment of research and school aims (Starkey & Madan, 2001). Such partnerships can offer opportunities for combining findings, learning from one another and bringing theory to practice while conducting research.

Boundary crossing theory appeared to be a useful lens for studying the phenomenon of narrowing the relevance gap. Four main conclusions emerged from our study: (1) narrowing the research-practice gap by teachers conducting PhD projects is possible; (2) specific personal factors (cognitive, flexible switching, communication/interaction skills, pro activity) and contextual factors (open school climate, space for experiments, interest and alignment between research and school aims) are required in order to do so and to become 'brokers'; (3) boundary objects are potential 'match makers' between the two communities; and (4) design-based research is a powerful research strategy to align research and school aims. The relevance gap might even disappear when working in partnerships of academics and teachers.

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## Appendix. Aspects from the individual PhD-projects contributing on the micro level and meso level towards science teaching

| Micro level in own classes and professional development (N = 16) | Meso level in PhD project (n = 8 out of 16) | Meso level knowledge sharing in own school team (n = 6 out of 16) |
|---|---|---|
| - Design of concept-context science lessons<br>- Scientific reasoning | Try-out of professional development program for science teachers (concept-context materials for biology, chemistry, science and Nature, Life and Technology) | |
| - Inquiry-based learning<br>- Scientific reasoning<br>- design of concept-context science lessons<br>- working with rubrics for research assignments | | - Scientific reasoning<br>- Concept-context education<br>- Working with rubrics |
| - Working on differential equations<br>- Scientific reasoning | Try-out of professional development program for science teachers on differential equations | |
| Development of concept-context materials for biology education | Try-out of a professional development program on concept-context biology education | |
| Development of assessment materials for context-based science and mathematics curricula | | |
| - Design of concept-context science lessons<br>- Content development for lessons in NLT | Try-out of a professional development program for content development for NLT lessons | |
| - Inquiry-based learning<br>- Scientific reasoning<br>- Recognition of scientific reasoning by reading scientific articles by students | Try-out of a professional development program regarding scientific reasoning and inquiry-based learning | - Scientific reasoning<br>- Recognition of scientific reasoning by reading scientific articles by students |
| - Concept context lessons in photosynthesis<br>- Inquiry-based learning | | - Supervision of biology in service teachers (research projects)<br>- Concept context lessons photosynthesis<br>- Inquiry-based learning |
| - Design of concept-context lessons for biology<br>- Successful strategies for designing context-based biology lessons | Try out of a professional development program to support biology teachers in the design of context-based lessons | |
| - Scientific (mathematical) reasoning<br>- Inquiry-based learning<br>- Switch problems regarding three different mathematical topics | Try out of prototypes in three schools: use of appropriate switch problems in a collaborative learning setting on mathematical discussion, reasoning and level raising | |
| - Inquiry-based learning<br>- Insights into multiple science domains in coherence<br>- designing tools for evaluation of concepts of accuracy, reliability and validity in different kinds of science education contexts | - Inquiry-based learning<br>- Tools for evaluation of concepts of accuracy, reliability and validity in different kinds of science education contexts<br>- a series of science lessons | Same as meso level in PhD project* |
| - ICT-tools for acquiring, practicing and assessing algebraic expertise<br>- Series of lessons for practicing basic algebraic expertise and symbol sense | | - ICT-tools for acquiring, practicing and assessing algebraic expertise<br>- Series of lessons for practicing basic algebraic expertise and symbol sense |
| - Concept-context teaching, enabling students to experience coherence between the subjects chemistry and biology<br>- Insights into a coherent cognitive structure (relations between chemistry and biology, incl. PCK) | | |
| - Insights into the concept of evolutionary thinking<br>- Design guidelines for concept-context lessons on evolutionary thinking<br>- Series of lessons and one assessment on evolutionary thinking | | - Inquiry-based learning<br>- Investigating effectiveness of lessons |

(*continued*)

| Micro level in own classes and professional development (N = 16) | Meso level in PhD project (n = 8 out of 16) | Meso level knowledge sharing in own school team (n = 6 out of 16) |
|---|---|---|
| - Series of concept-context lessons on recontextualisation of cellular respiration (biology)<br>- Inquiry-based learning- scientific reasoning<br>- Concept-context lessons for students reinventing the general law of energy conservation<br>- Design principles for context-based lessons for the acquisition of concepts | | Meso 'knowledge sharing': scientific reasoning |

* Macro level: this PhD-project also was transferred to other schools outside the context of the PhD-project or school of the teacher researcher.

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