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Pre-service science teachers' and in-service physics teachers' views on the knowledge and skills of a good teacher

Abstract

Science teacher knowledge and skills have been thoroughly discussed by researchers; however, less is known about how teachers themselves conceptualise their professional qualities. We asked first and final-year pre-service science teachers and in-service physics teachers to describe the knowledge and skills needed to be a good science/physics teacher. Data was collected through a one-item questionnaire, followed by interviews. Using thematic coding with inductively defined codes as well as codes derived from theoretical perspectives on teacher knowledge and skills (notably the Refined Consensus Model of PCK), we found that all respondent groups emphasised science content knowledge as important. In-service

teachers also often described external factors such as working conditions. First-year pre-service teachers put more emphasis on pedagogical skills and personality traits, whereas final-year pre-service teachers expressed a more integrated view of science teacher knowledge and skills. Further, we discuss the need for teacher education to focus on integrating science content knowledge and pedagogical knowledge through articulating aspects of PCK, and on giving pre- and in-service teachers arenas for professional development and for research-based discussions of teaching and learning.

INTRODUCTION AND BACKGROUND

In this article, we explore how pre-service science teachers and in-service physics teachers describe and reflect on the qualities of a good science or physics teacher. Based on the results, we discuss how essential skills and knowledge can be developed through science teacher education.

New professional expectations of science teachers

During the last few decades, research on science teaching and learning has led to changes in the view of what constitutes quality science education. Calls for improvement highlight varied, student-active and inclusive teaching and learning practices, more attention to science processes and the nature of science, incorporation of computing and learning technologies, and more (see e.g. Bøe & Henriksen, 2013; Meltzer, Plisch, & Vokos, 2012; Meltzer & Thornton, 2012). Implementing such changes implies changes in the skills required of science teachers (National Academies of Sciences, Engineering, and Medicine 2015).

Science teachers and their students are parts of a pronounced disciplinary culture which students tend to describe in terms of transmissive pedagogy, de-contextualised content, an overloaded curriculum, and unnecessary difficulty compared with other subjects (DeWitt, Archer, & Moote, 2018; Duit, Schecker, Höttecke, & Niedderer, 2014; Lyons, 2006; Osborne & Collins, 2001). Further, the traditional physics student has been described as largely embracing traditional teaching approaches focused on factual content knowledge, teacher-led instruction, individual problem solving, correct answers, and traditional assessment practices (Bøe, Henriksen, & Angell, 2018; Huibregtse, Korthagen, & Wubbels, 1994).

Windschitl (2009) remarked that many pre-service teachers have the idea that learning is acquired ‘*from listening, reading, and memorization*’ (p. 9). Huibregtse et al. (1994) noted that in-service teachers tend to favour the teaching approaches they themselves prefer as learners. Making this disciplinary culture more varied and inclusive, targeting students with a broader range of interests (Bøe & Henriksen, 2013), is an important challenge involving present and future teachers of physics and related subjects.

In Norway, ongoing educational reforms also entail new expectations of science teachers. New curricula for all school subjects are being implemented during the period 2020-22, with a stronger focus on deeper learning, inquiry-based learning, programming and modelling (Ministry of Education and Research, 2015). This creates a need for professional development for teachers.

In addition to these requirements for change in science and physics instruction, teachers also face other demands on developing their role and knowledge and skills. The British Education Research Association (BERA-RSA, 2014) suggested ‘research literacy’, understood as a capacity to engage with and in (educational) research, as one of three main dimensions of teacher effectiveness and teachers’ professional identity and promoted a research-rich culture in schools for this to be achieved. Likewise a report from the US Task Force on Teacher Education in Physics (T-TEP) similarly recommended that physics teaching should be informed by published research on teaching and learning the subject (Meltzer et al., 2012).

What constitutes science teacher knowledge and skills?

The question about what makes a good science teacher has been extensively discussed in the literature (Angell, Ryder, & Scott, 2005; Kind, 2009; Schneider & Plasman, 2011). This research has moved from differentiating between effective and less effective teachers to Shulman's categorisation of teacher knowledge bases including content knowledge, general pedagogical knowledge, and pedagogical content knowledge (PCK) (Lederman & Lederman, 2015). According to Shulman (1987) PCK '*represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction.*' (p. 8).

While there are research-based models of science teacher knowledge and skills, less is known about how teachers themselves conceptualise the characteristics of a good science teacher, with the exception of a few studies. Asikainen and Hirvonen (2010) analysed the conceptions of physics teacher knowledge held by experienced physics teachers acting as mentors and instructors for pre-service teachers. Their respondents emphasised the practical sides of teaching such as '*knowledge of strategies, representations, and methods*' (p. 446). Lee and Luft (2008) similarly investigated how experienced science teachers acting as mentors conceptualised PCK. They identified the following common components in respondents' descriptions: science, goals, students, curriculum organisation, assessment, teaching, and resources. de Winter and Airey (2019) investigated, through one open-ended question, how a range of stakeholder groups in the UK, including physics students, pre- and in-service physics teachers, and physics teacher educators, conceptualised physics teacher attributes. They found that attributes such as subject matter knowledge, communication and explanatory skills, and teacher enthusiasm were frequent in the responses. In a study among biology and mathematics teachers participating in a professional development programme, Rozenszajn and Yarden (2014) found that content knowledge was viewed by the biology teachers as the most important knowledge for their teaching practice. A recent survey asked Norwegian upper secondary biology teachers (a comparable group to the one investigated in the present survey) how various components of their pre-service education had prepared them for their daily classroom practice. The study found that subject matter was the component from their training that teachers felt was most important in this respect (Sjøberg, Gregers, Ødegaard, & Tsigaridas, 2020).

From this limited research on how pre- and in-service science and physics teachers think of their own professional knowledge and skills, we see that science content knowledge appears to be prominent. However, we are not aware of research of this kind focusing on physics teachers in a Scandinavian context. The present article aims to contribute in this respect. As Lee and Luft (2008) argue, seeing how science teachers portray PCK from their own point of view may contribute to developing and improving both pre- and in-service science teacher education. Furthermore, we believe that raising awareness of in-service teachers' view on their professional knowledge and skills will guide professional development programmes to accommodate the previously mentioned new expectations of teachers.

Building knowledge and skills through science teacher education

With the new expectations of science teachers, as discussed above, teacher education must prepare pre-service teachers to become lifelong learners who can act as change agents in schools. Teacher education needs to model the kinds of inquiry-based, varied, inclusive and student-centred learning approaches that are advocated for schools. Moreover, teacher education must equip tomorrow's teachers with experience in using educational research to reflect on and improve their own teaching and with a vocabulary enabling them to discuss educational development with colleagues.

Pre-service teachers often come to teacher preparation programmes with a set of ideas and beliefs about teaching informed and coloured by their own compulsory schooling and by events and individuals in their lives (Etkina, Gregorcic, & Vokos, 2017; Huibregtse et al., 1994; Korthagen, 2004). Thus, pre-service teachers often have to undergo considerable transformations in their professional identity

during teacher education (Korthagen, 2004). Hence, we find it important to explore what their own initial views on knowledge and skills are. Larsson, Airey, Danielsson, and Lundqvist (2018) investigated how physics department staff in Sweden conceptualised their role in physics teacher education and pointed out challenges for pre-service physics teachers to build up a professional identity in a learning environment focused on creating future physicists and where a teaching career was regarded as an unnatural choice. This may be related to the T-TEP report's (Meltzer et al., 2012) finding that US physics departments running physics teacher education programmes have problems with justifying necessary staff, specialised courses, and other resources for teacher preparation programmes. Thus, it may be argued that pre-service physics teachers experience a somewhat marginalised position in some of the educational settings they are a part of. Meltzer et al. (2012) argued that physics departments must take on a commitment to support their physics teacher education programmes if they consider these as part of their mission.

Aim and research questions

In a situation where the understanding of what constitutes science teacher knowledge and skills is changing, it is of interest to know how physics teachers conceptualise their necessary knowledge and skills and what pre-service teachers consider as necessary attributes to become a good teacher. Although our main focus is on teaching physics, we extended our pre-service teacher sample to include teachers of other science subjects for reasons explained in the methods section. In the present study, we address the following research questions:

RQ1: How do first and final-year pre-service science teachers enrolled in a 5-year masters' degree programme, describe the knowledge and skills needed in order to be a good science teacher?

RQ2: How do in-service physics teachers describe the knowledge and skills needed in order to be a good physics teacher?

ANALYTICAL FRAMEWORK

PCK was introduced as a remedy to what Shulman (1987) saw as 'the missing paradigm' connecting teachers' disciplinary knowledge with their pedagogical knowledge. A recent revision of the model is the Refined Consensus Model of PCK (Carlson et al., 2019). In this model, collective PCK (cPCK) may be seen as an expression of the common 'tools of the trade'; the agreed-on knowledge that a group of teachers typically share. The cPCK component of the consensus model is in focus in the present paper, together with the components *content knowledge*, *pedagogical knowledge*, *knowledge of students*, *curricular knowledge*, and *assessment knowledge*, which are described in the model as dynamically interacting with cPCK.

Rollnick and Mavhunga (2017) proposed five knowledge components from which transformation of subject matter into teachable forms emerge: 1) *representations* which includes explanations, analogies, examples, illustrations and demonstrations; 2) *what makes the learning of specific topics easy or difficult*; 3) *learners' prior knowledge* including misconceptions, 4) *curricular saliency* which includes the big ideas in the topic, why the topic is important to teach and how topics are sequenced; and 5) *knowledge of conceptual teaching strategies* which ties up the other four components and informs the teacher how to teach a specific topic for specific students in a specific context. We interpret these components to be sub-groups of cPCK of the Refined Consensus Model.

Korthagen (2004) offered a different perspective on the question 'What are the essential qualities of a good teacher?' (p. 87), with a stronger focus on teachers' personal qualities such as behaviour, beliefs, identity, and the teacher's teaching mission.

In the present paper, we will use the concept of cPCK coupled with Rollnick and Mavhunga's (2017) framework and aspects of Korthagen's (2004) perspective, to identify and interpret themes in our respondents' description of the knowledge and skills needed to be a good science teacher.

METHODS

Our study is explorative in character and uses qualitative methods to obtain an overview of central aspects of teachers' reflections on their knowledge and skills. The data material comprises written responses to an open-ended questionnaire item and transcripts of individual interviews. When composing the questionnaire item wording and the interview guide, priority was given to using formulations that would align with respondents' natural way of expressing themselves. This was particularly important to ensure validity in the case of the pre-service science teacher group, since many of these respondents came straight from secondary school and could not be expected to have a sophisticated vocabulary for reflecting on teacher knowledge and skills. Although the first-year pre-service science teachers have no teaching experience, we consider their views as valuable since they bring with them experiences as students in upper secondary school and they have actively chosen a teacher education, which suggests that they already have some initial reflections about themselves as a teacher. The pre-service science teachers were following integrated, five-year study programmes leading to a masters' degree at five different Norwegian universities. These programmes are targeted towards teaching in secondary and upper secondary school. The programmes focus on developing teacher identity and on integrating theory and practice (Hatlevik, Engelién, & Jorde, 2020), and school practice is implemented throughout the 5-year programme. It is worth mentioning that this educational path differs from the educational background of most of the current in-service physics teachers (Smith, 2011), who usually have a master's degree in a science discipline followed by a 6- or 12 month pedagogy course including classroom practice.

The number of pre-service teachers specialising in physics is small on a national level, so we chose to invite all pre-service science teachers. The majority of these will qualify to be teachers in two of the following subjects: physics, chemistry, biology, geoscience, general science, and mathematics. At the start of their five-year science teacher education, where most students have not yet entered a science discipline culture but come straight from school, differences between these sub-groups of pre-service science teachers are assumed to be relatively small.

The reason for using only one questionnaire item was twofold: to raise response rates, and to limit class time allotted to answering the questionnaire in the case of the pre-service teacher respondents. The questionnaire item was 'What do you need to know to be a good physics/science teacher?' Originally, the question was asked in Norwegian, and the word for knowing in Norwegian ('kunne') incorporates both knowledge and skills and is in line with the formulation used by Davis and Bricker in the publication 'Science and Literacy in Teacher Education: What do Preservice Teachers Need to Know and Be Able to Do?' (2013). Thus, the question formulation addresses mainly knowledge and skills and does not directly address attitudes or personal traits. Interestingly, however, many of the responses nonetheless incorporated such aspects.

A pilot study conducted at the University of Oslo with 58 first-year pre-service teachers as respondents confirmed that the questionnaire item wording yielded the kind of responses that we were interested in. The main data collection provided responses from 154 first- and 26 final-year pre-service science teachers, and 212 physics teachers in Norway; see Table 1. Seven individual interviews were conducted to help us interpret the written answers and to check the respondents' interpretation of the question.

Table 1 Overview of respondent groups and typical lengths of individual responses from each group in the questionnaire data.

Respondent group	Number of respondents	Average number of words per respondent	Range of number of words per respondent
First-year pre-service science teachers	154	40	2-136
Final-year pre-service science teachers	26	31	4-146
In-service physics teachers	212	25	1-616

Pre-service science teacher questionnaire: Respondents and data collection

The distribution of the questionnaires was managed by the administration at each of the five participating institutions. The first-year pre-service science teachers were invited to answer the questionnaire with pen and paper at a lecture during the first weeks of their study in August 2016. The final-year pre-service science teachers from the same five institutions were invited by email in May-June 2016 to answer the questionnaire using a web-form since they did not have common lectures. These respondents were given a deadline of one week, and a reminder was later sent with an extended deadline. The small sample of final-year pre-service teachers is most likely due to the fact that they received the invitation during the period when they were finalising their masters' thesis and preparing for their final exam.

In-service physics teacher questionnaire: Respondents and data collection

The teachers were invited by email in March 2016 to answer the questionnaire using a web-form. Since there is no official record of Norwegian physics teachers, an email was sent to an email-list with 600-700 physics teachers hosted by the Norwegian association for physics teachers. In addition, an invitation was posted in a closed Facebook group with 333 members, most of them physics teachers. The email-list and Facebook group have some member overlap.

An initial deadline of one week was given for answering the questionnaire, and a reminder was sent after one week with an extended deadline. We did not collect background information through the questionnaire, and it was therefore not possible to give a demographical overview of the teachers who responded – such aspects would be interesting to pursue in future research. However, we know that most Norwegian physics teachers in upper secondary school have a master's degree in physics and additional one-year pedagogical education, on average around 14 years of physics teaching experience, and only a few have attended continuing professional development programmes during the last two years (Grønmo, Hole, & Onstad, 2016).

In-service physics teacher and pre-service science teacher interviews

Both in-service physics teachers and first-year pre-service teachers were invited by email for a follow-up interview. The distribution list used for inviting the teachers was the same as used for the questionnaire. For reasons of convenience, we selected three teachers from the Oslo area who had at least four years of teaching experience. For the pre-service teachers, a distribution list with all first-year pre-service science teachers at the University of Oslo was used, this time inviting only pre-service physics teachers. It was not possible to have interviews with final-year pre-service teachers since this group had already graduated by the time of the interviews, and privacy considerations prevented us from tracking them after graduation.

The individual, semi-structured interviews were conducted in November 2016 and were audio-recorded with participants' consent. Each interview lasted 12-22 minutes following an interview guide covering topics derived from the research questions and from preliminary analysis of the questionnaire data for all groups. During the interviews, it was possible to elicit more about the interviewees' attitudes towards teaching in addition to what they considered as necessary knowledge and skills. The interview guide, consisting of twelve questions for both respondent groups, highlighted aspects like how the questionnaire item was interpreted, whether good teachers need to have a certain personality, the difference between pedagogical skills and pedagogical knowledge, how respondents would describe their favourite teacher from their own schooling, and more. A couple of questions differed for the two groups. As an example, the question "Imagine yourself as a teacher in the future, how would you appear?" was asked only to the pre-service teachers and served to highlight how respondents used experiences from their own education to reflect on the knowledge and skills they were aiming to develop. Where necessary, elaborating questions were given.

Analysis of questionnaire data

The questionnaire responses were coded thematically (Braun & Clarke, 2006). Part of the code-set used constructs from the theoretical frameworks of Carlson et al. (2019) and Rollnick and Mavhunga (2017) to identify and name prevalent themes. These codes fell into the three themes content knowledge, pedagogical knowledge, and cPCK, where the cPCK theme encompassed codes covering aspects from Rollnick and Mavhunga's model (2017). The rest of the code-set was developed inductively during coding and comprised two themes: personality traits and working conditions. A total of 25 codes, distributed between these five themes, constituted our code set, as shown in Table 2. Before coding the main data, the pilot data was coded by all three authors, and a common set of codes was agreed on after several iterations and discussions around interpretations of the codes. Several codes were assigned to the same passage where appropriate. The first author coded all data sets, while the two others coded half of the data each to ensure a common interpretation of the data.

Table 2 Themes with corresponding codes used for the analysis.

Theme	Codes
Content knowledge	Subject matter; Passion and interest for the subject
Pedagogical knowledge	Discipline and classroom management; Knowledge of students; Curricular knowledge; Pedagogical skills; Pedagogical knowledge; Assessment knowledge
cPCK	Representations; Students' previous knowledge and misconceptions; Thematic challenges; Curricular saliency; Conceptual teaching strategies
Personality traits	Empathy and interest for the students; Teacher's personality; Confidence; Sociable, passionate, and charismatic
Working conditions	Follow-up during and after teacher education; Collaboration; External conditions in place

Analysis of interview data

Analysis of the interview data was made with the same code set as for the questionnaire. For this dataset, there were also two coders for each interview, where the first author coded all. The interviews were analysed solely with a deductive approach.

RESULTS

The results obtained from the questionnaire and interviews for each respondent group are presented in combination. Whenever applicable, we will describe the answers from the questionnaire and elaborate on them with utterances from the interviews. All quotes are translated into English by the au-

thors. In the following, TQ will denote quotes from teacher questionnaire responses, TI quotes from teacher interviews, PSQ quotes from pre-service teachers' questionnaire responses, and PSI from pre-service teacher interviews.

First-year pre-service teachers' views on knowledge and skills

Among the first-year pre-service teachers answering the questionnaire, the most prevalent theme was Pedagogical knowledge:

Knowledge about how one learns. (PSQ)

This theme was closely followed by content knowledge. Three of the interviewed pre-service teachers mentioned content knowledge first, whereas the fourth mentioned communication skills first when asked about what they need to know to be a good science teacher:

You must be able to communicate well. And [...] at least you have to know your subjects well, but communication is much more important [...] (PSI)

Within the pedagogical knowledge theme, we chose, based on the responses, to differentiate between pedagogy as knowledge and as skills. In this group, pedagogical skills were mentioned more than twice as frequently as pedagogical knowledge:

[...] but it doesn't help to be knowledgeable and not be able to teach. Therefore, a good teacher must have good pedagogical skills. (PSQ)

In the above quote, the student responded with a term that in English is best translated into 'being able to teach', but in Norwegian indicates transferring knowledge ('lære bort'). The impression of teaching as transferring knowledge was notable among the pre-service teacher questionnaire answers. All the interviewed pre-service teachers expressed an explicit view of the teacher as a person transferring knowledge. Three of them also expressed a traditional view on teaching physics when asked about how they would imagine themselves as a physics teacher:

Um, I would probably start with repetition of stuff that we worked on in the previous lesson. [...] Then I would start to work on new topics, most likely a presentation and then maybe some practical examples very shortly [...] And then get them [the students] to work on problems [...] (PSI)

Aspects of cPCK could be identified in the questionnaire responses, for instance in passages coded with the Conceptual teaching strategies code:

You must be able to convey the subject in such a way that the big message (knowledge) reaches the public, crowds, and also you must be able to adjust to be able to reach those who would need their own methods (PSQ)

cPCK was less apparent among the interviewed pre-service teachers, but there were some indications:

[...] to be able to adapt the teaching to the students. (PSI)

One of the interviewed pre-service teachers expressed a view of teacher knowledge and skills as something rather straightforward based on sufficient content knowledge and that was developed through classroom experience:

To be a teacher and become a teacher, you'll need to have more content knowledge, sort of, and then the other [qualities] will follow by itself. (PSI)

Personality traits such as showing empathy and interest for the students were mentioned far more often by the pre-service teachers than by the in-service teachers. Many responses emphasised the ability to be sociable, engaged, and charismatic:

Create good relations with the students. Be able to have a relationship with the students besides the professional. (PSQ)

An important trait I feel that you need to have in place is that you get engaged in the subject – that you have a passion for the subject. (PSI)

The pre-service teachers accentuated that everyone can learn to be a better teacher:

Everyone can learn to be a good teacher, even if you are not born to. But of course, there are people who are simply natural talents. (PSI)

Three of the interviewed pre-service teachers described their favourite teacher from their own schooling as an inclusive person who took care of them and their learning. These teachers were highly respected among the students and were all persons with positive personality traits, as the following excerpt shows:

[...] she was cheerful and kind and very – you know – always a smiling person [...] she was strict, but still – or she was not strict but more like [...] fair and reasonable [...] She managed to make it completely safe, [...] It was safe and enjoyable and engaging and we learned [...] (PSI).

This teacher was described as creating a safe and positive learning environment, with pronounced expectations of the students, and seemed to have functioned as a role model for the respondent.

The Working conditions theme seldom appeared in the pre-service teacher sample, but when it did, it was most often connected with students' need for follow-up during and after their pre-service teacher education.

Final-year pre-service teachers' views on knowledge and skills

In the 26 questionnaire responses from the final-year pre-service teachers, content knowledge and pedagogical knowledge were mentioned with roughly equal frequency. Responses interpreted as cPCK were more dominant among this group of respondents than in the other groups. Personality traits were less emphasised by this group, but when such traits were mentioned, empathy and interest for the students were described as important.

The following quote shows how members of this group were able to give reflective and comprehensive accounts of science teacher knowledge and skills:

Good content knowledge and understanding are of course an important cornerstone, in addition to good personal attitudes to the subject and a straightforward overview of its role in society [...]. Regarding personality traits, it is important to be positive and to be able to express pronouncedly that you care about your students, and to be able to create social bonds. The teacher should also be a professional and must therefore be in possession of knowledge of students' understanding/view on the subject, students' social everyday life in relation with peers and teachers, and the challenges that might turn up in relation to learning the subject. [...] Last but not least, the teacher has to be a distinct leader and be able to take actions that optimize the learning environment and class environment. (PSQ)

It should be emphasised that the above quote was the most elaborate answer among the final-year pre-service teachers.

In-service physics teachers' views on knowledge and skills

In the written responses describing the qualities needed to be good physics teachers, content knowledge was by far the most frequent theme mentioned by the teachers, and it was by most of the teachers listed first in their response:

To have a theoretical and practical understanding of physics on a level much higher than the upper secondary school level. (TQ)

On the same question, all three teachers interviewed mentioned content knowledge first. Some teachers also pointed at the importance of being enthusiastic about your discipline:

[...] passion for your subject [...] (TQ)

The other main themes were considerably less frequent in the written teacher responses, mentioned by far less than half of the respondents.

Several of the respondents answered in terms of pedagogical skills rather than knowledge:

Good pedagogical skills (TQ)

During the interviews, teachers were asked to reflect on this differentiation between pedagogical skills and pedagogical knowledge. The following quote is representative for all three teacher interviews:

[...] skills probably reflect a little more about what we actually do. Knowledge feels for me like a more static term, it is something you know, but it isn't something you [...] actively do. (TI)

Aspects of responses coded with the cPCK could also be identified, both in questionnaire responses and in interviews:

The students must be supervised on the way, be presented with examples and experiments connected to the current topic studied. (TQ)

[...] to understand what the best way is to attack the subject matter for exactly that group, or for that student. (TI)

These teachers pointed towards the importance of knowing the students, knowing conceptual teaching strategies, and appropriate representations. These answers were quite similar to those given by the first-year pre-service teachers, except for the conceptual teaching strategies code, which was even more dominant among the pre-service teachers.

Descriptions of teachers' ability to see the students, and to show empathy and interest for their learning, were coded within the Personality traits theme. This theme also covered being sociable, having the ability to engage students, and having a charismatic personality. Some respondents pointed towards personality characteristics like having humour, playfulness, creativity, flexibility, and curiosity in order to be a good physics teacher:

Commitment. Humour. Flexibility. (TQ)

[...] commitment and care for your students. (TQ)

When asked to reflect on the importance of personality traits for being a good teacher, all interviewed teachers expressed that some people were more personally suited for a teaching profession, but all of them, like the pre-service teachers, also emphasised that everyone can learn to be a better teacher.

Although the questionnaire item asked about what a good physics teacher needs to know in terms of skills and knowledge, many of the written responses also concerned working conditions such as cooperation with colleagues and school management, possibility for continuing professional development, and a well-equipped physics laboratory:

Time to prepare for teaching. Enough equipment for experiments/demonstrations. A good textbook. A good and suitable room for teaching/laboratory work (TQ)

Such responses appeared in roughly half the questionnaire responses from the physics teachers and was the second most frequent theme.

When the respondents mentioned research or development, it was mostly concerned with keeping up to date with recent developments within physics as a discipline:

It is also important to be up to date about new research and discoveries within physics. (TQ)

Hardly any mentioned being informed about educational research or using research and development to improve their teaching.

DISCUSSION

In this qualitative study, we have asked first and final-year pre-service science teachers and in-service physics teachers to describe the knowledge and skills needed in order to be a good teacher of science or physics, respectively. The data was collected through a one-item questionnaire, followed up with interviews. We believe the study adds to the very scant body of research literature about how science teachers themselves conceptualise their necessary knowledge and skills.

Views on knowledge and skills: PCK still a missing link?

In terms of the models for science teacher qualities discussed in the Analytical Framework section, respondents mentioned many of the central components of PCK as described by Carlson et al. (2019) and Rollnick and Mavhunga (2017). Also, many respondents described personality traits such as empathy, enthusiasm, personal passion and charisma as central for being a good physics teacher. Similar findings were made by de Winter and Airey (2019). These qualities are not prominent in the consensus model, but are brought more to the fore in the model of teacher identity presented by Korthagen (2004). However, we found slightly different foci among the three respondent groups: first-year pre-service teachers answered more in terms of pedagogical knowledge and the importance of seeing the students, while the in-service teachers put most emphasis on content knowledge. Some respondents in our admittedly small sample of final-year pre-service teachers were able to express an integrated and reflected view of the importance of both content knowledge and pedagogical knowledge, with more articulated expressions of cPCK. All components of the Refined Consensus Model of PCK from the Analytical framework section were mentioned by all respondent groups with the exception of curricular knowledge and assessment knowledge which were seldom mentioned.

The pronounced focus on content knowledge displayed by our in-service teacher respondents resembles the findings of Larsson et al. (2018), where experienced physics teachers acting as mentors in the physics teacher training programme displayed a 'physics expert model' of teacher education with the ideal that a physics teacher is first and foremost a physics expert. de Winter and Airey (2019) also found physics subject knowledge to be among the central attributes valued by stakeholders in physics teacher education in the UK, and Sjøberg et al. (2020) made a similar observation for Norwegian biology teachers. In line with the assumption for biology teachers made by Rozenszajn and Yarden (2014), it is possible to speculate that the focus on content knowledge among in-service physics teachers, in particular, is a result of physics as a discipline being in rapid progress and therefore a need for always being updated is imposed. Opposed to our findings, Asikainen and Hirvonen (2010) reported a slightly different focus for their respondent group of expert physics teachers acting as mentors: This group was concerned with knowledge of strategies, representations, and methods, which are in line with cPCK. Our respondents' emphasis on working conditions may be seen in connection with Lee and Luft's (2008) finding that 'knowledge of resources' such as activities, multimedia, laboratory technology etc. was among the components of PCK mentioned by their respondents.

While Shulman (1987) introduced the concept of PCK in order to call attention to the close integration between subject matter and pedagogical knowledge, this connection was not prominent among our respondents except for the in-service teachers when cued in the interviews and for the final-year pre-service teachers answering the questionnaire. It appears that PCK as a body of common knowledge is not very well articulated among physics teachers and only exists as tacit knowledge as also proposed by others (see for example Loughran, Berry, & Mulhall, 2012). Do pre- as well as in-service teachers need more experience with articulating these aspects of their knowledge and skills in order to be able to participate in the kinds of research-rich and reflective cultures that educational authorities aim to build up in schools? Maybe a more pronounced focus on PCK would foster a vocabulary and a mindset that would help teachers to have meaningful dialogues and reflect on their own practice with peers, as also suggested by Kind (2009).

While most Norwegian in-service teachers have a disciplinary masters' degree before an additional pedagogical education (Grønmo et al., 2016), final-year pre-service teachers have spent more time on reflections around their teacher identity during their five-year integrated teacher preparation programme (Hatlevik et al., 2020). The programme includes classroom practice and pedagogy courses at several points and may therefore promote development of PCK in line with Kind (2009) who found classroom experience as one of three common factors important for developing PCK. This approach could explain the final-year pre-service teacher responses where there appeared to be a more integrated and reflective view on science teacher knowledge and skills. Such a reflective attitude to their professional development may also form the basis for developing their practice in dialogue with colleagues and with input from educational research.

Promoting research-informed science teaching

Research literacy and ability to engage in research-based educational development were more or less absent from our respondents' description of physics or science teacher knowledge and skills. This is in contrast with the new expectations of teachers where research-based teaching is one of the key components (BERA-RSA, 2014; Meltzer et al., 2012). Again, this may indicate that the culture in schools is still focused on traditional views on teaching and learning and has not yet taken ownership of the new demands of teachers such as using results from educational research to improve teaching (BERA-RSA, 2014) and moving from a more transmissive towards a more student-activating style of teaching (Kind, 2009). In order for this to happen, school owners and policy makers must be involved and challenged to focus more on PCK when planning for continuing professional development.

More research is needed to identify ways to support teachers in building a culture of using research-informed teaching methods to improve education and support their students' learning and motivation in science. Examples of how to support professional development based on research, have been conducted at University of Oslo, where one third of our pre-service teacher respondents came from: The science teacher education programme has increased the attention towards coordinating the disciplinary subjects with the pedagogical subjects of the programme, encouraging pre-service teachers to simultaneously reflect on educational and disciplinary research throughout their study. Consequently, pre-service teachers now get opportunities to develop and discuss their professional thinking and identity (Hatlevik et al., 2020).

If teachers are to get acquainted with school-relevant research and get the opportunity to discuss this with colleagues, arenas for professional development of in-service teachers are central. However, results from TIMSS Advanced show that Norwegian physics teachers to a smaller extent than their colleagues in other countries participate in continuing professional development (Grønmo et al., 2016). In a related project, we involved both in-service and pre-service physics teachers as participants in a design-based research project aimed at simultaneously developing learning resources for upper secondary students and to arrange for professional development among the participants (Frågåt, Bøe, & Angell, 2021). Furthermore, the teachers got an insight into research-based teaching and how they could contribute with their teaching experience.

Concluding thoughts

Our in-service teacher respondents' emphasis on content knowledge, and the first-year pre-service teacher respondents' description of teaching as transferring knowledge, resonate with the descriptions given in the Introduction of traditional physics and science classrooms. Pedagogical knowledge was also emphasised by our respondents, but was often described as an inherent trait or skill rather than knowledge that could be learned on a theoretical basis. Larsson, Airey, and Lundqvist (2017) pointed out that in physics departments, *'teaching physics is framed as coming naturally to anyone who knows physics'* (p. 2). Similarly, in Sjøberg et al. (2020) survey among biology teachers, some respondents expressed that good subject matter knowledge would give good communication skills. This point of view was also expressed by one of the interviewed pre-service physics teachers in our survey. Further, Frågåt et al. (2021) found that among a group of in-service physics teachers, general pedagogy was regarded as not very relevant for their daily teaching and was often attributed with negative associations. This could also explain the weaker focus on pedagogical knowledge among our in-service teacher respondents and the comparative scarcity of formulations referring to other components of teacher knowledge, notably the realms of PCK of the refined model. The recent developments in the direction of more integrated science teacher education programmes (Hatlevik et al., 2020) may be able to remedy this situation. Furthermore, science departments must acknowledge that science teacher knowledge comprises more than subject-matter knowledge and that teaching skills do not unproblematically arise from such knowledge. Similarly, education departments must acknowledge that pedagogical knowledge must relate to the science content to be taught and is not effective on a stand-alone basis.

The interviewed pre-service teachers often described a traditional physics classroom when asked to envision themselves as physics teachers. Likewise, Huibregtse et al. (1994) found that *'[t]he goals and approaches that [physics] teachers favour when teaching seem to be very similar to those preferred when they themselves are learners'* (p. 558). Further, Korthagen (2004) argued that teachers' beliefs about teaching often are based on their own education and might be diametrically opposed to what they learn during teacher education. Therefore, he argued, if the pre-service teacher sees teaching as transmission of knowledge, that is probably how he or she will be teaching. Thus, in order to renew education in schools, many pre- and in-service teachers need to re-evaluate their beliefs about teaching and learning (Korthagen, 2004). One important way to help pre-service teachers acquire research-based, varied and inclusive teaching and learning approaches is to let them experience this kind of teaching and learning through their own education. Academic staff involved in teacher education must act as models, displaying and using the kinds of teaching and learning activities that will promote pre-service teachers' professional development (Lunenberg, Korthagen, & Swennen, 2007). Our results suggest that the final year pre-service science teachers have cPCK more present in their thinking and vocabulary than the in-service teachers, which could be explained by the more pronounced focus on educational research and practice during their teacher education programme. However, it must be emphasised that most of the in-service teachers have a slightly different educational background. So, what will happen when the pre-service teachers enter the established cultures of experienced science teachers in schools? Will they adapt to a school culture with focus on content knowledge and traditional instruction, or will they be able to act as change agents, bringing their research-based knowledge of teaching and learning – and their vocabulary for discussing it – into the teacher community at their school? It is considered challenging to provoke a cultural change in educational systems, and expectations existing in an individual school or school district could discourage teachers from implementing innovative teaching (Crawford, 2014; Höttecke & Silva, 2011). Newly qualified teachers may therefore need scaffolding in terms of continued, in-service support if they are to promote change of the predominant culture. Therefore, teacher mentors and cooperating teachers who practice reform-based instruction have to understand how to scaffold pre-service teachers (Windschitl, 2009), as well as novices. Etkina et al. (2017) proposed that building a rich community of practice where in-service teachers are involved in a teacher preparation programme is one of three components for future teachers to develop their teaching away from the traditional physics classroom they often experienced themselves. It will take sustained work to establish a situation where newly educated teachers can act as change agents contributing to renewing and stimulating the existing school culture with necessary scaffolding from teacher mentors and cooperating teachers.

Finally, if teachers are to become life-long learners capable of using research to develop their teaching and to provide teaching that meets current expectations like student-active learning, teachers must be professionally equipped to constantly improve their teaching. More research is needed on how these components of teacher knowledge and skills can successfully be included in pre- and in-service science teacher education. The goal is a joint culture where teacher educators – including those in the science departments – as well as pre- and in-service teachers together develop the kind of research-rich cultures that are advocated for developing a more varied and inclusive science education for the future.

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