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Providing Professional Development for Physics Teachers through Participation in a Design-Based Research Project

Abstract

In this study, we examine professional development among twelve upper secondary physics teachers who participated in a design-based research (DBR) project. The teachers were involved in developing and testing learning materials in modern physics, and attended workshops and seminars with peers, disciplinary experts, and physics education researchers. Through a qualitative analysis of four focus group interviews, we found that the teachers had experienced professional development (PD) in content knowledge and pedagogical content knowledge (PCK), gained confidence, and discovered a need for more PD regarding assessment of qualitative competence. The teachers talked about content knowledge as the most important knowledge and skills to be a good physics teacher, but also valued knowledge about student thinking

and misconceptions. Content knowledge was mentioned as a prerequisite for PCK. Our results show how involving physics teachers in a DBR-project stimulated professional development in several areas and uncovered needs for continuing PD.

INTRODUCTION

High-quality science education is required to educate and engage a broad range of young people in science to meet the challenges of today and tomorrow. Therefore, calls for strengthened teacher education with a focus on research-informed teaching and continuing professional development (PD) have come from the British Education Research Association (BERA-RSA, 2014) and the US Task Force on Teacher Education in Physics (T-TEP) (Meltzer, Plisch, & Vokos, 2012). TIMSS Advanced 2015 (Grønmo, Hole, & Onstad, 2016) reported that Norwegian physics teachers were highly educated, with 86 % of TIMSS Advanced participants having had a physics teacher with a masters' degree or higher. Most of these teachers held a masters' degree in disciplinary physics. Nevertheless, in spite of the recent calls, only a few of these teachers reported that they had been involved in continuing PD, and if they had, the focus was primarily on content knowledge.

Bearing in mind that '[l]earning about teaching is considered a lifelong endeavour' (Schneider & Plasman, 2011, p. 534) teachers should be able to enhance their professional knowledge and skills through PD programmes involving them in educational research, and through developing school cultures for continued learning and sharing of knowledge and skills. In this article we explore how involving physics teachers in physics education research and development offers an arena for PD aiming to improve physics teaching.

Physics teachers' professional knowledge and skills

While good content knowledge is regarded as one of the main qualities of a good teacher, it does not in itself guarantee that one will become an effective teacher (Kind, 2009). For effective teaching skills that will promote student learning, content knowledge must be transformed in a way that makes it accessible to learners. This requires special knowledge unique to teaching, which is what Shulman (1987) referred to as pedagogical content knowledge (PCK). Although PCK is fundamental to successful teaching, several studies report that different stakeholders and science teachers regarded content knowledge, rather than PCK, as the most important knowledge for teaching (de Winter & Airey, 2019; Frågât, Henriksen, & Tellefsen, 2021; Rozenszajn & Yarden, 2014). However, as pointed out by Bucat (2005, p. 2) '*[t]here is a vast difference between knowing about a topic (content knowledge), and knowing about the teaching and learning of that topic (pedagogical content knowledge)*'. Further, Airey and Larsson (2018) suggested that some pre-service teachers from disciplines like physics with hierarchical knowledge structures might struggle to accept disciplines with other types of knowledge structures, such as pedagogy.

Content knowledge and transmission teaching styles have a strong hold in education. In their review of science teachers' PCK, Schneider and Plasman (2011) reported that many teachers regarded the nature of learning science as a process of receiving correct information of the material from lectures and note taking. The exception was when teachers '*participated in professional development such as curriculum reform or working with preservice education*' (p. 545). In those cases, the teachers' ideas of learning were shifted toward constructivist views of learning. Furthermore, Duit, Schecker, Höttecke, and Niedderer (2014) showed that many teachers are not well-informed about research on teaching and learning, and their dominating views on teaching practices tend to be topic centred, employing transmissive teaching in a teacher-centred classroom, hereafter referred to as traditional physics teaching (Bøe, Henriksen, & Angell, 2018). The teachers' focus on content knowledge as the core of teaching could be a challenge if teachers find continuing PD to be equivalent to gaining content knowledge. Grangeat (2015) suggested that PD involves teacher reflection about professional activities in order to act effectively. Therefore, for developing and implementing a PD programme that will support continuing PD, it is necessary that the participating teachers reflect on what they themselves conceptualise as important knowledge and skills to become a good teacher.

Professional development for in-service physics teachers

In a review study, Kagan (1992) investigated the professional development of teachers leading to a model for professional growth. She accentuated that a lot of literature has found teachers' professional knowledge to be built on '*informal, contextual, highly personal theories from their own experiences*' (p. 163) rather than on formal theories.

Several scholars have pointed out that teachers need to continually develop their skills and knowledge – both content and pedagogical – through PD programmes (Buabeng, Conner, & Winter, 2018). There is a substantial body of research focusing on continuing PD programmes, and many studies offer teachers' perspectives of PD and their consequences for teaching and learning in the sciences. In a review of 25 high quality PD programmes for science and mathematics teachers across the USA, Blank, de las Alas, and Smith (2007) found that 22 of the programmes focused on content knowledge, but that the majority of the programmes also provided important PCK. In a study among science teachers with different levels of experience, Grangeat (2015) found that experienced teachers who were unable to participate in PD programmes on inquiry-based teaching did not report using any PCK when planning a science lesson, and they demonstrated a professional knowledge that was content- and teacher-centred as opposed to first-year teachers who were involved in a continuing PD programme run by teacher educators. Buabeng et al. (2018) found that physics teachers in New Zealand reported the need for PD in several areas, in particular for understanding student thinking in physics and for deeper content knowledge.

Eylon and Bagno (2006) conducted an inquiry into practices for increasing awareness of the importance of knowledge gained through physics education research (PER), and reported on a PD model that attempted to respond to these needs. The model included a programme focused on building a community of practice among physics teachers, where teachers developed lessons dealing with a topic identified by PER as problematic, using PER-based instructional strategies and carrying out assessments. The results suggested that '*teachers realized that even in the standard topics of high school physics there is more to learn both about content and about pedagogical content knowledge*' (Eylon & Bagno, 2006, p. 11).

The Action Research for Physics (ARP) programme in the UK trained teachers to use action research to increase student interest in physics. The programme provided physics teachers with research-informed guidance, while allowing them to develop their own action research intervention within their classrooms, resulting in increased teacher self-efficacy and confidence in engaging students in physics (Grace, Rietdijk, Garrett, & Griffiths, 2015). Furthermore, the participating teachers reported that they had adopted new teaching strategies and increased their motivation towards teaching physics. Similarly, Etkina (2010) argued that development of PCK is best achieved when teachers are actively constructing their knowledge base. Borko (2004) investigated the importance of PD programmes for improving teaching and learning in schools. Advocating for a situated perspective where the contexts and activities play a fundamental role, she offered several paths for the future direction of PD design and research. Among other ideas, Borko suggested that '*design experiments, with their repeated cycles of design, enactment, analysis, and redesign, can be particularly useful for such investigations*' (p. 12). Moreover, results from the Teaching and Learning International Survey (TALIS) (OECD, 2014) highlighted the importance of collaborative professional learning for teachers by, for example, joining '*already established collaborative research groups*' (p. 13).

van Driel, Meirink, van Veen, and Zwart (2012) conducted a substantial review of PD in science education. They emphasised six core features of an effective PD programme: 1) focus, specifically on student learning based on current research; 2) active, inquiry-based learning; 3) collaborative learning, among teachers and outside experts; 4) duration and sustainability; 5) coherence, in goals and design; and 6) school organisational conditions, including resources, facilities, and support from school leaders. The authors remarked that, unlike the other core features, the last item was missing from most PD programmes, suggesting that PD programmes did not take the daily reality of schools into

account. The majority of research on teacher PD has focused on changes in teachers' cognition as a result of the programme, whereas a few studies examined changes in classroom behaviour caused by the intervention (Fischer, Borowski, & Tepner, 2012; van Driel et al., 2012).

The ReleQuant Competence project and the role of teacher professional development

The present article reports on the ReleQuant Competence project, which studied the development of knowledge, skills and attitudes among participants in the broader project, ReleQuant (see Henriksen et al., 2014). In ReleQuant, teachers, physics experts, and physics education researchers collaborated in developing web-based learning resources for general relativity and quantum physics for final-year upper secondary physics that emphasise conceptual understanding, history and philosophy of physics, the nature of science, collaborative learning, and student motivation. Because of the complex mathematics of modern physics, only a qualitative approach is used at this level. The learning resources invite learners to develop their understanding through a sociocultural approach in interaction with others using language (Vygotsky, 1978).

The literature suggests that teaching modern physics in upper secondary school presents notable challenges for many physics teachers due to the abstract and counterintuitive nature of the topics (Bouchée, de Putter - Smits, Thurlings, & Pepin, 2021), the lack of well-established teaching strategies, and teachers' lack of training within quantum physics and general relativity (Bungum, Henriksen, Angell, Tellefsen, & Bøe, 2015). Therefore, it was important that the ReleQuant project would create an arena for continuing PD by joining our DBR project involving collaborating disciplinary expert, education researchers, and fellow teachers as suggested by TALIS (OECD, 2014).

The project employed a design-based research (DBR) framework based on the principles and features suggested by Juuti and Lavonen (2006). Versions of the learning resources have been tried out and revised in several cycles. Beyond carrying out the trials of the learning resources in their own upper secondary physics classrooms, participating teachers contributed to the development of the resources and attended workshops and seminars together with physics education researchers and disciplinary experts in both quantum physics and general relativity. Here, topics in quantum physics and general relativity were presented by disciplinary experts, while physics education researchers presented topics such as student understanding and learning of modern physics, typical misconceptions, and conceptual teaching and assessment strategies. Preliminary results from the classroom trials were presented by the researchers and the teachers presented their experiences. Presentations led to extensive discussions and were followed up with workshops discussing how to best incorporate these results into the learning material for increased student learning. The teachers' voices were considered equally important to the researchers' voices, and these workshops gave valuable input for development of the learning resources and development of the teacher guide that was released with the second classroom trial. During the workshops and in focus group interviews, the teachers were given an opportunity to reflect on their own practice, knowledge, and skills (Juuti & Lavonen, 2006). Thus, they were able to identify in which areas they needed continuing PD. This kind of knowledge is important to elicit for developing effective PD programmes.

Theoretical and analytical framework for teacher professional knowledge and skills

Shulman (1987) conceptualised teacher knowledge into seven different knowledge bases, where three types of interconnected knowledge are of special interest for this study: content knowledge, pedagogical knowledge, and PCK. Content knowledge is knowledge of the subject matter and is similar to the knowledge of a disciplinary expert. Pedagogical knowledge refers to general pedagogical knowledge and comprises for example classroom management (see for example Grangeat, 2015). PCK was originally defined by Shulman (1987, p. 15) as:

[...] the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students.

How PCK has been interpreted and used through the years has led to a diversity of PCK models (e.g.: Fischer et al., 2012). In this study, we draw to some extent on the Refined Consensus Model of PCK as presented in Carlson et al. (2019). In this model, PCK is placed in the centre surrounded by the broader knowledge bases *content knowledge*, *pedagogical knowledge*, *curricular knowledge*, *knowledge of students*, and *assessment knowledge*. There is a two-way exchange of knowledge, filtered and amplified by the teacher's beliefs and attitudes, between the broader knowledge bases and PCK. At the heart of the model, we find the pedagogical reasoning cycle of instruction which is about planning of teaching, actual teaching, and reflection after teaching. Furthermore, we operationalise PCK into five components based on Rollnick and Mavhunga (2017): *Representations*, *students' previous knowledge and misconceptions*, *thematic challenges*, *curricular saliency*, and *conceptual teaching strategies*. These components are used as codes for PCK, see Table 1.

All the knowledge bases of the Refined Consensus Model incorporate skills and the model, therefore, also takes the act of teaching into account (Carlson et al., 2019).

Research questions

The present study explores how including teachers in a DBR project can support their continuing PD in areas crucial for improving physics education. We ask:

RQ1: What characterises the teachers' view on which areas of professional knowledge and skills are necessary for what they perceive as good physics teaching?

RQ2: Which aspects of their professional knowledge and skills do the teachers express as having been developed within the project?

RQ3: Which needs for continuing professional development do the teachers express as having emerged within the project?

METHODS

Participants and data collection

Twelve physics teachers from four upper secondary schools participated in the ReleQuant project and in four focus group interviews. Ten of these teachers were identified as experienced physics teachers with at least four years' experience of teaching final-year upper secondary physics. Semi-structured focus group interviews were carried out at four different stages of the project (Figure 1). Before the second classroom trial, the teachers got access to a teacher guide with focus on subject matter and how to use language to promote student learning. The third classroom trial used a close-to-final version of the learning resources. The interview guides were developed by the authors and focused on experiences with teaching modern physics, views on professional knowledge and skills, and needs for teaching support.

Only one teacher participated in all four focus group interviews; the other teachers participated in years when they taught the physics course in question. Some teachers also entered the project after it was underway. The focus group interviews lasted between 30 and 90 minutes. The 2013 and 2015 interviews were conducted by the second author, those in 2016 and 2017 by the first author.

Figure 1 Project timeline indicating the trials and focus group interviews.

Data analysis

All the interviews were audio recorded and transcribed, and thereafter analysed using Atlas.ti software. Each teacher was assigned a unique identifier through all interviews: Teacher 1, Teacher 2, etc. Only the first author coded all the interviews. The interpretations of codes, identification of themes and how the actual coding was carried out were discussed and validated by the two other authors to strengthen trustworthiness.

The data were analysed thematically, following Braun and Clarke (2006). Some codes were based on the Refined Consensus Model of PCK (Carlson et al., 2019) and Rollnick and Mavhunga (2017), and others were similar to or guided by those used by Frågåt et al. (2021). Additional codes were derived inductively (Braun & Clarke, 2006). We identified five main themes, four of which were relevant for the research questions. The research questions together with their relevant themes and corresponding codes are listed in Table 1. Segments of the transcribed interviews were sometimes coded with co-occurring codes.

Table 1: Codes used and their corresponding themes.

Research Questions	Theme	Sub-theme	Codes
RQ1, RQ2, and RQ3	Knowledge and skills	Content knowledge	Content Knowledge
		Pedagogical knowledge	Pedagogical knowledge, Discipline and classroom management, Knowledge of assessment, Curricular knowledge, Knowledge of students
		PCK	Representations; Students' previous knowledge and misconceptions; Thematic challenges; Curricular saliency; Conceptual teaching strategies
RQ2 and RQ3	Professional development		Gain as project participant, Professional development, Need for teaching aid for professional development
	Classroom teaching practice		Teaching practice, New teaching practice, Traditional teaching, Variation
	Focus on final exam		Exam, Not important for exam

RESULTS

The following presents our findings in the order of the research questions and illustrates them with excerpts from the interviews. All excerpts are translated from Norwegian to English by the authors. To facilitate readability, we have removed repetitions and false starts.

Teachers' reflections on which areas of professional knowledge and skills are necessary for good physics teaching

In the 2016 and 2017 interviews, the teachers were asked what they needed to know in order to be a good physics teacher. The question used a Norwegian verb which incorporates having both knowledge and skills. In both interviews the participants pointed to the importance of content knowledge:

Teacher 2: In addition to mathematics and, of course, content knowledge.

Teacher 4: Content knowledge is absolutely important.

Further, the teachers talked about knowledge that was coded as PCK, such as students' previous knowledge and misconceptions. Here, Teacher 2 appears to regard content knowledge as a prerequisite for PCK:

Teacher 2: So, I think it's very important to know what the students know: where they are [with respect to content knowledge]; what prerequisites they have; what kind of system of concepts they have.

Interviewer: M-hm [murmurs of consent].

Teacher 2: And, if you're doing that, you have to know your subject.

Pedagogical knowledge was mentioned only once as a direct response to the same question, when the teachers talked about creating a good classroom environment:

Teacher 1: M-hm. You have to know the subject, and then you have to make sure there is a safe environment in the classroom so that the students dare show what they also don't know.

Teacher 2: Feeling of safety, yes.

Several teachers at once: M-hm.

The lack of mentions of the importance of pedagogical knowledge was remarkable, and the impression that teachers did not value this kind of knowledge was strengthened by several statements explicitly denouncing general pedagogy:

Teacher 2: Understanding of how learning of physics happens, understanding the thing about everyday conceptions and, yes.

Teacher 1: And a very positive contrast to what is encapsulated by the collective term pedagogy...

Teacher 2: Yes.

Teacher 1: ... which makes me feel sick.

Although this excerpt demonstrates that the teachers valued PCK, there seemed to be an agreement among several of the teachers that general pedagogy was something only researchers in pedagogy were working on which was not useful for what happens in the physics classroom.

To summarise the findings related to RQ1, the physics teachers expressed that content knowledge was the most important part of teacher professional knowledge. Also important was PCK, especially in relation to student misconceptions and how students learn physics. In addition, content knowledge was mentioned as a prerequisite for PCK. What seemed remarkable was the expressed negative attitude to general pedagogical knowledge.

Teachers' reflection on their professional development during project participation

The interviews suggest that PD had occurred among teachers throughout the project. Moreover, while the teachers in the first three interviews expressed a need for support to be able to use the ReleQuant material as intended, this need was not mentioned in the last interview.

The theme Professional development most often co-occurred with the PCK, Content knowledge, and Classroom teaching practice themes. In the following excerpt, Teacher 2 talked about development in PCK, such as increased understanding of student thinking:

Teacher 2: Yes, and I believe that [...] when it comes to students' understanding, when you're [as a teacher] going to school – as I feel I've been doing in this project – then you get a better idea of what the students are struggling with, because it's so new and hard for us, and then, in a way, we get an idea about how they are thinking. And, yes, I've realized during the last years how little they actually know, or [...] that you actually have to get down to their level, and yes, handle it there.

Teacher 1 talked about his motivation for participating in the project:

Teacher 1: What I think is motivation for me, is that I also learn about what the students actually learn – because you will never have a 100 per cent control over [...] but by learning about the students' learning, I can change my teaching.

Interviewer: That's exciting.

Teacher 1: Yes, it's very exciting and you try to do it all the time, but...

Excerpts in which teachers talked explicitly about what they gained from participating in the project, were coded with the Gain as project participant code. Excerpts coded with this code tended to co-occur with New teaching practice, Conceptual teaching strategies, and Representations, the latter two being part of PCK.

The teachers expressed that they seldom found time for PD in their everyday work, and they also mentioned other factors that prevented them from updating their professional knowledge. Teacher 1 talked about a lack of access to research literature:

Teacher 1: Twice every year I propose that our school [...] should get access to the electronic library system so that we can read [research] papers, but nothing happens.

[Discussion about economic considerations]

Teacher 1: I'm thinking about, for example, 'Physics Teacher', only to mention one journal that is extremely relevant to us.

During the discussion, it became clear that access to relevant research literature was not prioritised by school boards and that being part of a DBR project like ReleQuant helped fill that void. The project participants also discussed being able to pass their experiences on to colleagues in their schools:

Teacher 2: But now the language teachers [in our school] have taken an interest in ReleQuant. [...] So they became very interested in doing something together. [...] They were interested to see if there's something we do in ReleQuant that they can do in language subjects [...].

In both the 2016 and 2017 interviews, the teachers were asked to describe a typical physics lesson in their classrooms. Predominantly they described traditional approaches. For example, Teacher 3 described a typical lesson as introducing some new topics, perhaps enhanced with some demonstrations, and then students solving problems with calculations while the teacher walked around in the classroom and talked to the students.

According to the teachers, being a project participant gave them new insights into teaching strategies. Teacher 4 suggested that he was no longer sure about what constitutes an ordinary lesson after using the ReleQuant learning material. He expressed that working with the material made him consider adding more discussions into his lessons in topics other than modern physics and opening up for a sociocultural approach, an idea that was supported by the other teachers:

Teacher 4: I feel now, sitting here talking about ReleQuant, that there is possibly too little discussion in my lessons...

Teacher 2: M-hm.

Teacher 10: Yes.

Teacher 4: ... like – now, ReleQuant is of course well suited for that. Maybe it is not that easy to discuss Newton's laws and the like, I have been thinking, but maybe they could've gotten more room for discussion topics then, yes.

Not only did the teachers report increased professional knowledge regarding teaching strategies and PCK, they also described much needed gains in content knowledge. Teacher 2 followed up by claiming the following:

I spend more time on [teaching the subject] because I've gained more [content] knowledge.

The teachers agreed that the seminars were important, especially when experts gave presentations on physics content. Also, the teachers spoke of gaining new teaching approaches at these seminars. In addition, collaborating with other teachers and researchers in physics education and with disciplinary experts was regarded as valuable and as promoting self-confidence:

Teacher 1: I think [the researchers] has done a good job including us teachers.

Several teachers: M-hm.

Teacher 2: And [...] that we are equals, right ...

[The discussion continues emphasising the above]

Teacher 10: Nice meeting other physics teachers too.

[...]

Teacher 10: That are having the same problems, I mean, or challenges.

Several teachers: M-hm.

Teacher 10: That you don't feel that you're sitting alone not knowing what light is and that everybody else knows. [Laughter]

To summarise the findings related to RQ2, the physics teachers reported that they had gained new professional knowledge and skills in several areas, most prominently enhanced PCK and content knowledge in addition to becoming more confident as teachers. The seminars with other teachers, disciplinary experts, and educational researchers were emphasised as important arenas for PD, making it possible to try new teaching strategies, such as a more sociocultural approach, where they would usually have chosen a traditional approach.

New needs for professional development

The interviews suggested that participating in the ReleQuant project made teachers more aware of their needs for continuing PD. Teacher 2 uttered that

[...] being part of the ReleQuant [project] has just [...] underpinned that need [for developing yourself] and- or given me an eye-opener to realise it's smart to keep up to date.

In our analysis, we found that the most prominent areas in which teachers expressed the need for continuing PD were related to students' previous knowledge and common misconceptions, thematic challenges, conceptual teaching strategies, knowledge of assessment, and content knowledge. The first three of these fall within PCK. Teachers' responses regarding common misconceptions were often followed by a request for conceptual teaching strategies to resolve those misconceptions accompanied with correct answers to point them in the right direction, as shown in the 2015 interview:

Teacher 3: If [the project researchers] try to extract something from all the student responses you have: misconceptions students have, the most common, recurring misunderstandings. Give examples of the students' responses that are misunderstandings, and then you write what you as teachers would have corrected, and give the right answers.

In particular, the teachers found it difficult to do formative assessment of written and oral tasks, which are prominent in the ReleQuant material. One stated reason was that it was both time-consuming and difficult to assess such answers:

Teacher 3: Yes, I tried going in and looking at the students' responses and then comment, but I found out that it was too difficult for me and took way too much time ...

In the same interview, teachers expressed that spending time on assessing student answers in modern physics was not their first priority since they believed the topic to have limited relevance for the final exam:

Teacher 12: ... but I think [feedback] is important. But I think it is very demanding for, I mean – since there is so little of this on the exam.

The teachers expressed that the final exam guided their chosen teaching strategies and content. Furthermore, they found previous exams to offer more guidance than the curriculum, and saw qualitative competence aims as less relevant because they were less likely to be represented in the exam:

Teacher 2: The thing is that those topics on the exam, the things they ask for in the exam, are such a small part compared to the time we spend on it [using the ReleQuant material]. I do think it is very nice to be part of [the project] and it has definitely done something with... lets me reflect about being a teacher too, but I get a pit in my stomach when looking at the exam questions. And what they actually ask. So ...

Teacher 1 expressed in another interview that as a teacher

you have a mandate to make sure that the students perform as best as they can [at the exam]. [...] because they have their future too that you have to aim at.

To summarise the findings related to RQ3, the physics teachers expressed needs for continuing PD in several areas. The most prominent need was for knowledge to assess qualitative competence aims. Further, they reported that they needed more knowledge regarding student misconceptions, thematic challenges, as well as conceptual teaching strategies to resolve the first two of these. Time constraints and the power of the final exam to dictate the teaching were mentioned as limiting.

DISCUSSION

In this study, we have explored how physics teachers expressed their views on professional knowledge and skills, including how their knowledge and skills developed and how new needs for PD emerged through participating in a DBR project. The ReleQuant project gave the participating teachers an are-

na for acquiring new professional knowledge through developing learning materials in collaboration with educational researchers and testing different teaching strategies in classrooms. The development and testing were followed up with reflections and discussions with peers, disciplinary experts, and researchers.

Teachers' reflections on which areas of professional knowledge and skills are necessary for good physics teaching

PD involves teacher reflection about professional activities in order to act effectively (Grangeat, 2015). Therefore, knowing teachers' conceptions of what knowledge and skills are necessary is essential when developing PD programmes. The teachers participating in our study suggested that content knowledge was most important for being a good physics teacher, as found in other studies (de Winter & Airey, 2019; Frågåt et al., 2021). As the teachers recognised during the project, content knowledge is regarded as a prerequisite for developing PCK (Kind, 2009) and is therefore a requirement for effective PD. However, if teachers only participate in programmes that focus on content knowledge, this can undermine that awareness of other knowledge and skills is needed to provide good and effective teaching (see for example Bucat, 2005). During the project, the teachers experienced increased awareness of the importance of knowledge about student misconceptions and about how students learn physics.

Although there were valuable discussions and reflections on teaching and the need for PCK, the teachers found general pedagogy to be irrelevant except when it came to creating a safe learning environment. Negative associations towards general pedagogy could be caused by the failure of teacher education to deliver a programme that appears adequate for teaching (Kagan, 1992), or it could be that pedagogical knowledge is regarded as unproblematic and something that simply emerges by itself if the teacher has good content knowledge (Frågåt et al., 2021; Larsson, Airey, & Lundqvist, 2017). Airey and Larsson (2018) suggested that pre-service teachers 'who are steeped in the epistemological commitments of a coherent, hierarchical, positivist, physics knowledge structure may experience the contingent nature of educational science as disjointed, incoherent and unscientific'. This point coincides with our findings. Further, our results corroborate Kagan (1992), who claimed that even experienced teachers based their knowledge on personal theories rather than formal ones and, therefore, regarded general pedagogy as irrelevant. Physics teachers in New Zealand reported a negative attitude towards centralised government-funded PD programmes; these were regarded as largely ineffective and less relevant for their teaching (Buabeng et al., 2018). This was explained by the fact that these PD programmes mostly focused on assessment, and that teachers consequently were dissatisfied by the lack of opportunities for PD in terms of understanding student thinking and deepening their own content knowledge.

Teachers' reflection on their professional development during project participation

We found that the participating teachers were not only equipped with new educational tools including sociocultural approaches, they also reflected more on their professional knowledge and on how to advance their teaching. Being part of a DBR project was seen as beneficial for equipping the teachers with a learning environment grounded in research and mutual development among researchers and teachers, and for continuing PD. Below, we analyse the teachers' experiences of PD in light of the six core features of an effective PD programme presented in the Introduction (van Driel et al., 2012):

1) *Focus on classroom practice.* Being part of a DBR project ensured a focus on classroom practice with support from researchers. As a result, the teachers experienced more confidence in teaching abstract topics and using new teaching strategies. Similar effects were found by Grace et al. (2015). The ReleQuant project facilitated important factors for PD such as situated learning (Borko, 2004) and active construction of knowledge (for example Etkina, 2010). The teachers were, in several iterations and with support from researchers, able to plan, teach, and reflect, which is the pedagogical reasoning cycle at the core of the Refined Consensus Model of PCK (Carlson et al., 2019).

2) *Active and inquiry-based learning.* The teachers took active part through workshops and seminars. They reported that they had gained understanding of how their students learn and about com-

mon misconceptions, suggesting that the teachers acknowledged the importance of thinking about their learners before focusing on their teaching (Schneider & Plasman, 2011). It has been argued that allowing teachers to be active participants, involved in designing lessons and learning resources based on research findings and experience, enhances learning outcomes (Eylon & Bagno, 2006; Grace et al., 2015). In our project, researchers observed the teachers' lessons and studied student learning (for example Bøe et al., 2018). Results from the research were presented at seminars and discussed with the teachers. Teachers reported increased acknowledgement of the importance of understanding student thinking when learning challenging physics concepts, similar to what was found by Grace et al. (2015).

3) *Collaborative learning*. The teachers appreciated collaborative learning and emphasised the value of discussing teaching challenges with researchers and colleagues. Some of the teachers even worked at the same school, making it possible to continue the exchange of ideas beyond project seminars and workshops. The importance of collaboration with other teachers, experts, and researchers has been noted by OECD (2014). The teachers also appreciated that their voices were considered equally important to the researchers'. They expressed that it was valuable to establish a level of trust among the participants to foster a critical dialogue about teaching and to uncover deficiencies in knowledge. This has been determined to be important for PD by Borko (2004) and Eylon and Bagno (2006).

4) *Duration and sustainability*. We found a positive relationship between the degree of continuing PD that teachers had experienced and the duration of the project. For example, being part of the project for several iterations allowed teachers to gain experience and confidence with new teaching strategies. During the school-years in which they taught the physics course in question, they were in regular contact with the researchers and the other participants, meeting several times in seminars and classroom trial observations. Each school year of the project period started with a start-up-seminar and ended with a debriefing-seminar where preliminary results were presented and discussed, meeting the core feature of duration and sustainability.

5) *Coherence*. The teachers found the teaching materials to not be fully coherent with what is usually tested in the national examinations, and expressed that they would devote less teaching time to the materials after the project had ended, arguing that their primary obligation was to prepare their students for the examinations. Therefore, for this type of PD to maximise its potential, it is important that new learning strategies and goals are coherent not only with the curriculum, but with examinations.

6) *School organisational conditions*. Grace et al. (2015) found that senior managers, who could address potential constraints for teachers to participate in PD programmes, were a criterion of school success. There can be several reasons for why most of the teachers could not participate for the entire project period, but it could indicate a lack of recognition of the importance of long-term participation to foster teacher PD.

As also found by Blank et al. (2007), the teachers in this study raised concerns about whether they would have time to fully implement their new learning gained from PD programmes. As long as qualitative conceptual understanding in modern physics was less relevant for exams, the teachers could not justify spending time on a sociocultural approach in modern physics. However, they would consider trying a similar approach when teaching classical physics.

New needs for professional knowledge and skills

The teachers in our study expressed a sense that participation in the project brought to the fore and even created the need for continuing PD. The importance of knowing what could suppress student learning and how to resolve misconceptions were strengthened during the project and expressed as an on-going need for continuing PD. Eylon and Bagno (2006) found that teachers were surprised by their lack of knowledge of both subject matter and PCK. Similarly, we found that our participating teachers reported less than expected understanding of the topics that they were supposed to teach in modern physics. As project participants, the teachers often felt like learners that were given a chance to learn what is difficult and to experience typical misconceptions that their students experienced.

As a consequence of participating in the project, the teachers experienced a need for more knowledge related to the teaching approach in the resources. Notably, they wanted more knowledge about how

to assess qualitative student answers which had not been considered necessary prior to the project participation. Like the physics students who participated in the project (Bøe et al., 2018), the physics teachers wanted listed solutions accompanying the learning resources to help with formative assessment. However, it seems like knowledge of assessment is weakly linked to PCK. The challenges of assessing qualitative student answers were directly linked to the topic taught; therefore, we believe it would be necessary to add this item to PCK in future revisions of the models of PCK.

Among the challenges experienced by the teachers in their everyday work were that they did not find time for PD and did not have access to research literature. This is in line with other research showing *'that many teachers are not well informed about research findings on teaching and learning'* (Duit et al., 2014, p. 450), and underscores the need to make educational research accessible in order to strengthen teachers' opportunities for continuing PD.

The answer to the calls for continuing PD and increased focus on research-informed teaching (BERA-RSA, 2014; Meltzer et al., 2012) could be manifold. One approach could be to involve physics teachers in research and development projects. A particular goal of doing a project like ReleQuant was to introduce a repertoire of new teaching strategies that could be used in topics other than modern physics and therefore challenge the current teaching culture of physics. Höttecke and Silva (2011) found external demands and structures such as examinations to be challenges teachers meet when implementing new ways of teaching physics. In our study, we found that teachers felt conflicted between spending time on the curriculum and ReleQuant learning materials and the prospect of preparing their students for the national examination, where qualitative competence aims are under-represented (Lange, 2016). Furthermore, the teachers expressed feeling anxious about losing control of the students' learning when using a student-centred sociocultural approach, as seen by Schneider and Plasman (2011) in the case of students conducting inquiry. We argue that both the need for knowledge in qualitative assessment and for keeping control of the learning activity were created by the project's introduction of new approaches to physics teaching.

Limitations

The results are closely linked to one particular project involving a limited number of teachers which makes it hard to generalise. However, we believe the results will contribute to the field of research in physics education, when placed in a broader context with other research results, and help guide similar PD programmes in the future.

The first author, who conducted the two last interviews, has been working as a physics teacher in upper secondary school and also served as one of the participating teachers in the 2013 interview. Therefore, the two other authors have carefully crosschecked the analysis in order to strengthen the trustworthiness of the results.

CONCLUSION

We have explored the professional development of teachers participating in a DBR project in modern physics. Teachers expressed that they had increased their content knowledge and PCK, and gained awareness of the need for developing their professional knowledge further, in particular concerning student thinking, misconceptions and assessment. Collaborating with other teachers and researchers promoted improved professional knowledge and self-confidence, and the participation provided much wanted access to educational research. By using a DBR approach, we found that the gap between practice and educational research was narrowed as suggested by Juuti and Lavonen (2006).

The study contributes to research on teachers' ideas about components of PCK (Schneider & Plasman, 2011) and the less researched field of the relationship between PD programmes' intervention and changes in teachers' classroom behaviour (Fischer et al., 2012; van Driel et al., 2012). The results provide new insights into possible ways for physics teachers to develop their professional knowledge,

in particular as part of a DBR project. Our study suggests that DBR projects contribute to improving physics education not only by developing learning resources and teaching strategies, but also by providing a fruitful arena for teachers' continuing professional development.

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