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Article

A Knowledge Framework for Teachers of Physics and Physics Teacher Educators: The Genesis of a Knowledge Framework Based on the Knowledge Quartet

Stuart Farmer

Institute of Physics, London N1 9BU, UK; stuart.farmer@iop.org

Abstract: To teach a subject successfully it is necessary to have knowledge of that subject and of pedagogy as it relates to that subject. Based on the observation of teachers teaching mathematics, Rowland and colleagues developed the Knowledge Quartet. Whilst some aspects of the Knowledge Quartet are set in the context of teaching mathematics, much is more generic and applicable to other subjects. In many jurisdictions, the professional standards for teachers do not have any subject-specific content. This paper describes the development of a knowledge framework, primarily based on the Knowledge Quartet, for teachers of physics, which is designed to sit alongside any teacher professional standards and school curriculum documents. The framework provides subject-specific guidance on the knowledge-base necessary for the teaching of physics as well as providing a common language to help facilitate collaboration between colleagues in relation to their professional learning. The framework was also extended to include the knowledge required by physics teacher educators supporting the professional learning of teachers of physics. The development process included gathering data from a range of physics teachers and physics teacher educators on the value and content of the framework and it being piloted with several physics teacher educators, resulting in an amendment and refinement of the framework. The resulting framework is offered as a useful tool for those involved in the education of physics teachers and as an exemplar of a knowledge framework that could be extended to other subjects.

Keywords: teacher knowledge; professional learning; professional development; professional standards; physics teachers; physics teacher educator

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1. Introduction

It is well recognised that to teach a subject well it is necessary to have a range of knowledge that includes knowledge of that subject, general pedagogy, and subject-specific pedagogy, often referred to as pedagogical content knowledge (PCK) [1,2]. In recent decades, it has been common practice in many countries to introduce some form of professional standards for schoolteachers [3–12]. The format and content of these standards vary but generally include statements on topics such as professional values, practice, and responsibilities. Few give more than a passing mention to the need for teachers to have specific knowledge for the teaching of the subject(s) they teach. For example, in Scotland, the professional standard states "*As a registered teacher you are required to demonstrate a depth of knowledge and understanding of curriculum content and its relevance to the education of every learner*" [3] (p. 7). It is understandable that such statements provide little curriculum or subject detail, as these professional standards must be applicable to practitioners working in a wide range of settings, from generalists in early years through primary education and to specialists in upper secondary education, and with curricula and subjects that evolve over time. To include more specific content would result in large unwieldy documents compared to the fairly short and concise documents found in many jurisdictions [3,4,7,11,12]. However, from my experience, many teachers and teacher educators would appreciate guidance, to sit alongside the generic professional standards, on the subject knowledge appropriate for teaching a particular subject. The need for subject-specific guidance on teacher knowledge to help underpin its work supporting the professional learning of teachers of physics was also identified by the Institute of Physics, the learned society for physics in the UK and Ireland. This paper goes on to describe the process whereby a knowledge framework to support teachers of physics, and the physics teacher educators who support them, was developed; however, first is a discussion of existing literature on the knowledge-base for teaching a subject and of teacher educators.

1.1. The Knowledge-Base for Teaching a Subject

In his seminal paper, Shulman [2] introduced the concept that teachers require distinctive knowledge beyond that of a scholar of the subject they teach and of general pedagogical knowledge about the process of teaching, such as classroom management. Shulman called this pedagogical content knowledge (PCK) and went on to identify it as one of a minimum of seven forms of knowledge in the knowledge-base of teachers:

- Content knowledge;
- General pedagogical knowledge;
- Curriculum knowledge;
- Pedagogical content knowledge;
- Knowledge of learners;
- Knowledge of educational contexts;
- Knowledge of educational ends, purposes, and values [13] (p. 8).

Nevertheless, the nature of PCK is contested and different researchers have subdivided or categorised its constituents differently [14,15]. It is perhaps best to think of PCK rather than as an assemblage of different constituent parts but as a synthesis of multiple components of knowledge enacted in a context [16]. There is nevertheless good agreement in the centrality of Shulman's original two categories of PCK "*ways of representing and formulating the subject*" and "*an understanding of what makes the learning of specific topics easy or difficult*" [2] (p. 9).

Building on Shulman's ideas, Rowland and colleagues developed an empirically based conceptual framework to describe the knowledge for teaching mathematics known as the Knowledge Quartet (KQ) [1]. This theoretical framework was developed by taking a grounded approach to analysing observations of how learning teachers exhibited their knowledge in practice in the classroom, including both subject matter knowledge (SMK) and PCK. The KQ has four dimensions, each synthesised from several contributory codes: see Table 1.

Table 1. The Knowledge Quartet dimensions and contributory codes [1] (p. 25).

Dimension	Contributory Codes
Foundation: Knowledge and understanding of mathematics per se and of mathematics-specific pedagogy, beliefs concerning the nature of mathematics, the purposes of mathematics education, and the conditions under which students will best learn mathematics.	• awareness of purpose • adherence to textbook • concentration on procedures • identifying errors • overt display of subject knowledge • theoretical underpinning of pedagogy • use of mathematical terminology
Transformation: The presentation of ideas to learners in the form of analogies, illustrations, examples, explanations and demonstrations.	• choice of examples • choice of representation • use of instructional materials • teacher demonstration (to explain a procedure)

Table 1. *Cont.*

Dimension	Contributory Codes
Connection: The sequencing of material for instruction, and an awareness of the relative cognitive demands of different topics and tasks.	• anticipation of complexity • decisions about sequencing • recognition of conceptual appropriateness • making connections between procedures • making connections between concepts
Contingency: The ability to make cogent, reasoned and well-informed responses to unanticipated and unplanned events.	• deviation from agenda • responding to students' ideas • use of opportunities • teacher insight during instruction • responding to the (un)availability of tools and resources

Just as Shulman identified PCK as only part of the overall knowledge-base of a teacher, the KQ does not aim to include all forms of knowledge required of a teacher. It is common for teacher professional standards to specify not only the knowledge teachers are expected to possess but also other attributes such as values, commitment, skills, practices and engagement [3,7]. However, the statements of knowledge in such documents tend towards the generic, which leaves a gap in terms of identifying and specifying the knowledge-base of teachers with respect to the subject(s) they teach. Within a subject, knowledge can be categorised in different ways; for example, the Organisation for Economic Cooperation and Development (OECD) has identified and used the following categories: disciplinary knowledge—the foundational subject-specific knowledge; epistemic knowledge—knowledge of how to think as a practitioner of that subject; and procedural knowledge—knowledge of the processes used in a subject, particularly those used for solving complex problems [17] (p. 4). There is also interdisciplinary knowledge—key concepts that can be transferred or bridge between subjects, and skills where knowledge can be applied in useful ways [17,18].

It could be argued that the curriculum documents provided to teachers in most jurisdictions specify knowledge of what ought to be taught; however, Shulman categorised knowledge of the curriculum separate to the knowledge of the subject matter to be taught. Curriculum documents tend to set out the substantive disciplinary knowledge students are expected to learn, and perhaps some of the procedural knowledge, but rarely the epistemic knowledge of the subject. Such curriculum documents also often set out only broad curriculum topics or big ideas which means there is still the need for significant curriculum-making by the teachers responsible for teaching the curriculum. Teachers must be able to break broad curriculum guidance down into components that can then be made into a coherent teaching sequence which covers the underpinning knowledge and allows the building of a conceptual understanding of the topics involved. Even when curriculum documents more prescriptively set out the curriculum content for the students, this still requires significant knowledge on the part of teachers as to how to make this knowledge accessible for the students.

To teach a subject, it is necessary to not only have knowledge of the relevant subject matter but also pedagogical knowledge, as it relates to that subject matter and broader curriculum and contextual knowledge of how the subject matter fits within the broader curriculum. I now discuss the knowledge-base of teacher educators before going on to describe how the knowledge framework for teachers of physics and for the physics teacher educators who support the professional learning of teachers of physics was developed. This framework is designed to sit alongside the generic teacher professional standards and curriculum materials with which they work.

1.2. The Knowledge-Base of Teacher Educators

The improvement in pupil outcomes and the development of the education system has been linked to the quality of teaching [19–21]. Although there is little research on the impact of teacher educators on pupil outcomes, by common sense reasoning, it seems reasonable to conclude that quality teaching by teachers relies, at least to some extent, on quality teacher education by teacher educators [22] (p. 284). Although there is reasonable consensus about the knowledge-base teachers need, both in terms of theories such as PCK or the KQ and professional standards as discussed above, the same cannot be said about the knowledge-base of teacher educators [22]. Again, by common sense reasoning, it seems reasonable that the knowledge-base of teachers should not only be a subset of that for teacher educators, but that teacher educators also require additional knowledge relevant to the education of adult learners and 'teaching about teaching' [23]. Unfortunately, there is a commonly held view that a good teacher can become a good teacher educator with little in the way of additional professional learning or support [24,25]. Indeed, there is a 'taken-for-grantedness' in the literature of this assumption, particularly when teacher educators are recruited from experienced teachers. However, this is an under-researched field and this assumption lacks empirical support [22] (p. 285). That the field is under-researched is likely due to the low status in which it has been held compared to other areas of Higher Education [25–27]. Teacher education, even more so than teaching itself, is a complex process [28] (p. 25), but it is reasonable to use descriptions of the knowledge-base of teachers, such as the KQ dimensions and contributory codes (see Table 1) as the starting point for identifying the knowledge-base of teacher educators [22] (p. 286). John [29] (p. 323) introduces four dimensions of teacher educators' knowledge: Intentionality, Practicality, Subject specificity and Ethicality, but these are somewhat opaque terms and not immediately accessible in the manner of the dimensions of the KQ (Foundation, Transformation, Connection and Contingency) which I consider to be a more useful framework for describing the knowledge-base of teacher educators as well as of teachers. Goodwin [30] identifies five knowledge domains for teaching. Of these Personal, Contextual and Pedagogical include aspects similar to the KQ, but Goodwin also includes Sociological and Social Knowledge which recognises the importance of teachers being skilful in interacting with individuals and groups and recognising the different dynamics at work with each. By including these domains, Goodwin places greater emphasis on the relational aspect of teaching than Rowland in the KQ which is focused on the knowledge for teaching a subject and omits knowledge of broader educational aspects such as the affective domain. The importance of this in the work of teacher educators is demonstrated by Allsop and Benson [31] and Ellis and McNicholl [32] and, in my view, including knowledge of managing relationships ought to be seen as part of the knowledge-base of teachers and of teacher educators.

There have been many attempts to identify the fundamental principles for teacher education programmes and practices [23,33–35] and the knowledge-base of teacher educators [22,29,36]; however, much of this focusses on teacher educators transitioning from teaching pupils to become teacher educators with pre-service teachers, what Murray and Male [37] describe as 'first-order practitioners' (school teachers) transitioning to be 'second-order practitioners' in a 'second-order setting' (teacher educators in Higher Education). However, much teacher education for in-service teachers occurs when practitioners who identify first and foremost as a 'first-order practitioners' working in a 'first-order setting' also act as 'second-order practitioner' supporting other teachers' professional learning. Others may be what could be considered 'third-order practitioners' working neither in schools or Higher Education but for professional bodies or other organisations supporting the professional learning of teachers. The work of these types of teacher educators is under-researched.

I have identified several principles for an effective teacher educator working with either pre-service teachers in initial teacher education or for the professional learning of in-service teachers. These have much in common with those of Loughran [26]:

1. Knowledgeable about the subject matter knowledge (SMK) of the topic;

2. Knowledgeable about the pedagogical content knowledge (PCK) of the topic;
3. Knowledgeable of the context of the teachers at the professional learning event(s);
4. Sympathetic to the issues and realities teachers might face in implementing change due to new information from the professional learning event(s);
5. Able to model appropriate pedagogy and strategies during the professional learning event(s);
6. Able to build an open trusting learning environment with good relationships between all involved;
7. Knowledgeable about appropriate theory and research related to the topic, and when this might be introduced;
8. Prepared to make, take and facilitate opportunities which encourage reflection, an enquiry stance, teacher agency, and adaptive expertise.

The dimensions and language of the KQ provides a framework to describe the knowledge-base of a teacher educator needed to enact these principles in practice. Therefore, I now turn to how such a knowledge framework for teachers of physics and physics teacher educators has been developed.

2. Methods and Findings

2.1. Initial Extension of the Knowledge Quartet

I was first introduced to the KQ in 2017 when studying the unit "*What does it mean to teach the subject? What knowledge does a subject teacher need?*" as part of the MSc in Teacher Education at the University of Oxford [38]. Since 2003, alongside working as a physics teacher, I had worked part-time for the Institute of Physics [39], providing professional learning for other teachers, and the Institute of Physics (IOP) supported me and some other colleagues to complete the MSc. As a practising teacher and teacher educator at the time, I found the KQ dimensions (Foundation Knowledge, Transformation Knowledge, Connection Knowledge, and Contingency Knowledge) gave me a language which allowed me to discuss progress and development areas with student, early career, and more experienced teachers of physics in a concise and clear way I had not been able previously. I and some of the teachers I worked with readily adopted its language into our practice. In a later unit of the MSc, "*What is a teacher educator? What is the knowledge-base of a teacher educator? How do teacher educators design their teaching?*", I returned to the dimensions and language of the KQ to describe and analyse some of my own practice as a teacher educator. This resulted in me adapting some of the contributory codes to better reflect practice in physics rather than mathematics; for example, it is not common in Scottish physics classrooms to use textbooks but to use teacher authored workbooks and other instructional resources, so I therefore adapted 'adherence to textbook' to 'adherence to textbook and other resources'. I also extended the list of contributory codes to include ones which in many respects mirror those for teachers but described relevant teacher educator knowledge within each dimension. Adopting a 'core plus extension' model, I assumed that all physics teacher educators also required the knowledge of a physics teacher. This extended framework allowed me to describe and analyse my practice supporting the professional learning of a network of physics teachers working across several schools.

In 2019 I left the classroom to work full-time for the IOP and shortly after provided my extended version of the KQ to one of my colleagues who was then conducting, as part of the MSc, action research into the development of IOP coaches who support other physics teachers [40]. My colleague used the extended framework as a tool to allow IOP coaches, two in England and two in Scotland, to analyse their work as teacher educators. None of the four coaches had consistently used any knowledge framework to support their work previously. However, all recognised the value of adopting a more structured approach and were generally positively disposed towards the extended framework based on the KQ, although they struggled with some unfamiliar terminology, especially 'episteme' and 'phronesis'.

Around this time, it was decided that IOP would develop a knowledge framework for the teaching of physics and for physics teacher educators and it was realised by me and my colleague that the extended KQ might be a suitable basis for this. As the IOP is the learned society for physics across the UK and Ireland, it works with five different national education systems with different curricula and teacher professional standards. Early in the development process, it was decided that any framework had to complement any national policy context, and therefore needed to be grounded in the teaching of physics rather than driven by a particular set of national requirements or policy documents. It was also decided that the framework ought to be aspirational in nature and be suitable for use by anyone at whatever career stage they might be. By doing so, it was hoped that a minimum competency 'tick-box' approach to the framework would be avoided. It was therefore decided to conduct a series of consultations to see if a framework based on the extended KQ would be appropriate, and if so, gain views on how it ought to be developed further.

2.2. Consultation with Physics Teachers and Physics Teacher Educators

Following initial discussions with colleagues and drawing on findings from other research I had been conducting [41], I made further minor amendments to the contributory codes within the four dimensions and began referring to them as sub-dimensions. Conversations with teachers and school leaders in Scotland had made it clear that teachers would appreciate some illustrations to exemplify how teacher professional standards might be demonstrated. The self-evaluation and inspection framework in Scotland [42] contains illustrations of what 'very good' practice might look like for each of its fifteen 'quality indicators'. These illustrations, together with associated lists of 'features of highly effective practice' and 'challenge questions', were well regarded compared to the format of the General Teaching Council for Scotland's professional standards which include statements but no illustrations of practices which might be considered to meet the standards [3,12]. Therefore, I drafted at least one illustration for each sub-dimension based on my own experiences as a physics teacher and physics teacher educator to exemplify practices in each of the four dimensions. However, many of the illustrations described scenarios which could be associated with several sub-dimensions and even more than one dimension. This emphasised the need to consider the framework dimensions holistically and that an overly atomistic approach should be avoided, not least because this would promote the 'tick-box' approach we wished to avoid. Some of the initial draft illustrations were the following:

Transformation—Teacher—choice of examples.

A physics teacher carefully chooses a series of numerical problems which gradually become more complex in a progressive way to minimise the cognitive load on their students, and to ensure they experience a good level of success as they progress through the problems. This is designed to build up the students' problem-solving skills and maintain a good level of motivation.

Connection—Teacher—making connections between concepts.

When teaching different topics, a physics teacher draws the attention of learners to the concept of conservation, and that this can apply to different quantities such as energy, momentum, and charge.

Foundation—Teacher Educator—awareness of context of learning teachers, and pressures and dilemmas they may face.

A teacher educator, aware of Berliner's stage theory for teacher development, adapts professional learning activities depending on the mix of more or less experienced teachers involved.

Connection—Teacher Educator—making connections between 'learning about teaching' and 'teaching about teaching'.

A physics coach when developing a session for early career science teachers researches misconceptions on teaching Earth in Space on IOPSpark and uses this to illustrate important topics for the early career teachers to consider when teaching about day/night, the seasons, and the phases of the Moon.

The content of the illustrations was variable, from quite generic to more specific, but it was intended that the range included could ensure any physics teacher or physics teacher educator could see aspects of their work in them. The illustrations were never intended to be exhaustive, but a useful guide to prompt users when considering their own practice.

Following some initial proofreading of the draft framework by IOP colleagues, two online focus groups (see Appendix A for details) were arranged to determine whether a wider group of physics teachers and physics teacher educators considered this framework to be meaningful and helpful in identifying the subject knowledge for teaching physics. Using the IOP's physics education networks, participants were invited from across all five nations in the UK and Ireland with the aim of ensuring that views were obtained from all national contexts. Those invited were selected to have good classroom teaching experience and a variety of teacher educator roles including coaches providing career-long professional learning to experienced teachers, teachers mentoring early career teachers, university staff responsible for initial teacher education, and staff in learned societies and other organisations providing career-long professional learning. The focus groups were therefore populated by people likely to have well informed views on the matter. All those who accepted the invitation to the focus groups were sent a copy of the draft framework around a week before the meeting to give time for participants to read and reflect on its contents. The focus groups were asked three questions:

1. Does the expanded Knowledge Quartet provide a suitable framework for the discussion of the development of teacher knowledge by teachers and teacher educators?
2. Are the illustrations helpful? If so, would you have additional examples you are willing to share? If not, what alternative guidance would be helpful?
3. Will the expanded Knowledge Quartet be helpful in relation to planning, delivering and evaluating coaching and other professional learning for teachers of physics?

Notes of the focus group were taken. These were then analysed to identify common themes and to determine the extent of support for the continued development of the framework.

2.2.1. Response to Question 1

There was general support for the framework.

> "*It would be useful as a tool for my own reflection. . . . I feel that I may be able to use it to help the two trainee teachers that are in my department. I feel that no matter what stage you are at, it could be useful*." (Teacher/coach)

However, concerns were raised about the purpose of the framework, how it might sit alongside other documents, and the danger that the use of the sub-dimensions might promote a 'tick-box' or deficit culture where the illustrations are interpreted as 'things that must be done'.

> "*There is a risk that [the framework] is looked at as a deficit model, but if we look at what [teachers] have developed, I can see where they are on their journey*." (Teacher/coach)

> "*I am wondering if accompanying this document there could be a set of fairly open questions that a teacher could use to reflect on when planning a sequence of lessons on a topic. 'How will you ensure that . . . ?', 'What evidence will inform you . . . ?'. That could influence daily practice in a positive way*." (Learned society manager)

There was also some discussion about how the Foundation and Transformation dimensions of the KQ related to SMK and PCK and some considered SMK and PCK to be important terms to include as many teachers are likely to be familiar with them. Overall, although concerns were expressed, including many I already shared myself, it was clear that there was a desire to see the framework developed further.

2.2.2. Response to Question 2

Teacher participants in particular considered the illustrations to be useful and many wished to see a broader range appropriate to people at different career stages.

> "*[The illustrations] are helpful, and I can see if we took this idea on, we could add further that are personal to our way of working.*" (Teacher/coach)

However, there were concerns about whether they would drive a 'tick-box' culture and how they might sit alongside national policy documents.

> "*There's a real tension between providing exemplars to bring the document to life and it appearing prescriptive.*" (Learned society manager)

On balance, the illustrations were seen to be helpful but the messaging around how the framework might best be used, both in itself and alongside other documents such as teacher professional standards, must be communicated and considered carefully to ensure it is used in a positive manner.

2.2.3. Response to Question 3

There was general, but sometimes qualified, support for use of the extended KQ with comments such as follows:

> "*Experience you build up by yourself, but [these illustrations] are useful and have all that background that 20 years ago I didn't have*" (Teacher/coach)

> "*It would be useful as a planning and reflection tool for coaches, but is it trying to be too many things?*" (Learned society manager)

The response from the focus group participants was sufficiently positive to encourage further development of the extended KQ. As a result, additional illustrations were added by me, IOP colleagues, and in particular by two of the teacher/coaches who had been invited to the focus group, one from England and one from Scotland. The names of the Foundation and Transformation dimensions were changed to SMK and PCK with slight amendments to the illustrations to match.

2.3. Consultation with University-Based Researchers and Teacher Educators

Following the focus groups, one-to-one discussions were had with two university-based teacher educators who had carried out previous work around physics teacher knowledge. Both immediately identified that combining the terminology of Shulman's and Rowland's frameworks was problematic and diminished the strength of basing the framework on the empirically derived KQ. This change was immediately reversed. They also both raised questions around the purpose of the framework, its intended audience, and the introductory text in the draft document. This was subsequently clarified and simplified. Despite the concerns expressed and the need for further development and clarification, the framework was nevertheless seen as a potentially useful addition to the literature.

> "*[The framework] has real value in helping teachers scrutinise their work and so as an analytical/reflective tool it has real utility*." (University-based researcher and teacher educator)

2.4. Wider Consultation

Once the draft framework was reworked, it was decided to consult more widely on it. The IOP operates a forum whereby members of the physics education community can opt in to be consulted on different issues within physics education. Links to the draft framework and a confidential online survey were sent to the forum members who had opted in to be consulted on professional learning. It is reasonable to assume that those opting in to this aspect of the forum are likely to have a particular interest and knowledge of the area. Twenty-two responses were received; see Appendix B for details of participants.

The survey included thirteen questions which participants were asked to rate on a 5-point Likert scale from ‘strongly disagree’ to ‘strongly agree’; see Table 2 for the number of responses for each question and mean rating. There were also opportunities for open explanatory responses.

Table 2. Online survey responses.

Survey Question	1—Strongly Disagree	2—Disagree	3—Neutral	4—Agree	5—Strongly Agree	Mean Rating /5
It would be helpful to have a framework that describes in terms of physics knowledge what it means to be a physics teacher	1	0	2	4	15	4.45
It would be helpful to have a framework that describes in terms of physics knowledge what it means to be a physics teacher educator	1	0	1	4	16	4.55
It helps to guide professional learning	1	0	3	7	11	4.23
It helps give teachers ownership of their own professional learning	1	0	1	11	9	4.23
It provides a common language for discussing professional learning and professional growth	0	1	1	6	14	4.50
It helps ensure consistency of approach across different providers/events	0	1	2	8	11	4.32
It provides a structure through which professional learning scaffolds on itself	0	2	0	7	13	4.41
The structure of the “Knowledge Quartet” is appropriate	0	1	4	14	3	3.86
Each of the four dimensions of the Knowledge Quartet is appropriate	0	1	5	11	6	3.91
It has obvious links to physics teaching and teacher education	0	0	3	8	11	4.36
The exemplification within physics is appropriate	0	0	3	7	12	4.41
It is applicable at all career stages	0	0	2	13	7	4.23
The narrative approach (rather than a list/tick boxes) is appropriate	1	2	1	8	10	4.09

The overall response was very positive regarding the principle of a knowledge framework for physics teachers and physics teacher educators with most responses either agreeing or strongly agreeing. One respondent was somewhat of an outlier, strongly disagreeing with several questions; however, their open text responses did not entirely support their Likert scale responses, e.g., “*I think having the framework is useful, but it would to me mean a tick-box activity of what needs to be done but I feel it should be kept as open as it can be to encourage creativity*.” (Teacher—England). It may have been they had misinterpreted the direction of the Likert scale, or their concern about the framework becoming ‘tick-box’ and stifling creativity may have trumped all other considerations.

The questions receiving the least positive responses were those regarding the structure and terminology of the KQ which perhaps in part reflects the participants’ relative unfamiliarity with it, but participants made comments such as the following:

> "*The KQ is a good choice for the framework. I was initially sceptical about its value as an organisational scheme, but it has been well applied and forms a good backbone with well-balanced categories*." (ITE tutor—England)

> "*On first reading, I was dubious about the KQ as I had not encountered it before. . . . but since the KQ is intended for structuring physics pedagogical knowledge rather than physics knowledge or student thinking then it seems like a sound choice*." (Physics teacher—England)

Some of those giving lower ratings referred to the length of the framework document. This had been a consideration from the outset. Initially, the framework was envisaged as a webpage with hyperlinks from a concise menu page that led to further explanations and to the illustrations for each dimension. Due to limits on time and resources, and the need to ensure the content was appropriate and correct before developing a website for it, the drafts were kept as a simple A4 text document which was never longer than fourteen pages in total. Some participants clearly considered this to be too lengthy. Despite this, several suggested additions, including more information on common misconceptions, more support for out-of-field physics teachers, more illustrations on the history of physics, the theory of knowledge in physics, and on the most impactful pedagogical approaches for teaching physics. Some also recommended matching the framework to specific policy documents in their nation, which of course negates the aim to have a single framework which can be used across several nations. However, this could be a further development giving greater personalisation.

Alongside the survey, the draft framework was introduced to the participants in the IOP's pilot physics teacher educator (PTE) programme. This is a programme designed to provide professional learning for those supporting physics teachers, including initial teacher education and career-long professional learning. The PTE participants were asked to use the framework to analyse their work as teacher educators. Their feedback had much in common with that from the other groups reported above. Some of the PTE participants commented on the format of the framework and wished to see a simplified, interactive graphical version.

Overall, the survey and feedback from PTE participants provided further evidence that the draft framework was worth pursuing and was developing into a document both physics teachers and physic teacher educators would find useful.

3. Discussion

Based on the data gathered throughout the development process, the description of the dimensions and sub-dimensions were amended slightly making them more suitable for physics education. The number of illustrations, now referred to as 'examples', was increased, and they were disassociated from sub-dimensions, giving a list for each dimension to help prevent the sub-dimensions being used in a manner promoting 'tick-box' approaches. Many of the illustrations also spanned several sub-dimensions making that level of granularity potentially confusing. It was decided in the immediate future to retain the framework document as a document rather than to convert it into an interactive website, but to address the issue of length, as it was unnecessary for teachers to consider the teacher educator sections, and to separate the framework for teaching physics from that for physics teacher educators. With a cover, introductory text, some graphics, references, and a consistent double page spread for each dimension, this has resulted in two fourteen-page documents [43,44], available at [45].

As was intended from the outset, these framework documents are designed to sit alongside and complement whatever curriculum documents and teacher professional standards practitioners are obliged or choose to use. The examples are designed to be indicative and not a definitive list of practices of activities for users. To attempt to provide an atomistic breakdown of all the knowledge required of a teacher or teacher educator would be a never-ending task, and one which would require different results for different national, curriculum and stage contexts. The examples in the framework are not designed to define a minimum competence but to be aspirational and therefore illustrative not of things to be achieved but as prompts for reflective practice. It is intended that the framework provides a common language to facilitate the improved discussion of effective subject-specific professional learning amongst teachers and the teacher educators who support them. The framework, drawing as it does on theoretical descriptions of teacher knowledge from the literature [1,2], provides a vehicle to operationalise these in practice by both teachers and teacher educators. By taking this approach, it is hoped the frameworks will stimulate reflective professional practices [46] and lead to teachers of physics and physics teacher educators participating in, depending on the purpose of the professional learning, a good balance of activities, including more transformative as well as transmissive forms of professional learning [47], thereby facilitating teacher agency and activism [48,49]. The examples, as well as being grounded in my own and other contributors' real-life experiences, also make reference to further sources of advice and guidance from the IOP and other support organisations with which I would expect effective practitioners in the UK and Ireland to consult. They also reference educational research, which is hoped will encourage users to read further and engage critically with physics education research and wider educational research literature, helping to stimulate and challenge teachers, even those towards the twilight of their careers.

The KQ originated as a tool for analysing the knowledge-base of teachers of mathematics. It is perhaps not too great a leap to extend the KQ to physics, given the close links between the two subjects; however, the framework extends the KQ to apply to physics teacher educators to help provide a common language facilitating better communication between teachers of physics, their educators, and peers. I see no compelling reason why the format of the KQ-based framework could not be applied to the knowledge-base of teachers and teacher educators in any subject, provided of course, appropriate examples are used to illustrate how the four KQ dimensions might manifest themselves in that subject. At the very least, I hope that this paper might play a part in stimulating greater debate about the knowledge-base of teachers and teacher educators, not only in the subjects of mathematics and physics, but beyond.

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Informed Consent Statement: Informed consent was obtained from all subjects in the study.

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Appendix A. Focus Groups

Focus group 1: Experienced teachers with some previous involvement as physics teacher educators, e.g., IOP Teacher Network Co-ordinators or IOP School-based Physics Coaches.

Two or three participants were invited from each of England, Ireland, Northern Ireland, Scotland and Wales, together with relevant IOP staff. I chaired the focus group and my colleague who had conducted the previous study with IOP coaches acted as reporter.

Table A1. Focus group 1 participants.

Type of Participants	Nation	Number
Teacher/coach	England	2
Teacher/coach	Ireland	1
Teacher/coach	Scotland	2
Teacher/coach	Wales	3
IOP manager/coach	England	4
Total		12

In addition, one teacher/coach from Scotland and one IOP manager/coach from England, despite accepting the invitations, gave their apologies as they could not participate.

Focus group 2: Physics teacher educators and staff from professional learning agencies and learned societies.

Several participants were invited from relevant organisations in each of England, Ireland, Northern Ireland, Scotland and Wales, together with some with roles across the UK and Ireland. Focus group 2 was chaired and reported as for focus group 1.

Table A2. Focus group 2 participants.

Type of Participants	Nation	Number
Initial teacher education lecturer	England	1
Initial teacher education lecturer	Ireland	1
National agency officer	England	2
National agency officer	Northern Ireland	1
National agency officer	Scotland	1
National agency officer	Wales	1
Regional agency officer	Wales	2
Learned society manager	England	3
Learned society manager	UK and Ireland	3
Total		15

Appendix B. Online Survey Participants

Table A3. Online survey participants.

Type of Participant	Years in Teaching	Nation
physics teacher	1–5	England
physics teacher	1–5	Scotland
physics teacher	11–15	England
physics teacher	16–20	England
physics teacher	31–35	England
physics teacher	36–40	England
head of department	11–15	England
head of department	11–15	England
head of department	11–15	England

Table A3. *Cont.*

Type of Participant	Years in Teaching	Nation
head of department	16–20	England
head of department	21–25	England
head of department	31–35	England
senior leader	11–15	England
senior leader	21–25	England
ITE tutor	11–15	England
ITE tutor	21–25	England
CPD leader/coach	11–15	England
CPD leader/coach	16–20	England
CPD leader/coach	16–20	England
CPD leader/coach	16–20	Wales
CPD leader/coach	21–25	England
CPD leader/coach	26–30	England

References

1. Rowland, T. The Knowledge Quartet: The genesis and application of a framework for analysing mathematics teaching and deepening teachers' mathematics knowledge. *J. Educ.* **2013**, *1*, 15–43. [CrossRef]
2. Shulman, L.S. Those Who Understand: Knowledge Growth in Teaching. *Educ. Res.* **1986**, *15*, 4–14. [CrossRef]
3. GTCS. *The Standard for Full Registration: Mandatory Requirements for Registration with the General Teaching Council for Scotland*; General Teaching Council for Scotland: Edinburgh, Scotland, 2021; pp. 1–12. Available online: https://www.gtcs.org.uk/wp-content/uploads/2021/09/standard-for-full-registration.pdf (accessed on 21 May 2024).
4. Teaching Council. *Code of Professional Conduct for Teachers*; The Teaching Council: Maynooth, Ireland, 2016. Available online: https://www.teachingcouncil.ie/fitness-to-teach/updated-code-of-professional-conduct/ (accessed on 21 May 2024).
5. Livingston, K. Approaches to professional development of teachers in Scotland: Pedagogical innovation or financial necessity? *Educ. Res.* **2012**, *54*, 161–172. [CrossRef]
6. Welsh Government. *Professional Standards for Teaching and Leadership*; Welsh Government: Cardiff, Wales, 2019. Available online: https://hwb.gov.wales/api/storage/19bc948b-8a3f-41e0-944a-7bf2cadf7d18/professional-standards-for-teaching-and-leadership-interactive-pdf-for-pc.pdf (accessed on 21 May 2024).
7. AITSL. *Teacher Standards [Internet]*; Australian Institute for Teaching and School Leardership: Melbourne, Australia, 2017. Available online: https://www.aitsl.edu.au/standards (accessed on 21 May 2024).
8. Muavia, G.; Keevy, J. *Standards Framework for Teachers and School Leaders*; The Commonwealth Secretariat: London, UK, 2014; pp. 1–46. Available online: https://evaeducation.weebly.com/uploads/1/9/6/9/19692577/[muavia_gallie_and_james_keevy]_standards_framework.pdf (accessed on 21 May 2024).
9. OECD. *Learning Standards, Teaching Standards and Standards for School Principals: A Comparative Study*; OECD Publishing: Paris, France, 2013; pp. 1–80. Available online: https://www.oecd-ilibrary.org/docserver/5k3tsjqtp90v-en.pdf?expires=1711884193&id=id&accname=guest&checksum=C97AB8DFE67A5EC65493BE8274C2920E (accessed on 21 May 2024).
10. McMahon, M. *Literature Review on Professional Standards for Teaching*; General Teaching Council for Scotland: Edinburgh, Scotland, 2021; pp. 1–22.
11. Department for Education. *Teachers' Standards: Guidance for School Leaders, School Staff and Governing Bodies*; DfE: London, UK, 2011; pp. 1–15. Available online: https://assets.publishing.service.gov.uk/media/61b73d6c8fa8f50384489c9a/Teachers__Standards_Dec_2021.pdf (accessed on 21 May 2024).
12. GTCS. *The Standard for Career-Long Professional Learning: An Aspirational Professional Standard for Scotland's Teachers*; General Teaching Council for Scotland: Edinburgh, Scotland, 2021; pp. 1–12. Available online: https://www.gtcs.org.uk/wp-content/uploads/2021/09/standard-for-career-long-professional-learning.pdf (accessed on 21 May 2024).
13. Shulman, L.S. Knowledge and Teaching: Foundations of the New Reform. *Harv. Educ. Rev.* **1987**, *57*, 1–22. [CrossRef]
14. Kind, V. Pedagogical content knowledge in science education: Perspectives and potential for progress. *Stud. Sci. Educ.* **2009**, *45*, 169–204. [CrossRef]
15. Lee, E.; Luft, J.A. Experienced Secondary Science Teachers' Representation of Pedagogical Content Knowledge. *Int. J. Sci. Educ.* **2008**, *30*, 1343–1363. [CrossRef]
16. de Winter, J.; Airey, J. What makes a ood physics teacher? Views from the English stakeholder community. *Phys. Educ.* **2020**, *55*, 015017. [CrossRef]

17. OECD. *Conceptual Learning Framework: Knowledge for 2030*; OECD Publishing: Paris, France, 2019; pp. 1–13. Available online: https://www.oecd.org/education/2030-project/teaching-and-learning/learning/knowledge/Knowledge_for_2030_concept_note.pdf (accessed on 21 May 2024).
18. OECD. *Conceptual Learning Framework: Skills for 2030*; OECD Publishing: Paris, France, 2019; pp. 1–16. Available online: https://www.oecd.org/education/2030-project/teaching-and-learning/learning/skills/Skills_for_2030_concept_note.pdf (accessed on 21 May 2024).
19. Barber, M.; Mourshed, M. *How the World's Best-Performing School Systems Come Out on Top*; McKinsey and Company: Chicago, IL, USA, 2007; pp. 1–56. Available online: https://www.mckinsey.com/industries/education/our-insights/how-the-worlds-best-performing-school-systems-come-out-on-top (accessed on 21 May 2024).
20. Hattie, J. Teachers Make a Difference, What is the research evidence? In *Building Teacher Quality: What Does the Research Tell Us?* Australian Council for Educational Research: Melbourne, Australia, 2003; pp. 1–18. Available online: https://research.acer.edu.au/cgi/viewcontent.cgi?article=1003&context=research_conference_2003 (accessed on 21 May 2024).
21. Hattie, J. *Visible Learning: A Synthesis of over 800 Meta-Analyses Relating to Achievement*; Routledge: Abingdon, UK, 2009; pp. 1–378.
22. Goodwin, A.L.; Smith, L.; Souto-Manning, M.; Cheruvu, R.; Tan, M.Y.; Reed, R.; Taveras, L. What Should Teacher Educators Know and Be Able to Do? Perspectives from Practicing Teacher Educators. *J. Teach. Educ.* **2014**, *65*, 284–302. [CrossRef]
23. Korthagen, F.; Loughran, J.; Russell, T. Developing fundamental principles for teacher education programs and practices. *Teach. Teach. Educ.* **2006**, *22*, 1020–1041. [CrossRef]
24. Korthagen, F.A.; Loughran, J.; Lunenburg, M. Teaching teachers—Studies into the expertise of teacher educators: An introduction to this theme issue. *Teach. Teach. Educ.* **2005**, *21*, 107–115. [CrossRef]
25. Zeichner, K. Becoming a teacher educator: A personal perspective. *Teach. Teach. Educ.* **2005**, *21*, 117–124. [CrossRef]
26. Loughran, J. *Developing a Pedagogy of Teacher Education: Understanding Teaching and Learning about Teaching*; Routledge: Abingdon, UK, 2006; pp. 1–197.
27. Czerniawski, G.; Gray, D.; Macphail, A.; Bain, Y.; Conway, P.; Guberman, A. The professional learning needs and priorities of higher-education-based teacher educators in England, Ireland and Scotland. *J. Educ. Teach.* **2018**, *44*, 133–148. [CrossRef]
28. Berry, A.; Loughran, J. Developing an understanding to teach in teacher education. In *Improving Teacher Education Practices Through Self-Study*; Loughran, J., Russell, T., Eds.; RoutledgeFalmer: London, UK, 2002; pp. 13–29.
29. John, P.D. The teacher educator's experience: Case studies of practical professional knowledge. *Teach. Teach. Educ.* **2002**, *18*, 323–341. [CrossRef]
30. Goodwin, A.L. Globalization and the preparation of quality teachers: Rethinking knowledge domains for teaching. *Teach. Educ.* **2010**, *21*, 19–32. [CrossRef]
31. Allsop, T.; Benson, A. *Mentoring for Science Teachers*; Open University Press: Buckingham, UK, 1997; pp. 1–122.
32. Ellis, V.; McNicholl, J. Teacher Educators at Work: Narratives of Experience. In *Transforming Teacher Education: Reconfiguring the Academic Work*; Bloomsbury: London, UK, 2015; pp. 85–102.
33. McIntyre, D. Ideas and Principles Guiding the Internship Scheme. In *Oxford Internship Scheme: Integration and Partnership in Onitial Teacher Education*; Benton, P., Ed.; Calouste Gulbenkian Foundation: London, UK, 1990; pp. 17–33.
34. Bullough, R.V. Practicing theory and theorizing practice in teacher education. In *Teaching about Teaching: Purpose, Passion and Pedagogy in Teacher Education*; Loughran, J., Russell, T., Eds.; Falmer Press: London, UK, 1997; pp. 13–31.
35. Crowe, A.R.; Berry, A. Teaching prospective teachers about learning to think like a teacher: Articulating out principles of practice. In *Enacting a Pedagogy of Teacher Education: Values, Relationships and Practices*; Russell, T., Loughran, J., Eds.; Routledge: Abingdon, UK, 2007; pp. 31–44.
36. Goodwin, A.L.; Kosnik, C. Quality teacher educators = quality teachers? Conceptualizing essential domains of knowledge for those who teach teachers. *Teach. Dev.* **2013**, *17*, 334–346. [CrossRef]
37. Murray, J.; Male, T. Becoming a teacher educator: Evidence from the field. *Teach. Teach. Educ.* **2005**, *21*, 125–142. [CrossRef]
38. Univertsity of Oxford. MSc in Teacher Education—Department of Education. Available online: https://www.education.ox.ac.uk/study/msc-teacher-education/ (accessed on 20 June 2024).
39. Institute of Physics. Institute of Physics–For Physics • For Physicists • For All. Available online: https://www.iop.org/ (accessed on 20 June 2024).
40. Aspinall, C. *What Ways Can the Deveopment of IOP Coaches as Educators of Physics Teachers and CPD Leaders be Supported with Access to New Knowledge and Frameworks?* [Unpublished dissertation]; University of Oxford: Oxford, UK, 2022.
41. Farmer, S. *The Alignment of Policy and Practice for the Career-Long Professional Learning of Teachers in Scotland*; University of Strathclyde: Glasgow, Scotland, 2024.
42. Education Scotland. *How Good is Our School?* 4th ed.; Education Scotland: Livingston, Scotland, 2015; pp. 1–69. Available online: https://education.gov.scot/media/2swjmnbs/frwk2_hgios4.pdf (accessed on 21 May 2024).
43. Institute of Physics. *Subject Knowledge for Teaching Physics: A Framework for Teachers of Physics*; Institute of Physics: London, UK, 2024; pp. 1–14.
44. Institute of Physics. *Subject Knowledge for Educating Teachers of Physics: A Framework for Physics Teacher Educators*; Institute of Physics: London, UK, 2024; pp. 1–14.
45. Institute of Physics. IOP Spark [Internet]. 2024. Available online: https://spark.iop.org/framework (accessed on 21 May 2024).

46. Schön, D.A. *Educating the Reflective Practitioner: Toward a New Design for Teaching and Learning in the Professions*; Jossey-Bass: San Francisco, CA, USA, 1987; pp. 1–355.
47. Kennedy, A. Understanding continuing professional development: The need for theory to impact on policy and practice. *Prof. Dev. Educ.* **2014**, *40*, 688–697. [CrossRef]
48. Priestley, M.; Biesta, G.; Robinson, S. *Teacher Agency*; Bloomsbury: London, UK, 2015; pp. 1–186.
49. Sachs, J. *The Activist Teaching Profession*; Open University Press: Maidenhead, UK, 2003; pp. 1–171.