Fostering Learning Improvements in Physics

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Setting the Scene

Physics Education Research (PER) - discipline-based research into the teaching and learning of physics at Higher Education (HE) level - is a relatively young branch of applied physics that arose primarily from studies of student difficulties with the basic concepts of physics. From these beginnings it became clear that what is taught and what is actually *learned* in tertiary level physics can be very different things. PER is now an internationally recognised field of applied physics that touches on many aspects of the undergraduate physics curriculum and on teaching and learning more broadly. Nevertheless, it is instructive to consider the impact of the outputs of the field not only in terms of contributions to knowledge but also in relation to changes in practice and attainment in the classroom. These two factors do not necessarily go hand-in-hand.

The Fostering Learning Improvements in Physics (FLIP) project aimed to investigate how advances in teaching and learning in undergraduate physics education are achieved. Within this broad topic, we focussed on two distinct research themes: the prevalence and impact of PER, both in the UK and internationally; and how UK undergraduate physics teaching develops in practice. Five research questions were identified for the study:

- How does the field of PER in the UK compare to that in Europe, Australia and the United States?
- What factors have supported communities of PER practitioners capable of producing high-impact knowledge advances and/or widespread dissemination of PER knowledge advances?
- What is the relationship between PER and the diffusion of improved teaching and learning in undergraduate physics?
- How has improvement in UK undergraduate physics teaching and learning occurred in practice and which factors have encouraged and discouraged improvement?
- What are the likely necessary conditions to build and sustain a UK PER community with the capacity to foster improvements in undergraduate physics teaching and learning?

Research approaches

Data were collected through a mixed-method study consisting of: a targeted review of the relevant literature; focus groups with UK physics teaching staff; online surveys with UK physics teaching staff and with PER practitioners in the UK, wider European Union (EU) and Australia; follow-up in-depth interviews with UK-based physics teaching staff and UK-based PER practitioners; and a funding survey.

Survey response rates were high, with staff at over 80% of UK physics departments represented in the physics teaching survey. Researchers from at least 80 universities in 21 countries took part in the PER surveys. Interviewees were selected from willing survey respondents and chosen to reflect the range of demographic characteristics and attitudes demonstrated in the surveys.

Key Messages

The prevalence and impact of PER

We considered the impact of PER upon undergraduate learning, the communities of practice undertaking PER internationally, and factors likely to sustain impactful discipline-based PER in the UK. Key findings are:

- When adequately supported and strategically promoted, PER is capable of fostering improvement in undergraduate physics education.
- Diffusion of PER and PER-based innovations into teaching practice remains a significant and complex challenge.
- A threshold level of funding is necessary to allow PER to develop as an academic field.
- Funding for PER is a necessary but not sufficient condition to ensure impact on undergraduate physics learning.
- Advocacy for PER by cohesive communities of practice, prominent researchers and professional bodies aids development of the field.
- The relationship of PER to the wider physics community is key to the development of the field and its impact on undergraduate teaching.
- UK PER is relatively widespread among physics departments and is supported by informal national networks.
- UK PER is best characterised as a 'cottage industry', with most researchers conducting PER as an optional extra in their jobs.
- There is limited formal support for UK PER from departments, institutions and national bodies.
- The threshold level of funding required to develop PER in the UK is not currently achieved, as most PER is funded through one-off, low-value, teaching development grants from institutions.

How UK undergraduate physics teaching develops in practice

We considered UK physics instructors' attitudes toward, and experiences of, undergraduate teaching, including their engagement with teaching enhancement and professional development. Key findings include:

- The majority of UK physics teaching staff find teaching enjoyable and personally rewarding and derive satisfaction from teaching enhancement activities.
- Many staff are open to learning more about how PER could be used to inform their teaching development.
- Conceptions of teaching excellence are varied and often relate to individual experiences or departmental procedures.
- A number of identified challenges to high-quality undergraduate physics education are similar across the UK. Staff across all regions and types of university raised concerns about deficits in mathematics among incoming students, engaging students in large classes, and effective teaching of mixed-ability cohorts.

- Staff believe the achievement of teaching excellence may be thwarted by intense time pressure and by reward and recognition policies that are perceived to favour research excellence.
- Teaching staff report high levels of dissatisfaction with the generalised lecturer training that is most commonly provided.

Recommendations

Drawing on our findings, we make the following recommendations:

1. ***The strategic development of UK PER***
   i) We recommend strengthening existing networks to develop a cohesive academic community for UK PER that has the ability to work toward common priorities and coordinate advocacy for the field within the country.
   ii) We suggest that both informal promotion through local and national networks and formal lobbying – e.g., seeking endorsement from national bodies – would be of benefit in raising the profile of the field.

2. ***Funding for UK PER***
   i) We recommend that stakeholders concerned with undergraduate physics education work to identify funding streams for PER which support basic research and allow for the development of researchers and research projects over time. Specifically, funding should be sought for PhD studentships and postdoctoral research positions in PER, and multi-year research projects.
   ii) We note that funding from a well-respected national body may also serve to validate PER within the physics community and to promote research topics that address national priorities.

3. ***Addressing common teaching challenges***
   i) We recommend that the PER community prioritises some of its research effort in areas that have the potential for widespread impact across UK undergraduate learning and teaching of physics. We note the value of cross-institutional collaborations in this area.
   ii) We further recommend that those developing funding strategies for PER take a portfolio approach which supports both fundamental research and 'roll-out' projects aimed at embedding sustainable teaching enhancements.

4. ***Developing teaching practice***

   i) We recommend departments, institutions and professional bodies consider provision for initial and continuing professional development for UK physics teaching staff which is both subject-focussed and evidence-based. We further recommend that this should be based on a partnership model including physics teaching staff and PER practitioners as well as teaching and learning development professionals. We note the potential value of PER in this area.

5. ***Valuing excellent teaching***
   i) We recommend that institutional management, departmental management and teaching staff work to develop a shared understanding of teaching excellence and workable measures of teaching quality. We note that relevant studies in PER may usefully inform this process.

ii) We recommend that institutions work to counter the widely held view that there is a disconnect between reward and recognition policies and practice in relation to teaching. We urge greater transparency regarding promotion decisions based on teaching contributions.
iii) We recommend that institutional and departmental management ensure staff have adequate time for reflective teaching, teaching enhancement and sharing of good practice. We further recommend that they provide an infrastructure and promote a culture in which teaching is afforded legitimacy and prestige equal to other academic functions.

1. Introduction

Discipline-based research into the teaching and learning of physics at Higher Education (HE) level - Physics Education Research (PER) - is a relatively young branch of applied physics. Its origins can be traced back to the USA in the late 1970s, where it was initially focussed on student difficulties with basic physics concepts. In a relatively short space of time it became clear that what was being taught and what was actually *learned* in tertiary level physics could be very different things (McDermott, 1991). Since then, PER has developed into an internationally recognised field. While its roots lie in curriculum development and instructional design, research now encompasses both the 'applied', e.g., evaluating the effectiveness of a new teaching intervention, to the relatively 'pure', e.g., collaborative learning and models of discourse. Nevertheless, PER retains a strong disciplinary focus at its core:

> *'PER is focused inquiry into what happens as students struggle to grasp and use the concepts of physics'* (Beichner, 2009).

The impact of PER can be considered both in terms of contributions to knowledge and changes in practice and attainments in the classroom. These may be quite different. For example, in his landmark paper Bloom (1984) notes that 1:1 tutoring could move a classes marks up by two standard deviations: a huge effect. However, while this remains an important benchmark of what has been proved possible (high knowledge contribution), for cost reasons it will never be rolled out (zero adoption). Related to this, it may also not necessarily be a safe assumption that further research is a precondition for adoption and progress in teaching and learning practice. Thus, the question arises as to whether funding should be for 'research' projects or 'rollout' projects. One example of the latter is the REAP (Re-engineering Assessment Practices) project, which achieved substantial adoption of innovative course designs in a Scottish university (Nicol & Draper, 2009). This broadly followed the approach taken by Twigg (2003), in which client course teams are promised a fixed sum with no requirement to account for the money, but project plans are constructed interactively in advance and funding is not released until course evaluation data is delivered.

The Fostering Learning Improvements in Physics (FLIP) project aimed to investigate how advances in teaching and learning in undergraduate physics education are achieved. Within this broad topic, the study included two distinct strands. One aspect surveyed the prevalence and impact of PER internationally. In particular, we sought to examine the provision for and achievements of PER in the United States, Europe and Australia as well as the current state and future prospects of the field in the UK. These findings provide the basis of an informed consideration of the potential for sustainable, subject-based PER at HE level in the UK and its potential impact on undergraduate teaching and learning. Concurrently, we studied how UK undergraduate physics teaching develops in practice. We were particularly concerned to identify factors which support and challenge excellent teaching and learning and to understand what drives and constrains change within physics departments. This work underlies recommendations to promote and sustain high-quality teaching, encourage future development and dissemination of beneficial teaching innovations, and overcome barriers to improvement currently faced by UK teaching staff.

In the following section we outline the method used in the project. We then present key results and conclude with recommendations arising from the work. These are addressed to a broad audience including physics teaching staff, PER practitioners, physics departmental and university managers, funders and policymakers.

This report and supporting briefing papers summarising key points of relevance for stakeholder groups are available on the project website http://www.ph.ed.ac.uk/flip.

2. Method

The FLIP project had two core objectives: to assess the prevalence and impact of PER, both in the UK and internationally; and, to study how UK undergraduate physics teaching develops in practice. Within this broad framework, five underlying research questions were identified:

- How does the field of PER in the UK compare to that in Europe, Australia and the USA?
- What factors have supported communities of PER practitioners capable of producing high-impact knowledge advances and/or widespread dissemination of PER knowledge advances?
- What is the relationship between PER and the diffusion of improved teaching and learning in undergraduate physics?
- How has improvement in UK undergraduate physics teaching and learning occurred in practice and which factors have encouraged and discouraged improvement?
- What are the likely necessary conditions to build and sustain a UK PER community with the capacity to foster improvements in undergraduate physics teaching and learning?

A mixed-method approach was employed, consisting of five stages: preliminary desk-based research; online surveys; in-depth interviews; a funding survey; and a targeted literature review.

Research was conducted between January 2013 and January 2014.

2.1 Initial desk-based research

Initial research identified several recent and relevant studies of the PER landscape in the United States. Key references include a series of papers by Henderson and co-workers, including a PER funding census (Henderson, Barthelemy, Finkelstein, & Mestre, 2012); a small-scale interview-based study of physics instructors' awareness of and attitudes towards PER (Henderson & Dancy, 2008); a large-scale study of the impact of PER on the teaching of introductory physics (Henderson & Dancy, 2009); and a small-scale study of postgraduate and postdoctoral experiences of PER (Barthelemy, Henderson, & Grunert, 2013). Additionally, in-depth reviews of the status of physics and discipline-based STEM education research in the USA have been commissioned by the NSF (National Research Council, 2012, 2013) . Together, these studies characterised the state of contemporary US PER. We therefore excluded the USA from our primary data collection and focused on the UK, the wider EU and Australia.

2.2 Online surveys

We conducted four online surveys: three regionally specific surveys for PER practitioners based in the UK, the wider EU and Australia; and a survey for UK staff involved in undergraduate physics teaching.

For the physics teaching (PT) survey, initial survey questions were refined following focus groups with physics teaching staff at three UK universities. Focus group members were particularly helpful in their suggestions of how to boost participation in the study.

Substantial effort was applied to raising the profile of the project amongst UK and international physics communities both by direct appeals to key individuals and via a social media campaign. The surveys ran concurrently for three weeks, from 23 April to 14 May 2013.

As shown in Table 2.1, response rates for our surveys were high, with staff at over 80% of UK physics departments represented in the PT survey and researchers from over 20 countries taking part in the PER surveys. The strong response rate to the PT survey spanned all regions of the UK and all types of institution. International respondents to the PER survey represented a reasonably broad range of 72 identified institutions.

Table 2.1 Number of survey respondents

UK surveys		
	Physics Teaching (PT)	**Physics Education Research (PER)**
All responses	281	41
Complete responses* (% of all responses)	247 (88%)	30 (73%)
Institutions represented (% of physics depts.)	37 (82%)	18 (40%)
International PER surveys		
	Wider EU	**Australia**
All responses	85	48
Complete responses* (% of all responses)	76 (89%)	39 (81%)
Countries represented	19	1

**Responses were considered 'complete' where respondents click through to the final page of the survey, regardless of whether all questions had been answered.*

Respondents to the UK PER survey were based at 18 universities, indicating that there are PER groups or individuals doing PER in at least 40% of UK physics departments. Based on our knowledge of the UK PER community, we believe this sample represents a reasonably complete census of currently active UK PER practitioners. Similarly, a survey of physics teaching staff conducted for a Higher Education Academy report, *Review of the Student Learning Experience in Physics* (Edmunds, 2008) identified roughly 50 staff in UK departments who had undertaken PER and 30 who had published in this research area.

The job titles of survey respondents are shown in Table 2.2. It is evident that senior academics are particularly well represented in the UK physics teaching survey, with nearly a third of respondents at professorial level. This notably contrasts with the UK PER survey sample, where the same percentage identified as Teaching Fellows. Nationally, 18% of academic staff in physics departments are at professorial level (McWhinnie, 2013), suggesting that this group is somewhat over-represented in the physics teaching sample and under-represented in the PER sample.

Table 2.2 Job titles of survey respondents

	UK PT	UK PER	Wider EU PER	Australia PER
Professor	**30%**	13%	16%	13%
Associate Professor	-	-	16%	**23%**
Reader	16%	10%	1%	-
Senior Lecturer	14%	17%	7%	17%
Lecturer	23%	13%	15%	17%
Research Fellow	3%	3%	5%	2%
Teaching Fellow	4%	**30%**	1%	-
Postdoctoral Researcher	3%	-	9%	-
Postgraduate Student	-	13%	**17%**	6%
Other	7%	1%	13%	22%

In general, respondents to the UK physics teaching survey have many years of teaching experience. Indeed, as shown in Table 2.3 the majority have worked at their institution for more than 10 years. They are therefore likely to have a good understanding of local issues.

Table 2.3 Years worked at institution (UK - PT survey only)

	<1	1-2	3-4	5-10	>10
Percentage of respondents	7%	6%	9%	25%	**53%**

Female representation in the UK physics teaching sample, see Table 2.4, is broadly in line with national data, which indicate that 16% of physics academic staff are female (McWhinnie, 2013). In comparison, 38% of UK PER practitioners are female. This may reflect the high proportion of Teaching Fellows in the PER survey: Nationally, females comprise 29% of teaching-only physics staff (McWhinnie, 2013).

Table 2.4 Gender of survey respondents

	UK PT	UK PER	Wider EU PER	Australia PER
Male	81%	63%	60%	81%
Female	19%	38%	40%	19%

2.3 In-depth interviews

Follow-up in-depth interviews were carried out with 40 UK-based academic staff between June and August 2013. Participants were selected from survey participants who had volunteered. We designed three interview schedules, relevant to the differing professional roles of our volunteers. These were: a physics teaching interview (PT); a physics education research interview (PER); and a combined interview, for individuals involved in both teaching and PER. In all cases, interviews focused on emergent themes from the survey data and allowed further exploration of individuals' responses and their local context.

Due to the relatively small number of UK PER survey respondents, all individuals who volunteered for an interview received an invitation (n=17). These invitations led to 12 PER interviews.

The large number of physics teaching staff volunteering for interview (n=63) required the adoption of selection criteria. Since part of the interview rested upon earlier answers, we favoured individuals with more complete survey returns, and attempted to fairly sample the full range of attitudes toward teaching and PER exhibited in the survey responses. This strategy is likely to have introduced a degree of bias into our interview sample as teaching staff who returned more complete surveys tended to hold more extreme views than the full survey sample, being either more positive or more negative to both teaching and physics education research. This means that teaching staff who expressed either mildly negative or mildly positive views in the survey were less likely to be asked for interview, as a consequence of them tending to submit less complete survey responses.

We remained mindful of this bias when analysing the interview data, which were intended to provide us with a deeper understanding of the attitudes reported in the survey. In particular, the large data sets generated by the surveys enabled us to situate the interview data appropriately amid the more representative survey sample.

We held interviews with staff from 25 universities in total, visiting each institution where an interviewee worked. The institution sample was diverse, including Ancient, Red Brick, Post-'92 and a distance learning university, and spanned most regions of the UK. Table 2.5 shows the number of each interview type conducted.

Table 2.5 Number of interviews conducted by type

PT	PER	Combined
28	4	8

2.4 Funding survey

A funding survey was carried out to identify and query likely funders of PER in the UK. Additionally, as part of the international PER surveys, respondents in the UK, Europe and Australia were asked to list all PER project grants for which they had been Principal Investigator (PI) since 2003. Response rates are summarised in Table 2.6. US funding data was taken from a recent survey conducted by Henderson et al. (2012).

We believe the data collected through the surveys represent a lower limit on the actual funding received for PER over this time period. Some respondents did not detail the value of received funding, while others informed us they had skipped the question entirely, having found it too time-consuming. Based on desk-based research and our own knowledge of the UK PER landscape, we are however confident that the major regional funders of PER were identified through the surveys. Additionally, for the UK we contacted the most frequently mentioned funders, with a request for information regarding their funding of PER over the past decade. Where these data were obtained, we could see no significant differences in the grants listed by UK survey respondents and the records held by these funders.

Table 2.6 Self-identified PIs of PER project grants since 2003

	UK	Wider EU	Australia	US*
Number of self-identified PIs (% of complete responses)	14 (47%)	32 (38%)	27 (56%)	130 (55%)

**Data refer to the period 2006-2010 (Henderson et al., 2012)*

2.5 Targeted literature review

The final stage of research consisted of a targeted literature review of PER. This search was framed by the challenges identified by physics teaching staff, and by the examples of knowledge advancement, widespread adoption and dissemination of teaching innovations and local impact on teaching and learning that were provided by PER practitioners. These responses enabled us to collate and summarise examples of key pieces of high-impact PER.

2.6 Project consultation

Helpful feedback was obtained over the course of the study from our external advisor, Professor Martin Hendry, School of Physics and Astronomy, University of Glasgow. We also received useful input from the Institute of Physics (IOP) Education Committee, who were presented with interim results of the project in June 2013. Late stage results were presented at the FLIP symposium, held in February 2014 in London. Feedback from delegates – including physics teaching staff, physics education researchers, staff responsible for educational and academic professional development, and representatives from the IOP and the Higher Education Academy (HEA) – informed the final version of this report.

3. The prevalence and impact of Physics Education Research

We first examine evidence that work in PER has brought about demonstrable improvements in undergraduate learning, whether by amassing a useful body of knowledge about how undergraduates best learn physics or by developing and disseminating research-based resources and techniques for classroom use. We then discuss the community of practice that takes part in this field of research in the UK, comparing it to those in other international regions and commenting on factors that support or challenge the field. Finally, we consider what can be learned from this international comparison about sustaining impactful discipline-based education research in physics.

3.1 Can PER improve undergraduate physics learning

Though still a relatively young field, PER has produced several seminal results that have significantly advanced understanding of how undergraduate students learn physics. The most frequently cited by those in the field is that students come to their study of undergraduate physics with common strongly-held but incorrect conceptions of the physical world. Early work in PER identified some of these erroneous beliefs and provided rigorous evidence that traditional lecture-style courses do little to change them (McDermott, 1991). The development of easy-to-use diagnostic tests that can be used to probe students' conceptual understanding (e.g., Hestenes, Wells, & Swackhamer, 1992) further established that these findings were general over a wide range of local contexts and were largely independent of lecturing style and student cohort (Hake, 1998).

Related to this, a second strand of work which PER practitioners consider to be seminal is the identification of alternative instructional methods that produce significant improvement in students' conceptual understanding of physics. Among the most commonly cited by those in the field are pedagogically-structured tutorials (McDermott & Shaffer, 2003), peer instruction (Crouch & Mazur, 2001) and problem-based workshops (Laws, 1991). Key principles of these methods are that they focus attention specifically on student reasoning, including commonly held preconceptions, and that they encourage and support students to be actively engaged in their own learning. Students taught with methods emphasizing active engagement are typically found to exhibit learning gains, as measured by conceptual tests, in excess of twice those of students taught in traditional lectures (e.g., Hake, 1998). A number of PER-based instructional methods have been disseminated widely and extensively tested. Like the deficits identified with traditional lectures, the learning gains associated with evidence-based methods appear to hold over a broad range of local contexts (for a recent review, see Meltzer & Thornton, 2012).

In addition, existing and ongoing work in PER covers a broad range of topics related to understanding and improving undergraduate learning and teaching. Those most frequently discussed by PER practitioners include:

- Problem-based learning pedagogies, and how best to foster flexible problem-solving abilities among students (e.g., Chi, Feltovich, & Glaser, 1981; Duch, 1996; Heller & Hollabaugh, 1992; Heller, Keith, & Anderson, 1992; Meltzer, 2005; Raine & Collett, 2003);
- Student attitudes towards and beliefs about physics, and how best to promote 'expert-like' views of the subject among learners (e.g., Adams et al., 2006);

- Environments for learning, including optimizing physical, social and/or on-line spaces to meet students' needs (e.g., Beichner et al., 2007; Belcher, 2003; Breslow, 2010; Brewe, Kramer, & O'Brien, 2009; Brewe, Kramer, & Sawtelle, 2012; Gaffney, Richards, Kustusch, Ding, & Beichner, 2008);
- Technology-assisted and distance learning, e.g., simulations, interactive screen environments, etc. (e.g., Perkins et al., 2006);
- Under-represented demographics in physics, and how best to attract and retain women and minority students (e.g., Lorenzo, Crouch, & Mazur, 2006; Madsen, McKagan, & Sayre, 2013); and
- Assessment strategies to effectively demonstrate student learning and appraise teaching and innovations in teaching (e.g., Ding, Chabay, Sherwood, & Beichner, 2006; Hake, 1998; Hestenes et al., 1992).

However, while PER appears to offer a compelling body of knowledge about how students learn physics, this does not, in itself, demonstrate that the field is capable of making a significant impact on the experience of undergraduate learners. To effect learning improvements for large numbers of students, PER findings and PER-based innovations must be broadly disseminated and crucially, physics instructors must choose to make use of them in their teaching.

Nevertheless, there are examples of widely disseminated, evidence-based innovations in undergraduate physics teaching. In the US, commercially distributed materials range from resources to be used flexibly within traditional lectures (e.g., Interactive Lecture Demonstrations; Sokoloff & Thornton, 1997), to tutorials designed to supplement existing course elements (e.g., Tutorials in Undergraduate Physics; McDermott & Shaffer, 2003), to full course curricula (e.g., Workshop Physics; Laws, 1996). Evidence-based teaching innovations commonly used in the UK include peer instruction utilising interactive audience response systems ('clickers'; e.g., Crouch & Mazur, 2001) and problem-based learning strategies (e.g., Raine & Collett, 2003; Sahin, 2009).

Both in the UK and internationally, there seems to be a high level of awareness of PER innovations among physics instructors. In the UK, 95% of respondents to the teaching survey were aware that PER existed and 64% were familiar with at least one evidence-based technique (see Table 3.1). By comparison, in a survey of over 700 physics instructors in the US, Henderson & Dancy (2009) found the majority (87%) were aware of at least one research-based instructional strategy.

Table 3.1 Awareness and use of PER-informed enhancements by UK physics teaching staff

Aware that PER exists?		Aware of specific PER-informed teaching techniques?		Applied these in own teaching practice?	
Yes	95%	Yes, at least one	64%	Regularly / occasionally	60%
No	5%	Yes, but don't know much about them	30%	Tried but stopped	6%
		No	6%	Never tried	34%

Most of the UK respondents had learned about these techniques through word-of-mouth from other instructors.

Rates of adoption of research-based innovations also appear reasonably high, with roughly half the teaching staff in the US sample and over 60% of the UK sample having tried at least one evidence-based approach in the classroom (see Table 3.1). However, Henderson & Dancy (2009) report that US teaching staff rarely adopt teaching innovations wholesale, commonly making significant adaptations to better suit their local situation. In doing so, they may modify elements of the innovation that researchers would consider to be key to their efficacy.

There are quite high rates of discontinuance among the US staff who have tried research-based strategies, ranging from 30-55% depending on the specific innovation tried. Commonly cited reasons for discontinuing a PER-based method are that it took too much class time and/or 'didn't work'. Henderson & Dancy (2009) suggest that this high rate of discontinuance of teaching reforms may reflect a lack of knowledge among teaching staff about how to appropriately customise them to their local situation. Henderson, Turpen, Dancy, & Chapman (2014) further highlight that a lack of consensus over assessment of teaching quality may influence determinations of whether teaching innovations have been successful. Writing of the US situation, Henderson & Dancy (2008) note that:

> *'Most physics instructors continue to use traditional teaching practices and ... dissemination of reforms is an important unsolved problem'*

3.2 UK PER: Who, what and how

One major aim of the FLIP project was to compare the status and impact of PER across international regions, both to note the factors which support the development of the field and to comment upon its potential to impact undergraduate physics education within the UK. PER is most fully developed in the US, where it is possible to gain considerable insight into the community of PER researchers through published literature. To our knowledge, there is little available literature describing communities of PER practitioners outside of the US. Our impressions of the landscape for PER in other regions are therefore based mainly on responses to the online surveys developed for this study (described in Section 2.2). We focus here on the community of PER practitioners within the UK, with reference to findings from other regions where relevant. Summaries of our findings related to the US, the wider EU and Australia are included as appendices to this report.

3.2.1 Profile of UK PER practitioners

UK respondents to the PER survey are overwhelmingly based in and trained by physics departments; 92% work in physics departments (see Figure 3.1) and 84% hold PhDs in traditional areas of physics. Internationally, PER is a more diverse field and the extent to which it finds an intellectual home within physics departments varies by region. In the wider EU, for example, 33% of the self-identified PER practitioners we surveyed are based in education departments and only 25% hold PhDs in traditional areas of physics.

Within the UK many practitioners felt strongly that PER must be based within physics departments. As one senior teaching fellow explained:

> *'Links with schools of education are very useful but there needs to be the direct link to physics. [PER] requires an in-depth knowledge of the subject. It would be*

impossible if you didn't have a physics background. The scientific approach to conducting [PER] strikes me as being very natural if you're a physicist. Also, in the terms of convincing our physics colleagues that this is relevant I think we have a much better stance. There is quite a wide gap with schools of education… it's sometimes very difficult to find a common terminology.'

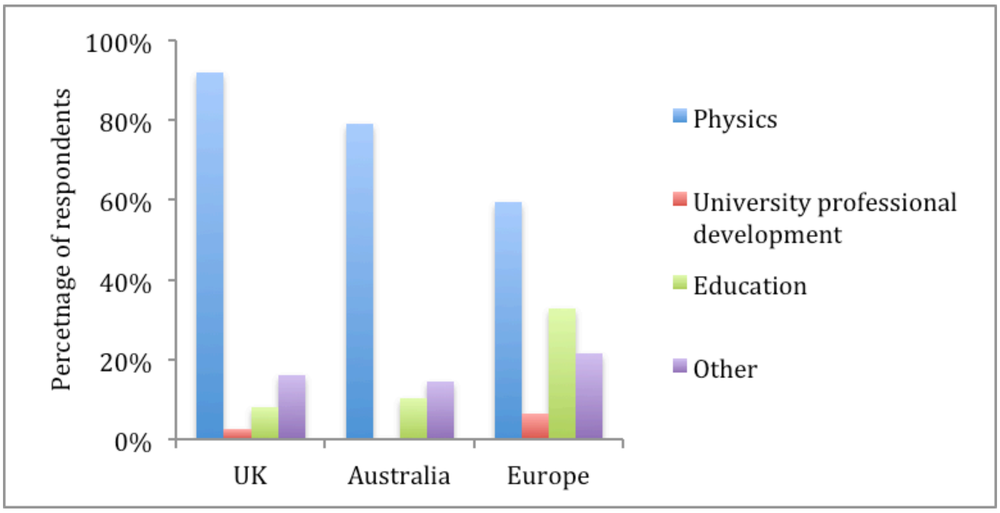

Figure 3.1 Departmental affiliations of PER practitioners

Although there is a large degree of overlap between the sample of UK PER practitioners and the larger sample of respondents to our survey of UK teaching staff, there are some conspicuous demographic differences between them, in particular:

- PER practitioners and physics teaching staff have similar age distributions, however PER practitioners are underrepresented at senior level (13% are Professors, compared to 30% of the physics teaching staff survey, see Table 2.2).
- A significant number of PER practitioners are employed in teaching-focused jobs (30% are Teaching Fellows, see Table 2.2, and 38% described their primary professional activity as teaching or mostly teaching compared to 17% of the physics teaching staff survey).
- PER practitioners are more likely to be female (38% compared to 19% of the physics teaching staff survey, see Table 2.4 and accompanying discussion). Women also appear to be over-represented in PER relative to the wider physics community in the US, where it has been suggested that an exploration of the attributes of PER which attract women may help to shed light on the overall gender gap in physics programmes (Barthelemy et al., 2013).

Strikingly, it also appears that most PER in the UK is done by staff who are primarily employed to do other things. Over half the respondents, a larger fraction than in any other region, reported that they conducted research in a traditional area of physics. This sense that PER is an activity done 'on the side' is not confined to the UK, where the field is still emerging. It also seems to be a common model in Australia, where over 75% of physics departments contain staff conducting PER.

It is telling that UK respondents report that PER is often allowed rather than expected, and that it is often done outside standard working hours. One Teaching Fellow explained:

'My responsibilities here are to teach as much as possible to lighten the load of everyone else doing discipline research. No one has ever complained that I'm doing [PER] - as long as I'm willing to put in 80-hour weeks, it's fine. The first 50 hours are for delivering all the courses, marking the tutorial work [and] dealing with administrative stuff.'

In addition to PER not being central to job roles, many respondents felt it is an undervalued component of their work. UK PER practitioners are less likely than their international counterparts to believe that their work in PER is a factor in reward and recognition. Nearly 30% of survey respondents felt it was *never* taken into account in promotion decisions, while one in five stated that they did not know whether it was a factor (for UK data, see Table 3.2). In contrast, a minority felt that *only* teaching contributions that have a broad impact on the community should be rewarded.

Table 3.2 Perceived support for PER practitioners (UK only)

	Yes	Mixed	No	Don't know
Do you feel your PER activities are well-supported by the physics department?	37%	27%	30%	7%
Do you think PER is well-regarded by physics staff who know about it?	17%	67%	13%	3%
Does your work on PER factor into reward and recognition?	6%	45%	29%	19%

Thus work in PER appears to be an optional extra for many UK practitioners, to the extent that PER in the UK could reasonably be thought of as a 'cottage industry'. As in Australia, there is little dedicated time for PER research in the UK, with just one in five respondents spending at least half their non-teaching time on PER. Indeed, one senior lecturer referred to PER as a 'hobby', while one professor detailed how his institution's PER group was formed through individual rather than departmental interest:

'There are a couple of people with interests… a small group of people who occasionally discuss things… [but] there is little incentive to do it and that group probably [owes] more to the fact that some people wanted to do it rather than it is something the school really thinks is important.'

Given this dynamic, it is perhaps not surprising that PER appears to be less established as an academic field in the UK than in other international regions, as judged by some common hallmarks of academic communities. For example, only 38% of UK respondents reported publishing in PER at least once a year, the lowest percentage of all regions we surveyed. While over half the UK respondents worked in an institution with a PER group and over 40% in one which offered PER PhD studentships, it should be cautioned that these responses arise from just a few institutions which produce very few PER PhDs in absolute terms. UK respondents were also overwhelmingly negative about career prospects in PER. Just one UK respondent believed that there were well-defined career paths for PER practitioners within the country, compared to a quarter of respondents in Australia and almost a third in the wider EU (see Table 3.3).

Table 3.3 Percentage of PER practitioners who think there are well-defined PER career paths

UK	Wider EU	Australia
4%	28%	24%

More positively, levels of community cohesion appeared to be higher in the UK than in other international regions outside the US. There was reasonable consensus over preferred dissemination routes for UK PER. The most frequently attended conferences were at national level – the ViCE/PHEC (69%) and HEA STEM (62%) meetings – but significant minorities also attended the European GIREP-EPEC conference (46%) and the American AAPT conference (38%). Respondents commonly published in *The European Journal of Physics* (50%) or the national-level journal *New Directions* (50%). One in five respondents had also published in American journals such as *Physical Review Special Topics: Physics Education Research*.

Perceptions of a supportive community for PER were also somewhat more favourable in the UK than in other regions outside the US. 89% of respondents felt there were both national and international communities of PER researchers (see Table 3.4), and the same fraction reported taking part in collaborations relating to PER. 79% reported membership of formal or informal PER networks.

Table 3.4 Percentage of PER practitioners who think a PER research community exists

	UK	Wider EU	Australia
Nationally	89%	64%	82%
Internationally	89%	89%	84%

3.2.2 Research topics in PER

Physics education researchers in the UK shared a more uniform research focus than those in other regions, at least with respect to the educational level they studied. All the UK respondents studied physics education at undergraduate level and fewer than 1 in 5 did research focused on any other level. While HE studies were prominent in all international regions, PER researchers in other regions often reported researching pre-university level teaching and learning. In the wider EU, in particular, PER was most commonly reported at secondary school level and researchers were frequently involved in training school teachers.

UK PER researchers described a wide variety of ‘hot topics’, among them:

- Technology-assisted learning;
- Problem-based learning;
- Laboratory instruction;
- Flipped classroom pedagogies / peer instruction; and
- Employability.

The most commonly cited areas of study by UK researchers – technology assisted learning and problem-based learning – were also among the most commonly reported by researchers in the wider EU and Australia, suggesting some degree of international consensus about priorities for the field. Most UK respondents (73%) felt these issues had risen to prominence because of the interests of PER practitioners themselves, though half also believed problems identified by teaching staff played a role in setting the PER research agenda. Both these factors were reported to influence topics of study for PER in the wider EU and Australia as well. However, the perceived influence of funding patterns and national and international priorities was more widespread in these regions than in the UK.

3.2.3 Grant funding for PER

UK respondents identified 43 grants related to PER over the ten years to 2013, worth a total of £3.8m. As shown in **Error! Reference source not found.**, just under half of the survey respondents reported having secured funding to conduct PER and the average number of grants was three. These reported grants were diverse, however, and included several projects which were only partially or tangentially associated with PER.

Financial support for PER, and particularly funding from national sources, is much more scarce in the UK than elsewhere:

- The median grant value for PER in the UK is £7k. This is indicative of the level of most practitioners' research funding and is only a quarter to a tenth of that in other international regions (US data from Henderson et al., 2012).
- The average grant value for PER is £102k. This is lowest of all regions except Australia. However, this value is significantly affected by a small number of very large grants for projects in which PER played only a small role – e.g., funding for the establishment of a Centre for Excellence in Teaching and Learning.
- The estimated annual funding per UK PER respondent is £13k.[1] This is roughly equivalent to that in Australia, 80% of that in the wider EU, and half that in the US. This value is also strongly influenced by a small number of large grants only tangentially aimed at PER.

UK respondents are also unique in reporting no funding whatsoever from national research councils and a very low fraction of grants from any publicly funded body. Projects funded through government for which details were provided were all funded through the Higher Education Funding Council for England (HEFCE) and included the £1.6m grant for the Centre for Excellence described above and two additional enterprise awards of £6k.

Roughly a third of the reported grants, providing 41% of all reported funding, were awarded by professional bodies run as charities, including the HEA, the IOP, Jisc and the Wolfson Foundation. The average and median award sizes in this category were £105k and £7k, respectively. The largest share (49%) of grants by number was provided in small awards at institutional level. These grants provided less than 10% of the total funding for PER by value, with average grant sizes of £13k. Only one EU-funded grant was reported in the UK survey, a £250k award for researcher development.

[1] Estimated from survey data by dividing the total funding reported by the time period covered by the survey and the number of PER practitioners in the full survey samples.

In summary, the majority of all funded PER projects within the UK appear to focus on development of resources or teaching practice, often funded by small 'one-off' institutional teaching development grants, with very few clearly focused on basic research into the teaching and learning of physics.

3.3 Sustaining PER capable of improving undergraduate learning

Our review of the achievements of PER and of the international landscape for work in this area suggest several key factors which impact the capacity of the field to become an established research area which effectively improves undergraduate learning. We discuss these below and comment on the implications for PER in the UK.

3.3.1 Financial support

Significant progress toward fundamental discoveries and/or useful applications of new knowledge in any field requires investment. While we cannot illustrate from our data that there is a straightforward relationship between higher levels of PER funding and a greater positive impact on undergraduate physics education, it is clear that the establishment of PER as a sustainable research field in the US would not have been achieved without significant levels of investment over the last three decades. Likewise, where researchers have been able to access higher levels of funding in the wider EU and Australia, PER appears to be better established as an academic field and/or more widespread among physics departments.

When asked which single change could do most to enhance the status and impact of PER, additional research funding was suggested by sizeable minorities of respondents in all international regions. In addition, they stressed the need for particular kinds of funding. In both surveys and interviews, PER practitioners emphasized that, in their view the key priorities were funding for basic research, longer-term funding, and funding which would allow the development of researchers through PhDs and postdoctoral positions.

The history of the growth of PER in other international regions provides some specific examples of effective funding routes. Three approaches are:

- In the US, the National Science Foundation (NSF) funded 62 postdoctoral positions for discipline-based education research in STEM disciplines between 1997 and 1999 (the Postdoctoral Fellowships in Science, Mathematics, Engineering, and Technology Education (PFSMETE) scheme). These fellowships were intended to build bridges between science disciplines and education researchers (National Research Council, 2012). Although the scheme was cancelled after three funding rounds, it is significant as it provided an infusion of staff just as the field was expanding and conferred legitimacy to the field through association with a national funding body (Libarkin & Finkelstein, 2001; National Research Council, 2012). In this case, even short-term funding from a national source played an important role in establishing the field.
- The NSF continues to provide significant support for PER in the US. Between 2006 and 2010 it funded an estimated 167 grants worth a total of \$66.4M (average grant size \$398k), corresponding to about 75% of all funding for PER in the US (Henderson et al., 2012). It is widely recognised that this support has been a crucial factor in the promotion and acceptance of PER as a discipline in the US (National Research Council, 2013).
- In Australia, national-level public bodies have provided over 90% of the reported funding for PER over the last ten years. Australian respondents were most likely to believe the PER research agenda was set by national priorities, and they exhibited the

highest levels of consensus over key research topics for PER. Here, a prolonged national funding strategy has clearly defined research areas of national importance.

While funding was a concern in all regions we studied, the funding environment in the UK appears to be particularly challenging. Specifically:

- Median grant sizes for all funding types are markedly smaller in the UK than in other regions.
- There is no evidence of support through research councils and other governmental sources as is seen in other regions.
- The most common form of funding for UK PER is through low-value, short-term institutional teaching development awards, which cannot be used to develop long-term research projects or research teams.
- The most common funding schemes reported in the survey – through the HEA Physical Sciences Centre and HEFCE's Centres for Excellence in Teaching and Learning – are now no longer available.

Over a third of UK survey respondents – the largest percentage of any international region – identified increasing funding for PER as the single change which could best support the field. Addressing this issue is a key priority for the growth of PER within the UK.

3.3.2 Developing a research community

Academic fields are often defined by common research interests and their success is often dependent on effective articulation of the value of these interests within broader research agendas. In reviewing the growth of PER in the US, several authors have noted that the development of a cohesive academic community and targeted advocacy for the goals of that community were pivotal (Beichner, 2009; Cummings, 2011; National Research Council, 2012). Though these topics were not often discussed directly by survey and interview respondents in our study, the data taken as a whole suggest that these are important areas to consider in developing the field across the UK and more broadly.

As was noted earlier, the vast majority of respondents in all international regions agree that communities of practice in PER exist both nationally and internationally (see Table 3.4). Nonetheless, there are differences of opinion as to how these communities are comprised and what the fundamental aims of the field should be. For example, while many self-identified PER practitioners report undertaking studies at school level, other practitioners describe these activities as 'not PER'. Likewise, many respondents were engaged in locally focused studies which aimed to improve the student experience within their departments, but some researchers felt strongly that such teaching development work should be viewed as distinct from PER. In addition, there was considerable diversity in respondents' perceptions of current priorities for studies in PER. A wide variety of 'hot topics' were suggested and no topic was mentioned by a clear majority of respondents in any region. There was a degree of international consensus, such that *technology-assisted learning* and *problem-based learning* were the most commonly cited topics in all regions. However, the extent to which practitioners working in these areas are able build upon and influence each other's work is unclear.

There was limited agreement among and between international regions as to preferred publications and conferences for disseminating PER results. Our respondents submitted work to a very large and quite diverse range of publications and conferences that spanned both physics and education. This relative lack of common dissemination routes for research may significantly limit the ability of PER researchers to develop a coherent body of knowledge that can be accessed easily by other researchers. It may also limit the extent to which those outside of PER are able to view the field as an established research activity and fairly judge the quality of PER studies for purposes of hiring and promoting staff.

The history of PER in the US underscores the importance of commonly agreed and well-respected publication routes. When a *Physical Review* journal specifically for PER, *Physical Review Special Topics - Physics Education Research*, was established in 2005, it provided researchers in the field access to a rigorously peer-reviewed publication which, crucially, was recognized as such by the wider physics community (Cummings, 2011). However, publication choices for PER remain problematic. For researchers hoping to impact teaching and learning in the classroom, there is a recognized tension between targeting more prestigious research journals which are less likely to be read by physics instructors or more widely-read publications focused on instructional development which may be less rigorously peer-reviewed and less valued professionally (National Research Council, 2012). This is an especially pressing issue for early-career researchers not yet in permanent positions.

3.3.3 Role of advocacy

Organized advocacy by PER research leaders is another important driver of acceptance of the field. In the US, meetings held in the mid-1990s defined goals for the PER community and convened committees to draft papers for funders and professional bodies which lobbied for support of the field (Beichner, Hake, Redish, & Risley, 1995; Meltzer, McDermott, Heron, Redish, & Beichner, 2004). For example, the white paper by Beichner et al. (1995) to the National Science Foundation is credited with promoting a generally positive view of PER by this funder and obtaining support for regular PER conferences. In addition, personal advocacy by individual researchers is viewed as significant. Cummings (2011) quotes one practitioner's view that a push by physics departments to hire faculty who could improve local teaching was '*fuelled in large part*' by widely respected PER researchers who '*would give talks anywhere that would have them, presenting the scientific basis of the field*'. The development of methods, e.g. conceptual tests, to produce easily understood and reproducible quantitative evidence to illustrate the deficits and benefits of different instruction methods in the instructors' local contexts is also seen as significant in overcoming physicists' misgivings about PER (Cummings, 2011).

Endorsement and promotion by a professional body has also been seen to play an important role in the development of PER. For example, the American Physical Society issued a policy statement in 1999 that recognized PER as a sub-discipline of physics and it has since been active in promoting the field as a means to improve physics education in practice. This activity is thought to have been significant in paving the way toward the hiring of additional PER staff and the establishment of high-quality publication routes for PER (National Research Council, 2012).

As discussed above, UK respondents to our PER survey exhibited higher levels of consensus around publication routes, conference attendance and topics of study than those in the wider EU and Australia. They were also most likely to collaborate on PER, to belong to PER networks and to agree that there was a national community of PER researchers. In this regard, the UK community may be particularly well suited to pursue the sort of organized advocacy that helped to develop PER in the US. Existing avenues for discussion, such as the ViCE/PHEC conference, might be usefully used to consolidate the goals of the community and spearhead appropriate lobbying efforts. As a professional body deeply engaged with physics education, the IOP could play a valuable role in this process. Other stakeholders whose support has been and could be particularly vital include the HEA and relevant research councils.

3.3.4 Relationship with the physics community

While some respondents, most commonly in the wider EU, appear to conduct studies in PER as a specialization within an education department, most view PER as a subfield of physics. Indeed, for many, the fact that PER takes place within physics departments is a defining characteristic of the field. The extent to which PER is regarded and supported as a physics discipline by the broader physics community – including funding bodies, institutional and departmental management, and other physics colleagues – is therefore of key importance to many PER practitioners. Furthermore, the ability of the field to successfully influence student learning is strongly dependent on physicists' attitudes toward PER and their willingness to adopt PER-based innovations in their classrooms. Concern about these issues was ubiquitous across all regions we surveyed, and was more frequently expressed than concern about funding in both the wider EU and Australia. When asked what single change would most improve the status and impact of PER, 45-50% of respondents in all regions suggested either increasing respect for PER among physics colleagues or promoting recognition of PER as a valid academic career route equal to other areas of physics.

Our surveys suggest that many PER practitioners face difficulties in terms of integration with and support from physics colleagues. Significant fractions of respondents based in physics departments stated that only a minority of their colleagues were aware of their work (for UK data see Table 3.5). Furthermore, the vast majority of respondents across all regions said their research was disseminated within their institution only occasionally. While the majority of PER practitioners based within physics departments reported contributing directly to improvement of teaching and learning within their departments, over half stated that their work was not well-supported by their departments or well-regarded by their colleagues.

Table 3.5 Integration of PER into physics community (UK only)

	Yes	Partially	No	Don't know
Has your PER improved teaching and learning at your institution?	53%	37%	0%	10%
Are your physics colleagues aware of your PER?	56% (majority)	35% (minority)	0%	9%
Is your PER disseminated within your institution?	10% (often)	76% (sometimes)	10%	4%

Most respondents based outside physics departments reported working with colleagues in physics regularly, but even fewer of these staff, in general, agreed that their work was well-regarded and well-supported. Notably, none of the (few) UK PER researchers based outside of physics departments felt well supported by those departments. Across the full sample, less than half the respondents in all regions felt their work was well-supported by their institutions.

Thus, overcoming issues surrounding the perceived legitimacy of PER and associated resistance to adopting PER-based techniques is a significant concern in the UK context and one discussed at length by UK survey respondents and interviewees. One UK professor believed that securing respect for PER entailed granting *'full status… the same as disciplinary physicists [to] people whose job is teaching and physics education research*'.

Others mentioned research council recognition and the inclusion of PER in the UK Research Excellence Framework as necessary steps towards legitimizing the field (Research Excellence Framework, 2012). One teaching fellow opined that any measures employed to enhance the standing of PER must '*be long term… to nurture [PER] practitioners, year on year*'.

However, our survey of the UK PER community indicates that many PER researchers have effectively stepped off the research career ladder in assuming teaching-focused roles. One Professor at a research-intensive university explains that, by doing so, they risk being viewed less favourably by their peers and their employer:

> *'There is a huge snobbery about teaching fellows... even though they are on the same pay grade, they are not treated in the same way. Universities think they have career paths... but that they're actually much more difficult to access. I'm not sure you can actually get to professorship if you start off as a teaching fellow.'*

In light of the over-representation of women in our PER sample relative to our physics teaching sample, it is interesting that this choice appears to be gendered.

Not continuing in a traditional area of physics may, in and of itself, be interpreted as evidence of the inferiority of PER researchers by staff who remain in those areas. One senior lecturer at a research-intensive university spoke of feeling like a '*second-class citizen… not doing proper research*'. Likewise, some respondents who have continued in traditional physics research feel that choosing to spend some time on PER, or focusing on teaching generally, serves to make them less valuable to their department, for example in terms of attracting funding or providing high-impact publications for the REF. The fact that PER is secondary to other job roles for most UK practitioners, with no dedicated time or funding and little motivation within the institution for publication and dissemination, may serve to further delegitimize the field in the eyes of many physics teaching staff.

Negative perceptions extend from the individuals involved in PER to the quality and utility of the research itself. A Professor engaged in PER spoke of his wish for the field to become '*well-known and well-regarded in UK universities*' but conceded that, at present, '*most university physicists are still very dismissive of even the published and refereed literature in PER*.' The words '*scepticism*' and '*indifference*' were frequently used by UK PER interviewees summarising responses of physics teaching staff to their work. One teaching fellow found that staff reactions vary depending on the message shared:

> *'I've noticed, if you were talking about things that they're already doing, then they're really receptive. If…you go out on a limb the vast majority [say] "this can't possibly work."'*

These problems appear to persist even where PER is relatively well established. Despite the substantial growth of PER in the US and its frequent incorporation into physics departments there, issues remain around acceptance of and professional respect for PER practitioners and their work by other physicists. For example, half the subjects in the Barthelemy et al. (2013) study of postgraduate and postdoctoral PER researchers stated that they had encountered problems being seen as 'real' physicists by colleagues. Similarly, Cummings (2011) states that in her opinion '*the field is still not widely accepted in [research intensive] physics departments as an appropriate form of physics research.*'

3.3.5 Embedding PER-informed teaching innovations

In addition to negatively impacting the career prospects and work experience of those engaged in PER, negative perceptions of PER among physicists may act as a significant barrier to dissemination of evidence-based techniques in undergraduate teaching. In a study of the use of PER by US physics teaching staff, Henderson & Dancy (2008) detailed specific negative views of educational research and/or educational researchers held by physics instructors which hindered engagement with evidence-based teaching reforms. In that study, PER practitioners were seen by some to be dogmatic; to imply that teaching staff are bad teachers; and to discount their teaching expertise. Some instructors were also found to be sceptical of the methods and results of educational research in general. Some respondents to our UK physics teaching survey expressed very similar views.

Even where teaching staff have no pre-existing opinions about PER, achieving widespread adoption and 'roll-out' of evidence-based innovations is problematic. We note above that authors studying PER in the US feel that dissemination and adoption of evidence-based techniques remains a significant challenge (Henderson & Dancy, 2008). These authors propose that teaching staff and educational researchers often hold divergent expectations about how reform happens. Specifically, while educational researchers often expect instructors to adopt new teaching techniques and materials wholesale, instructors may expect to collaborate with researchers around adaptable elements which can be used in ways which best suit their teaching preferences and local context. PER practitioners responding to our surveys echoed this view when they stressed the value of collaborative and, where possible, longer-term strategies in promoting research findings and new instructional techniques to teaching staff. When queried on effective dissemination routes, respondents favoured collaborations with teaching staff and workshops including interactive sessions and ample discussion time.

One example of best practice in dissemination from the US is the multi-day, residential New Faculty Workshop[2] created by the American Association for Physics Teachers to '*improve the quality of [undergraduate] physics teaching on a national scale.*' Run by PER research leaders, workshop sessions provide reviews of research findings and their implications for practice together with opportunities for discussion of and hands-on experience with research-based teaching methods. Now co-sponsored by the American Physical Society and the American Astronomical Society and funded by the National Science Foundation, these workshops are attended by 20-25% of all newly hired physics and astronomy teaching staff in the US (Beichner, 2009).

3.3.6 Implications for PER in the UK

Effecting cultural shift within physics departments such that PER and PER-based teaching innovations are more uniformly well-regarded will likely require change in many areas.

[2] See http://www.aapt.org/Conferences/newfaculty/nfw.cfm

Examples of successful advocacy, funding and dissemination strategies from regions in which the field is already better established may provide useful guides in this respect. For example, work in the US by high profile and well-respected advocates and publication in a high-profile journal have been shown to play a pivotal role in combating negative perceptions and raising the profile of the field amongst the physics community by dispelling the sense that PER is less valuable research done by less able physicists (Cummings, 2011).

Many authors comment on the particular value of support from a national funding body with respect to dispelling the perception that PER is not legitimate research (Cummings, 2011; National Research Council, 2012). As noted earlier (Section 3.3.1), the NSF funded 62 two-year 'pump priming' postdoctoral fellowships across STEM disciplines in the US. Pro-rata,[3] a similar scheme in the UK would need to support about 8 two-year postdoctoral fellowships.

In terms of overall funding, Henderson et al. (2012) estimated the total funding for PER in the US to be approximately $72.5M (£43.1M) between 2006 and 2010. Pro-rata this is equivalent to approximately £1.7M funding per annum for UK PER.

Encouragingly, as discussed below (Section 4.4), our survey of UK teaching staff suggests that many are receptive to learning more about PER and to exploring how it could help them to address challenges in their teaching.

[3] We used a ratio of 5:1 based on the relative sizes of the undergraduate physics population; 21.7k in the US compared to 4.4k in the UK in 2011/12 (Higher Education Statistics Agency, 2012; US Department of Education National Center for Education Statistics, 2013). A similar ratio (4:1) is obtained based on the number of physics departments; 187 in the US (including only departments which offer degrees from BSc to PhD level) compared to 46 in the UK (Higher Education Statistics Agency, 2012; Nicholson & Mulvey, 2013).

4. The development of UK undergraduate physics teaching

In this section, we examine the reported attitudes and experiences of UK physics teaching staff. We first discuss the overarching demographic trends of the teaching staff sample, and their general attitudes toward teaching, before considering staff conceptions of teaching excellence. Following this, we discuss staff views on factors perceived to support and challenge high-quality teaching. We then explore staff experiences of change and development in teaching and of training and professional development. Finally, we consider teaching staff recommendations for improving UK undergraduate physics education.

4.1 Demographics, attitudes and experiences of UK physics teaching staff

As noted earlier (see Section 2), staff at over 80% of UK physics departments were represented in the PT survey. Senior academics were particularly well represented, and the majority of individuals had worked at their institution for over 10 years. Teaching staff were broadly experienced in their teaching. The majority taught first to final year undergraduates, and many instructed postgraduates. The vast majority of staff delivered lectures, small group tutorials, and individual supervision. Many staff had experience of designing undergraduate courses.

On the whole, staff reported a positive approach to teaching (see Figure 4.1). The vast majority find teaching enjoyable and rewarding, intellectually stimulating and a source of professional pride at comparable levels to their research. Indeed, when asked to think about job satisfaction alone, most staff would choose to either maintain or increase the level of teaching they do.

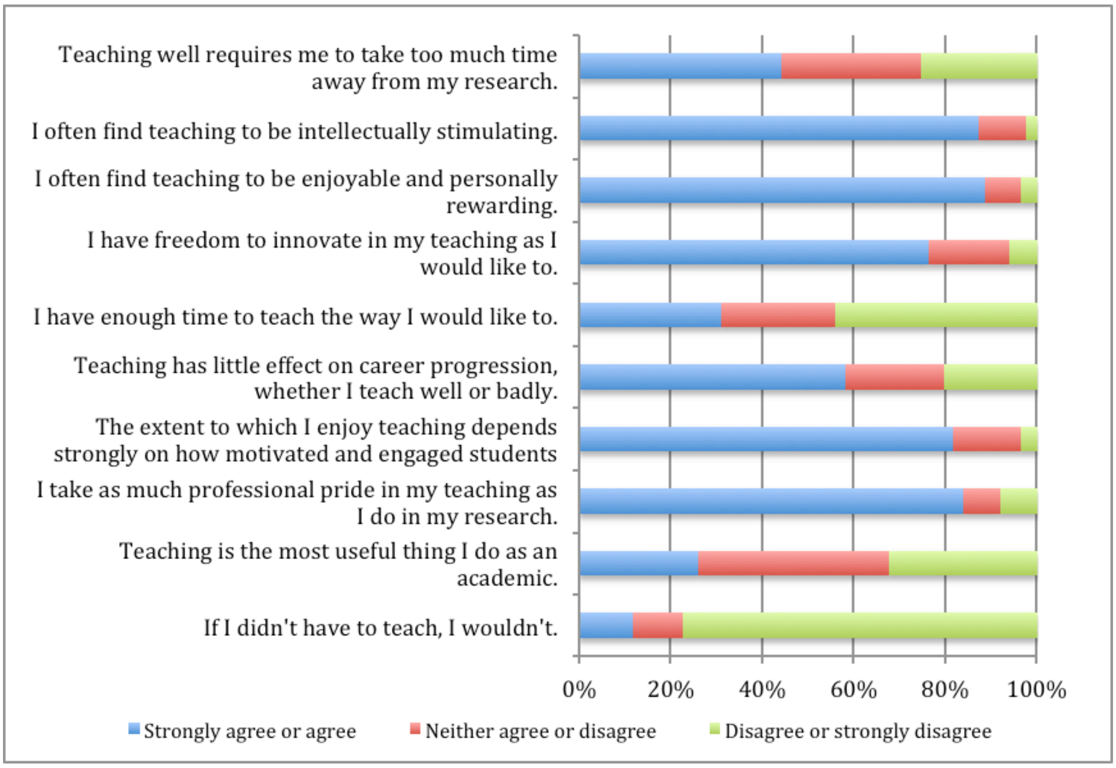

Figure 4.1 Attitudes to teaching among UK physics staff

Only 11% of teaching staff would choose not to teach if they could, with many staff expressing the view that the combination of teaching and research is integral to academic life. Indeed, nearly half our respondents characterised their job as a roughly even split between teaching and research. As one Senior Lecturer reflected:

> *'I think that the traditional role of a university lecturer, implicit in that is this combination of research and teaching and to try and deconstruct those is against the university principle.'*

This is not to say that balancing teaching with research is an easy task, and staff mentioned multiple other secondary activities, such as committee work or grant panel responsibilities, that make demands on their time. Teaching staff are strongly influenced by considerations of reward and recognition when making decisions about time allocation, as we will explore later (Section 4.3.4). Thus, while many staff would choose to spend more time on teaching for reasons of personal satisfaction, they would spend less time on it when thinking only of career progression. Indeed, when thinking of both career advancement and personal satisfaction, the only task staff would choose to spend more time on is research.

4.2 Defining teaching excellence

Given the diversity of teaching experience and responsibilities, it is perhaps unsurprising that we uncovered a wide range of opinions about what constitutes teaching excellence. Physics teaching staff are not uniquely positioned on this matter, however. Teaching excellence is a contested concept, and there is presently no agreed working definition in the context of UK higher education (Gunn & Fisk, 2013). Through our data, we see that subjective experience and individual professional values complicate the issue.

While we received a variety of definitions of teaching excellence, five overarching trends arose across the responses of teaching staff.

4.2.1 Process versus results

First, in constructing their definitions, teaching staff tended to focus either on the process of teaching, or on specific objectives. 'Process-focused' definitions of teaching excellence frequently referred to the provision of regular feedback, and to ensuring the sustained engagement of students – which may be evidenced by increased attendance rates or greater interaction between students and lecturer during a class. This Senior Lecturer explained how he recognises excellence during the process of teaching:

> *'A lot of my teaching is focused on demonstrating in labs in the physics department, also running workshops in the university. So it is an active buzz from students - that they're talking to each other; they're learning from each other and with each other. They are actively working; I think would be my main signal.'*

A further popular process-focused definition centred upon facilitating students' successful transition to becoming independent learners. Many teaching staff prioritised the cultivation of independent thought over the acquisition of curriculum knowledge. As this Teaching Fellow explained:

> *'The excellence idea of it would be more that if I give a lecture and the students left wanting to go back over their notes and look in to it a bit further, that's how I*

> *would describe excellence in teaching… because I can't teach them everything, if I can make them want to go and learn the rest of it, then I consider that excellence.'*

Conversely, a typical example of an 'objective-focused' definition referred to the demonstration of learning gains. Although many teaching staff expressed scepticism over whether exam marks necessarily convey students' conceptual understanding, indicators such as the ability to answer questions in a tutorial setting, or to '*make a well-reasoned argument*' in an essay were suggested.

4.2.2 The basic principles of teaching

Second, most teaching staff agreed that satisfactory teaching rests upon certain basic principles. Examples of such basic principles included: the clear communication and delivery of course components; an awareness of student understanding and pre-conceptions; and pitching teaching material appropriately to students' abilities. These principles illustrate the importance teaching staff attach to preparation as a cornerstone of good teaching. Nevertheless, it was seldom suggested that basic principles secure teaching excellence.

4.2.3 The role of the individual

Since the achievement of teaching excellence was considered to require more than adherence to certain basic principles, the abilities and efforts of the individual teacher emerge as the third significant theme. The vast majority of teaching staff posited personal enthusiasm as '*very important to good teaching and learning*'. While enthusiasm is clearly linked to preparation efforts, there was a sense that enthusiasm was also necessary to engage students in the moment of teaching:

> *'If the lecturer is bored with the subject, how is he or her actually going to deliver an exciting lecture? How are they really going to do that? And I think we are sort of cheating the students when we allow that. If we have a lecture we're really bored with then we shouldn't teach it - we should get rid of it, find someone else who is enthusiastic about it.'*

The emphasis on the individual therefore takes us beyond preparation to the teaching experience itself. Many staff expressed the view that certain personalities are naturally predisposed to being better teachers. As this Senior Lecturer reasoned:

> *'I think it's like any walk of life: you get some people who are naturally very gifted… if you're going to be one of those outstanding people then that's probably a natural talent that you have and that's down to your personality and your individual character… I think there's no substitute for natural talent. I think that's true in any walk of life.'*

However, we must also note that few respondents believed personality alone could lead to teaching excellence – for example: '*it's more than charisma; it's having direction as well*'. Furthermore, as we will see next, many believed that all teaching staff could enhance their practice with experience.

4.2.4 Improvement with experience

Fourth, teaching staff accepted that, regardless of initial aptitude, all individuals could improve their teaching over time. Moving on from considerations of personality and charisma, this Senior Lecturer explained:

> *'I think that there are some individuals who… as with being in front of a camera or something, just seem to have a natural authority and are able to hold the attention of an audience maybe better than others. But I don't really agree that it's natural in the sense that it's an innate ability which can't be learnt or practiced or developed in someone who, let's say, it's not so immediately easy - [for].'*

Accordingly, most teaching staff believed that their own approach to teaching had evolved with experience. Many staff noted how early on in their teaching career, personal memories of being an undergraduate student – both positive and negative – informed their teaching approach. One Professor explained the contribution of his formative experiences as a student:

> *'All teachers [influenced my approach to teaching]… you learn from the bad ones not to do it that way! And from the good ones you take whatever ideas you can. I…came out of my undergraduate years with… a desire to do equally good to any students that I came across in my career.'*

In terms of improving teaching, experience and peer observation of senior teaching staff were cited among the most effective means. Many lecturers we spoke to viewed university teaching as an apprenticeship, in the sense that progression from novice to expert can only occur through sustained participation. This conception of university teaching is similar to the model of situated learning described by Lave & Wenger (1991). This is not to imply that all staff were content with this de facto method of 'situated learning'. As one Professor reflected, '*it's maybe not ideal… we're not particularly aware of when new things happen*'.

Student feedback and technological advances were also considered influential in the development of teaching. Formal training delivered by university educational development units was widely criticised for being of little perceived value for physics teaching staff. We will later examine the particular critiques levelled against formal training (Section 4.4).

4.2.5 A broad range of local excellence

Fifth, and consistent with the diverse conceptualisations of teaching excellence suggested by respondents, staff provided a wide range of examples of local teaching excellence. This variance likely reflects, in part, actual pedagogic differences between institutions with different approaches to teaching in response to different student expectations and needs. It is not surprising that staff from different institutions offer contrasting examples of local excellence.

One notable disparity related to whether staff referred to traditional teaching approaches or reformed, PER-based methods. The following two quotes are instructive. This Reader, from a research-intensive Russell Group institution, took especial pride in his department's traditional lecture courses, which were closely linked to cutting-edge research:

> *'I think some of the lecture courses here are very good; well, excellent, in that they really give our students a very good view close to research, and the excitement of that, and I think it's borne out by some of the feedback the students give on that.'*

It is interesting that our interviewee revealed little about pedagogy, choosing instead to highlight course content. Many staff explicitly mentioned the lecture in their example, with several stating that the 'chalk and talk' model was popular with students and underpinned successful learning. Fewer staff referred to PER in their example of teaching excellence. One senior teaching fellow at a research-intensive institution described how PER informed their conception of teaching excellence:

> *'Student-centred environments seem to me critical in the sense that there are so many studies that show that interactive engagement can lead to more learning. The other thing is research-informed teaching - that, if you're teaching a course on, [for example] special relativity, you've read the papers describing common student difficulties: how to overcome them, resources that are available, how to implement [methods], and to use that in your teaching. Not to just come up with some great original idea and throw it at your students, but to be informed by careful studies.'*

Other examples of reformed approaches included the development of virtual learning environments and the inclusion of active pedagogies, such as the flipped classroom, or the use of clickers and other methods to sustain student-lecturer interaction during the lecture. Standout examples of innovative practice included a final year module, during which students create a 'journal' of their peer-reviewed work, and, at a different institution, the opportunity for final year project students to co-develop learning technologies for undergraduate physics teaching, instead of devising a project in a traditional area of physics.

Frequently, teaching staff from the same institution subscribed to different ideas of teaching excellence, and offered contrasting local examples. There is, therefore, a strong sense that the wide range of definitions and examples reflect rather subjective notions of teaching excellence and not just local specialties.

4.2.6 Reflections on teaching excellence

We have seen that there is no real consensus from physics teaching staff in relation to defining or evidencing teaching excellence. Some staff explicitly rejected the notion of teaching excellence; nearly half of the survey sample took issue with the concept of 'best practice' because they were wary of its 'one size fits all' connotations. It is clear that the local context in which teaching takes place is significant in creating expectations: the abilities and resources of teaching staff, as well as the unique abilities and needs of students vary from institution to institution, and with it, so do conceptions of teaching quality. The individual values of teaching staff are also important in determining views on teaching excellence. However, as we discuss later (Section 4.3.4), many interviewees felt that the development of robust measures of teaching quality was a necessary step to ensure that teaching contributions were properly rewarded.

The challenge for departments and institutions is to develop an understanding of teaching excellence that is suitably inclusive and flexible, in response to the multifaceted ideas and practices of physics teaching staff reported here.

4.3 Supporting and challenging high-quality teaching

4.3.1 Factors supporting high-quality teaching

Most physics teaching staff agreed that their department and institution value high-quality teaching (see Table 4.1). Most commonly, staff associated the achievement of high-quality teaching with factors at the individual or departmental level.

Table 4.1 Recognition and support for high quality teaching

		Agree / strongly agree	Neither agree nor disagree	Disagree / strongly disagree
High quality teaching is valued	*By department*	70%	19%	11%
	By institution	67%	20%	13%
There is sufficient support to promote good teaching	*From department*	57%	28%	15%
	From institution	48%	32%	20%
Good teaching is appropriately recognised & rewarded		27%	45%	45%

Nearly half of the answers provided by teaching staff suggested that the motivation and qualities of individual teaching staff underpin good teaching. Individuals with a professional responsibility for ensuring high teaching quality were also praised for their contribution: teaching fellows, Heads of School, Directors of Teaching, and Teaching Committee members. Several teaching staff highlighted the significance of a supportive departmental culture, mentioning the importance of colleagues who were committed to high-quality teaching, effective teamwork and a sense of shared responsibility.
Teaching staff noted the importance of having access to appropriate resources and facilities. Teaching assistants and suitable classrooms were each mentioned by 8% of teaching staff, particularly for the way they enable staff to work closely with smaller numbers of students. Relevant to our consideration of PER, only a few respondents specified access to, and use of, evidence-based methods as being teaching supports.

Institutions were perceived to impact mostly over formal matters relating to teaching. Policies on feedback and assessment, employability curricula and key information sets, which tend to be formulated at the level of senior university management, were the main ways in which institutions were understood to shape teaching practice. On the whole, physics teaching staff indicated a high degree of individual autonomy on pedagogical issues and believed that departments exercise devolved authority over most aspects of teaching. The following comments from a Senior Lecturer at a red brick university, is fairly typical:

> *'It's very autonomous really… people [have] a great deal of autonomy over the way they teach and what they teach… There is some departmental scrutiny and it may well be that it's going to be a little bit tighter in the future but senior management aren't that prescriptive.'*

Staff report that teaching committees commonly focus on considering changes to courses, overseeing peer-review and student feedback schemes and monitoring course assessments. Most staff believe that the work of committees is disseminated effectively. While time constraints limit the extent to which teaching staff feel able to engage with material circulated by the teaching committee, the activities of the committee are, on the whole, viewed favourably by staff. Teaching committees were credited with allowing staff to feel reasonably aware of what their colleagues do in the classroom and, perhaps more critically, confident that poor teaching would not go unnoticed.

Teaching practice is also shared through informal means, such as coffee room chats. However, staff pointed out that informal channels of communication are often limited; such conversations are necessarily ad-hoc and may only reach staff who already possess a keen interest in teaching enhancement.

While teaching committees were viewed by most staff as having an important role in supporting high-quality teaching, many staff expressed concern that committees are primarily absorbed with challenges or problems relating to teaching, rather than the dissemination of good practice. As this Professor at a Russell Group university reflected:

> *'It's only if something's really bad that you can actually get some feedback… sharing positives - I don't really know that there's that much of... There is a tendency [for committees] to concentrate on negative things.'*

A senior lecturer from a different Russell Group conveyed a similar image of their department:

> *'Sharing good practice could be done much more carefully. I would love to know what everybody else is doing. I would love to know how they get the students engaged and why they get good reviews.'*

This is not to suggest that staff thought committees purposely focus on teaching challenges, but that addressing problems takes up most of the available time and resources.

4.3.2 Factors challenging high-quality teaching

Similarly, our teaching staff sample were concerned foremost with challenges to teaching well. Questions encouraging reflection on individual, departmental and institutional teaching practices prompted answers that referred more often to difficulties than to enabling factors or exemplary practice. In contrast to the majority belief that departments and institutions value high-quality teaching, notably fewer staff stated that their department and institution supported them in achieving it. Only 57% thought that their department provided adequate support, while 48% believed that their institution did (see Table 4.1). We consider below the particular issues identified by teaching staff as prohibitive to the delivery of high-quality teaching.

While teaching practice was widely perceived to be heavily influenced by local factors, staff from a wide range of institutions produced strikingly similar examples of teaching challenges. In other words, physics teaching staff across the UK report facing similar problems, with little evidence of differences between institutions. We are therefore confident that our recommendations (see Section 5) will have resonance for higher education physics nationally.

4.3.3 Academic workload and time-pressures

The most commonly cited challenges to teaching well were lack of time and the high workload of academic roles. These perceptions are clearly related and suggest that many teaching staff feel that the major factors affecting the quality of their teaching are outside their control. That the two most commonly cited challenges to teaching well arise from environmental rather than individual factors – such as a lecturer's teaching abilities or their level of commitment – is concerning. While most of the teaching staff we surveyed enjoyed and valued undergraduate teaching, this enthusiasm appears to be challenged in many cases by a discouraging environment. Indeed, this interpretation is supported by our earlier observation that many teaching staff believe their department and institution do not provide adequate support to facilitate high-quality teaching.

Nearly half of surveyed teaching staff stated they do not have enough time to teach the way they would like to (see Figure 4.1). Many staff believed that simply too much is asked of academics. This Reader at a research-intensive university described the extent of these pressures:

> *'I think most people struggle with it… what's forced then is a compromise and I think in many cases the compromise is towards the teaching. [Teaching], administration and the research does not fit into a normal day. It doesn't fit into a normal day and actually most people probably don't take their full holidays.'*

A particularly troublesome issue for teaching staff concerned the balance of time struck between teaching and research. Many staff feel they are encouraged to prioritise research over teaching. Several respondents pointed out that this ethos begins at the point of recruitment, as academic staff are on the whole appointed on the basis of research performance. Once appointed, teaching staff overwhelmingly believed that university reward and recognition systems incentivised them to continue to strengthen their standing as a researchers. Many staff thought that individual performance in the Research Excellence Framework would have the greatest influence over the progression of their academic career. As a Professor at a research university explained:

> *'Performance related reward gives reward related performance, [so] if your reward is based largely on your research that's what you're going to get.'*

The majority of teaching staff believe research performance far outweighs teaching performance in relation to career progression. When time is limited, it is therefore considered risky to increase the amount of time spent on teaching or teaching development. Almost half of surveyed teaching staff stated that teaching well required them to take too much time away from their research. Often, it is staff who have established their status as leading researchers who then feel able to increase the amount of time spent on teaching, as noted by this lab technician at a Russell Group institution:

> *'It's interesting to see actually as [academic staff] are [moving towards] retirement, when they already have established careers and they're winding down, they actually dedicate more time to teaching.'*

Indeed, many teaching staff believed that time pressures were felt most acutely by early-career academics, many of whom are both new to teaching and are expected to establish an international research profile.

Many staff were keen to point out that the preparation and administration associated with teaching – rather than teaching itself – placed the biggest demands on their time. Particular criticisms were made of perceived restrictive regulations and excessive bureaucracy, imposed by both institutions and external bodies. This Professor at a research-led university believed that the time-intensity of managing and developing teaching deterred teaching staff from engaging with these activities:

> *'Teaching... that's not the thing that's takes the time, it's developing the teaching, managing the developments, changing things. [These] take so long to get anything done that staff are rightly dissuaded from changing anything.'*

In addition to teaching development, many staff believed that interactions with students and the quality of feedback and assessment directly suffered as a result of perceived time constraints. A minority of staff considered it their responsibility to achieve an '*acceptable minimum*' with regards to teaching. According to one Senior Lecturer at a post-1992 institution, to teach well meant '*to keep things ticking over*':

Some teaching staff stated that lack of time also hindered their ability to engage with research into physics teaching. As this Reader at a Russell Group institution explained, good intentions did not do enough to facilitate a sustained engagement with the field:

> *'It would be nice to have the time to keep up with this kind of research but I can't even keep up with all the research on my own experiment let alone various other fields. I really should spend some time catching up on [PER], but without the incentive… it just falls by the wayside.'*

4.3.4 Reward and recognition

For many teaching staff, decisions about time allocation are strongly influenced by consideration of reward and recognition. According to most respondents, reward and recognition policies tend to favour research performance over achievements in teaching. A slim majority (58%) of teaching staff agreed that teaching has little effect on career progression and that teaching neither well nor badly would affect them in terms of reward and recognition. A Reader at a Russell Group institution shared this view:

> *'Those who frankly teach badly or are not willing to put any effort in [are] almost rewarded for it because they get taken off teaching courses - they don't have to do as much. They've got more time free for what they actually want to do - which is their research, and that does attain career recognition. So those who care about their teaching and want to do a good job are effectively penalised because they end up [with] a larger workload.'*

Another Senior Lecturer shared his thoughts on the professional value of developing or enhancing one's teaching:

> *'It has no consequence to that person's career development whether or not they develop their module, none whatsoever.'*

Just over 10% of teaching staff commented on the negative influence that perceptions about reward and recognition yielded over individual attitudes and departmental culture. These staff typically mentioned a sense of apathy towards improving and developing teaching and a distrust of new methods. The reward system, they believed, encouraged staff to care and do little to evolve the teaching practices in their department.

Reward and recognition policies that value research over teaching were problematic not just for those staff seeking to balance the two activities, but also to those employed in teaching-only roles. Around a third of interviewees discussed how teaching fellows - who are in most cases neither expected nor afforded sufficient time to conduct research - seldom reach equivalent levels of seniority as research active staff. The impression created is of two distinct career trajectories, of unequal prestige and standing.

This teaching fellow at a Russell Group university believed the apparent lower status of teaching-only staff resulted from both historic understandings of academia as a profession and contemporary recruitment practices. Both, she believed, conveyed the assumption that research is the favoured and primary concern of any aspiring academic:

> *'There is still an attitude around that if you concentrate on teaching that must mean you're doing it because you're failing in research. I think that's still a quite prevalent attitude. It's not my attitude. I made an active decision to go along the teaching route rather than the research route.'*

Nevertheless, many research-active staff considered the relative position of teaching-only staff to be a clear signal that, in terms of professional gain, their finite time would be best directed at strengthening research performance. Despite deriving a high degree of personal satisfaction from teaching, one Russell Group Senior Lecturer explained that increasingly, his '*squeezed time*' was focused on research '*because it's valued much more, really.*'

Only a small minority of interviewees disputed the common perception that teaching is not duly rewarded, but their comments are important to note. Two Professors explained how teaching had contributed to their promotion. Their perspectives are worth quoting at length:

> *'I have been rewarded for teaching. I used it in part as a case for promotion which was successful. It can be done, and it is there in the documents. If you've got the nerve to produce evidence in those particular areas, this institution does take it seriously. There is a culture, a belief that teaching is never rewarded so therefore people don't have the nerve to go for, but it's there if you go for it. I've been round telling people, 'Go for it.' And I managed to get someone else promoted'.*

> *'If by concentrating on teaching you simply mean that you spend a lot of time making nicer power point slides and worrying about precisely what the material is, then I think quite right that should not detract from your research which is of far greater benefit to mankind. Your research is not local; your research is only valuable if it is acknowledged by the community. Parallel to that is a teaching development that is acknowledged by the community, not just internally, within your own classroom. The Vice Chancellor said to me that I wouldn't have got my professorship had I not had a profile on the teaching side.'*

A technician at a different institution also provided evidence that their department rewarded teaching. However, in describing her position as '*very, very lucky*', she implied agreement with the majority view that most institutions do not adequately reward teaching contribution.

Related to these views on reward and recognition however, was the finding that teaching staff held no clear consensus view on how best to judge successful teaching, as is evident from Table 4.2. This lack of clarity is starkly juxtaposed with the well-defined and long accepted criteria for assessing research performance (for example publications, research income, research impact and knowledge transfer).

Table 4.2 Potential measures of teaching quality

	Agree / strongly agree	**Neither agree nor disagree**	**Disagree / strongly disagree**
Examination results	28%	36%	36%
Level of interaction with & among students	41%	38%	22%
No 'best practice' - depends on instructor, student &/or context	51%	23%	26%

Many staff advocated that, in the absence of robust measures of teaching quality, institutions could do little to progress the way they reward teaching contributions and successes. More negatively still, some suggested that the introduction of workable and accepted measures of teaching quality would make little difference if institutions continued to privilege research performance in its reward policies. This teaching fellow likened the situation to an individual struggle, that she could not foresee ending any time soon:

> *'You're going to have to fight tooth and nail to get [promotion for teaching] and the vast majority [of staff] are going to say 'this is just not worth it". There are no clear goals. This is a losing game.'*

The interviews enabled us to further probe the issue of measuring teaching quality. Just over half of interviewees believed that teaching quality ought to be measured. Nevertheless, they concurred with the wider survey sample that this would be a difficult task. 45% believed that metrics focused upon capturing quantitative measures of teaching quality were largely inappropriate for the qualitative nature of teaching. Around a third of interviewees thought that no current indicator sufficiently measured teaching quality.

Just under half of interviewees were however willing to speculate about the sorts of characteristics that robust quality indicators would feature. Emphasis was placed on the recording and consideration of several distinct measurements in order to enable a multitudinal, or holistic, approach and the view that measurements ought to be longitudinal, i.e. taken over several years. Over a third of interviewees were willing to offer more precise suggestions of future teaching quality measures. PER featured several times in this list, which included: conceptual testing; graduate surveys; a standardised exam of core physics knowledge; an external review; peer review of teaching; and contributions to PER, evidenced in conference participation and publications in education journals. It is noteworthy that only a fifth of interviewees regarded student feedback as a valid measure of teaching quality.

Commonly, we heard that it served as an indicator of popularity rather than teaching quality, or, that students with the most extreme views were disproportionately represented.

Interviewees tended to be more optimistic about reward and recognition than the wider survey sample. Just under half expressed the view that the reward and recognition of teaching is improving in their local situation, with some citing examples of recent promotions, including appointments at the professorial level, which had been informed by teaching contribution. However, a similar fraction of interviewees maintained the view that the reward and recognition of teaching had not improved. Some explicitly linked poor indicators of teaching quality to the perception of improper rewards while others stated that even when teaching-focused promotion criteria existed on paper - as in the case of teaching fellow appointments – they rarely corresponded to lived experience.

Most interviewees agreed that the current system of reward and recognition, and the indicators employed to judge teaching performance, are in need of reform. Interviewees stressed that any new indicators of teaching quality must carry the confidence of teaching staff and should be linked transparently to decisions relating to promotion. Around 40% of interviewees believed that staff would dedicate more time to teaching and development activities if they were assured they would be rewarded for it.

4.3.5 Addressing students' abilities and expectations

A final prominent challenge to teaching well identified by a third of the PT survey respondents related to the abilities and expectations of undergraduate physics students. Most commonly, staff referred to deficits in incoming students' knowledge and skills levels and, in particular, their poor mathematical abilities.

In addition, the attitudes and expectations of incoming students troubled many staff. In essence, many teaching staff believed that new undergraduates were not prepared for independent study and deep learning. Staff complained that students expected to be 'spoon-fed' knowledge, were overly fixated on exams and assessments, and favoured superficial rote learning to deeper conceptual engagement.

A Lecturer based at a highly selective Russell Group institution explained how good grades seem to belie deep-rooted subject knowledge:

> *'They seem to work much harder at sixth form than in my day but they arrive at university not knowing as much and in some cases not as motivated to study. The students that we get here tend to have very good A-Level grades… usually three A's. It feels as though they've been trained to pass the exam rather than actually understand physics and maths.'*

A Senior Lecturer at a leading Scottish university noted that the problem of superficial learning was particularly damaging in the context of university-level physics:

> *'At school… it's a very modular approach - once you've done it, you've ticked something off, that's it, forget about it! We know that doesn't work in physics, particularly at university. We need the mentality of students to change; they have to retain some knowledge.'*

Many teaching staff associated the content and format of the physics A-Level with perceived deficits of incoming students. Others lamented the 'unhealthy' target culture of UK schools. One Professor based at a leading university with high entrance requirements linked the emphasis on memorisation and exams with a deficit in students' '*critical reasoning and intellectual stamina*'.

A fifth of teaching staff identified large, mixed ability classes as a significant teaching challenge. Many staff suggested that this challenge was a relatively new phenomenon resulting from mass participation in UK higher education (David et al., 2008). Staff noted, with concern, how expanding student cohorts have not prompted a corresponding rise in the number of teaching staff. As a direct result of high student: staff ratios, 16% of teaching staff believed they were unable to provide individual or targeted attention to students' needs. For many, the sheer numbers of students act to exacerbate all other identified challenges to teaching well.

Reflecting on their undergraduate classes, many staff believed that while the quality of top students had remained consistent over the years, the abilities and attitudes of the lowest-achieving students had declined. Furthermore, staff reported that lower-achieving students now comprised a higher proportion of their classes. The result is larger classes that accommodate a hierarchy of mixed abilities, with a significant gap between the few students at the top of the pyramid and the many students at its base. Many staff found ensuring courses were stimulating and inclusive for all students to be extremely difficult and, in some cases, unrealistic. The following quotes from a selection of teaching staff survey respondents provide exemplars:

> *'First year students are very challenging. They come from a variety of backgrounds, even though they may have similar entry qualifications.'*

> *'[It's] difficult in a large class to gauge how well students are learning. Some are clearly bored because I am going too slow for them, whilst others are struggling to keep up.'*

> *'Finding a level that is right for a group of students with different backgrounds and very varied knowledge of maths and physics is the most challenging aspect for me.'*

Concerns about incoming students were explored further in the follow-up interviews. Interviewees reiterated the view of the wider survey sample – that they face challenges relating to incoming students' knowledge, skills and attitudes – however, they provided examples of how instructors and departments sought to overcome these problems. A Russell Group Professor explains the approach of one department:

> *'We do all sorts of things to solve the maths problem. These kids haven't had the practical experience of just working through loads of problems. That's what they are lacking. [We apply] diagnostic tests for different aspects of mathematics, to check which ones are struggling. We give [struggling students] more work and try to get them up to speed quickly. There's tons of stuff like that in place. It will get them sufficiently mathematically able that they can then have a go at a physics degree and that's fine.'*

Elsewhere, this Professor at a post-1992 university explained that course content had been trimmed:

> *'Oh yes. A lot of materials, a lot of possibly harder material, have been dropped. And a lot has been moved into the fourth year.'*

Interviewees were less likely than the survey sample as a whole to view issues with incoming students as wholly problematic. Since just under half spoke of remedial courses at their institution, it is not the case the interviewees were less likely to have encountered challenges. However, many believed it to be unfair and unhelpful to blame the A Level or schools for capabilities of new undergraduates. They felt it was their job to teach all students in receipt of an offer from the university, and to focus on the development of proactive strategies to ensure that individual weaknesses were addressed:

> *'[Because of] the general perception that the quality of students, in terms of mathematical ability, had been going down, we had more mathematics courses in year one. Now, the mathematical ability of many of our students, certainly after year one, is much better than it used to be. I don't think [maths ability] is our biggest problem now.'*

The positive outlook of these staff led them to point out that, while maths was a commonly perceived weak-point for today's students, they excelled in other areas compared to their historic counterparts. One Professor suggested that these skills were most desired by contemporary employers:

> *'Yes, [our students] are not as mathematically strong as they were 15 years [ago]. On the other hand they have far better presentational skills; they can work in teams much more effectively. They have much better computing and IT skills.'*

Moreover, many interviewees shared anecdotal evidence that less able students regularly catch up to an acceptable level during the course of their degree. This was the experience of this Reader at a research-intensive institution:

> *'There are exceptional students that come through and their mathematical ability is perfectly sound…. As for other students… [in] third year they do a mathematical methods course, which is a pretty heavy course, and coming out of that their mathematical ability is okay.'*

4.3.6 Other challenges

Additional, less prominent challenges to teaching well included inadequate facilities (9%), issues with assessment (9%), and insufficient resources (6%). An example response of 'inadequate facilities' described large lecture theatres deemed unsuitable for teaching physics. Responses in the 'issues with assessment' category included: problems designing useful assessment tools; high workloads associated with assessment requirements; and uncertainty about how to provide useful feedback and encourage students to focus on deep learning rather than exam preparation. Staff who raised concerns about 'insufficient resources' typically referred to limited funding and poor teaching supplies.

4.4 Development of teaching practice

4.4.1 Experiences of change and development in teaching

The vast majority of teaching staff are involved with module or course development, typically in the form of content updates; changes to structure or assessment; or the introduction of new technology. The majority of staff feel they have freedom to innovate in their teaching, and developments are frequently instigated by individuals; institutional directives and external pressures appear to have far less impact on decisions about teaching development than individual instructors or departments.

Survey respondents were asked to reflect on the benefits of and challenges to development of undergraduate physics teaching. Strikingly, one in four of the teaching staff who expressed a view stated that there was no benefit to changing or developing teaching. However, one in five reported deriving personal enjoyment and satisfaction from their engagement with development activities.

Just 12% of respondents suggested that assisting with teaching developments was beneficial for career advancement. As might be expected, the most commonly cited challenges to teaching development were time and workload, mentioned by nearly half the respondents. Teaching development is a time-intensive task, and many staff lack confidence that reform will ease time pressure in the future or lead to due recognition and career progression. Other challenges mentioned by smaller minorities of respondents were tensions with colleagues or management and prohibitive or unhelpful bureaucracy. Only two members of staff stated that the quality of physics teaching at their institution was already of such a high standard that no development was needed.

4.4.2 Drivers of change and development in teaching

Most of the changes discussed by survey respondents were prompted by perceived problems or evidence of poor performance and, as such, reforms tended to be highly practical and remedial in nature. We described earlier some of the changes that had occurred as a result of the perceived shortcomings of incoming undergraduates. Routinely low pass rates were also cited by several teaching staff as the type of 'evidence' of poor performance that would likely lead to reformed practice. A senior teaching fellow at a Russell Group university mentioned how his department's 'relatively poor performance' in the National Student Survey had instigated change.

Indeed, many of the 'negative issues' identified as driving change related directly to the student experience. Examples included: poor student feedback; changing levels of student preparation and skills; the introduction of fees; and, an emphasis on employability issues. The items on this list may seem obvious, but it is nonetheless striking that seldom does a staff-centred issue appear to inspire change. Many teaching staff feel overworked and under-rewarded but we saw no evidence that these concerns presupposed changes in teaching practice.

Mirroring respondent comments on the priorities of teaching committees, the discussion of factors driving teaching development suggested that the strong emphasis on responding to problems left little time or resource for considering enhancements in their own right. Teaching staff very rarely reported that exemplary practice or simply a desire to try something new led to change. However, examples were given of innovative practice that yielded benefits for both students and instructors. One Senior Lecturer reflected on the results of his department's move towards 'student-centred laboratories', informed by PER:

> *'When we first ran the new laboratory, we discovered second year students standing outside looking in. We wondered what was going on, went out to talk to them and said, they said that looked like fun, they wished it had been like that when they did first year labs. The other indicator was that previously we'd had a lot of absenteeism: typically 25 per cent of the students wouldn't turn up for scheduled lab. The first year we ran the revised lab – 97/98 per cent attendance. Students who did genuinely miss a lab asked the technicians, can we come in Wednesday afternoon to do what we missed? It was a complete transformation'.*

4.4.3 The role of PER in change and development

A surprisingly high number of the survey sample – 47% – stated that enacted changes were partly informed by ideas or evidence-based innovations from PER. This figure is somewhat incongruent with staff awareness of, and engagement with, PER reported in other parts of the survey.

In light of this apparent inconsistency, we further investigated teaching staff attitudes towards and engagement with PER over the course of the follow-up interviews. It is important to be mindful that the interviewees tended to hold more positive views toward teaching and PER than the survey sample, which demonstrated more wide-ranging attitudes towards teaching and PER. Three interviewees stated they had consulted PER literature on peer instruction, and a further three had explored research on active engagement strategies. The vast majority of interviewees, however, admitted that they personally had not consulted any education literature, typically citing time limitations.

Moreover, the level at which PER is engaged with might be relatively casual – a few interviewees mentioned a brief coffee room discussion of PER as an example of its role in the reform process. A further point arising in the interviews was of an apparent confusion over definitions of 'physics education research'. Many interviewees clarified that they had been referring, in their survey responses, to generic education research. They were openly unsure whether the literature drawn upon in reforms included PER.

Interviewees complained that lack of time and discouraging reward and recognition policies often prevented them from engaging with PER, but they were less likely than the survey sample to criticise PER as a research activity in itself. Interviewees deemed current university teaching practices to be 'unscientific'. This Reader at a research-led university explained why the evidence-based approach of PER appealed:

> *'I'm a physicist and I like to look at data and draw conclusions. I'm perfectly happy to try [PER-based teaching methods] because there's evidence. A lot of the stuff is done at very well respected institutions, [with] large cohorts of students. I'm reasonably convinced by the evidence [which] seems to be that these types of approaches result in a better understanding, and improve the outcomes for the students.'*

Other interviewees approved of the fact that PER was subject-specific and typically developed by physicists. This Russell Group Professor justified the significance of PER being developed and promoted by physicists:

'I think it's an important distinction because there's the "what are these educationalists telling us about teaching physics, they know nothing" attitude.'

PER researchers may be buoyed by these findings, but our discovery that the majority of teaching staff believe they will not be rewarded for taking the time to enhance practice, and explore PER as part of this process, is concerning. The potential for this widespread perception to hinder the development of a progressive culture for enhanced practice is plain. However, is it difficult to envision such beliefs abating without policy change in areas such as workload and reward and recognition at the departmental and institutional level.

4.4.4 Evaluating change and development in teaching

Methods for evaluating the impact of change and developments in teaching are very similar to those currently employed to assess teaching quality. Two-thirds of survey respondents stated that developments were judged on the basis of student feedback, and a third cited student performance. Given our earlier discussion of how unsatisfactory teaching staff consider these tools to be as indicators of teaching quality, it is plausible to assume that they are considered equally ineffective in the context of evaluating teaching reforms.

Despite the low confidence teaching staff place in student feedback and exam performance, these indicators appear to be the main ways in which the impact of change is monitored. The absence of accepted and robust measures for assessing teaching quality and reform is significant. Research in the US suggests that the absence of valid assessment tools implies that teaching developments are not valued, and subsequently demotivates teaching staff to invest time and effort into reform (Henderson et al., 2014). Most staff in our sample believed that teaching enhancements are extremely difficult to evidence, and that, consequently, teaching metrics carry little weight when making a case for promotion. This Professor at a research-intensive institution outlined his perception of some of the difficulties involved:

'To measure in a quantitative way the quality of teaching is very difficult. Student evaluations don't really tell you what is going on. Counting the number of students you've taught doesn't help... Exams don't tell the full story either because if [exam marks are] particularly bad, it doesn't reflect and may not have anything to do with your teaching. So, measuring [teaching] quality hasn't been tried really and hence basing promotion on it is going to be very difficult.'

It is, therefore, once again easy to appreciate why many staff state that the less risky strategy for career advancement rests with high performance on the well established and universally accepted markers of research achievement.

For the moment, it would seem that, in the UK, insights from PER impact little on approaches of evaluating change and development in teaching. This situation is echoed in the US, where researchers have called for greater alignment in how instructors and institutions assess teaching practice and reform, and for both parties to make greater use of PER informed tools of assessment (Henderson et al., 2014). The result, Henderson et al. argue, would be a more standardised and holistic method of assessing and rewarding effective teaching practice (Ibid.).

4.5 Training and professional development of teaching staff

We noted earlier that teaching staff believe experience plays a significant role in refining their teaching practice. The majority of UK universities offering training for newer lecturers clearly believe that there is an important role for formal as well as ‘on the job’ learning. Often, successful participation in formal training courses leads to a qualification demonstrating the lecturer’s proficiency in teaching.

The majority of physics teaching staff reported having participated in such formal training to prepare them for teaching. About 70% of respondents had attended university-based professional development courses and roughly 20% had received training based in an education department. Most commonly, non-physics specialists deliver training of this kind to newer lecturers from a wide range of disciplines. There is therefore little opportunity to address teaching issues that are subject-specific or to discuss particular course material in any depth.

Despite the widespread prominence of university-based professional development courses, physics staff were, on the whole, negative in their reflections about the value of formal training. The generic content of training attracted frequent and strong criticism. Many staff believed that for training to be useful, it must be subject-specific or at least designed with cognate disciplines in mind. The following remarks, from two survey respondents, exemplify this viewpoint:

> *‘The idea that education research can help me in my teaching, particularly from academics who are not physicists in my area, is ridiculous and scary. The last thing I need is more activities, such as training courses, that do not help me to be a better teacher nor to progress in my career.’*

> *‘General principles of teaching undergraduate physics can be learned from more experienced staff. Not via training courses nor via general education research, unless that research is specifically targeted at physics education.’*

Formal training aimed specifically at physicists, however, is rarely undertaken by physics teaching staff. Only 10% of physics teaching staff had undertaken formal training within their department or with an external organisation.

Several physics teaching staff were apprehensive about language of ‘best practice’ – especially when interpreted in a didactic way. Just over half of the sample thought that there could be no universal definition of best practice in teaching, because appropriate teaching necessarily varies across distinct local contexts. This Reader at a research-intensive university shared his perspective:

> *An individual lecturer should have the capability of examining bits of evidence, examining advice, taking suggestions, and I think that, taken in that spirit, educational research can be extremely useful. It's never going to be a blanket that covers everything. It is never going to be instantly and obviously applicable to everything.’*

It is important to clarify what is being said here. Earlier, we saw how staff believe their teaching does improve with experience and time. Thus, staff do not reject qualitative judgments of teaching per se. However, they are troubled by the suggestion that there might be a universal, 'one size fits all', measure of 'best' teaching. While 'best practice' often does not imply one solution, teaching staff may interpret the concept in such a way, and consequently feel disengaged from training and professional development courses that promote such terminology. For many staff, the source of these concerns was a strongly held belief that teaching is a highly personal activity.

In the midst of this criticism, it is important to stress that staff believe that becoming a good teacher does involve an element of learning. Just under half of the survey sample thought that there are general basic principles that can be learnt – through peer observation, training, or consulting education research literature. Around two-thirds of teaching staff stated having learnt and developed their teaching through mentoring (both formally and informally arranged). Exploring this issue further in the interviews, we heard unanimously that there is a role for new lecturer training alongside experiential and peer learning. Suggestions for improving training courses included: the inclusion of evidence-based approaches; ensuring that training is practical; and, the introduction of more subject-specific training.

4.6 Looking to the future: Suggestions from physics teaching staff

Just under half of teaching staff responded to a final survey question seeking recommendations to improve the quality of undergraduate physics teaching in the UK.

- A quarter of recommendations related to improving student skills, an issue we have already discussed at length. Most respondents called for action at a national level to address the perceived problems with physics teaching and learning at school.
- Just under a quarter of teaching staff stressed the need to ensure professional reward for teaching. Individuals advocating for this suggested the creation of new career paths for specialised teaching staff and policies to overturn the priority status of research performance.
- A similar proportion of staff shared recommendations for what is taught and how. Proposals included: extending the length of degree programmes; raising the level of the material taught; and, increased use of active learning pedagogies.
- 16% of respondents offered recommendations regarding departmental or institutional staffing policies. Here, most argued for increasing the numbers of teaching staff and/or specialist teaching staff to reduce staff:student ratios and reduce academic workloads.
- 7% of respondents focused on training and continuing professional development; recommendations included the promotion of evidence-based techniques, the use of mentoring schemes and the effective dissemination of good practice.
- 6% of staff advised the need to develop effective teaching metrics and assessment methods that usefully and thoughtfully ascertain what is taught and learnt in the classroom.

5. Recommendations: fostering learning improvements in physics

Here we outline the recommendations arising from the project. We first address PER in the UK, considering both the strategic development of the PER community and funding to support it. We then turn to common teaching challenges, developing teaching practice and, finally, valuing excellent teaching.

5.1 Strategic development of UK PER

Our study of the international impact of PER suggests that the field is capable of fostering improvement in undergraduate physics education when adequately supported and strategically promoted. PER is already relatively widespread among UK physics departments and informal networks exist across the country which support it. However, most UK researchers conduct PER as an optional extra in jobs with other priorities and there is limited formal support for the field at departmental, institutional and national levels. This 'cottage industry' dynamic is damaging both to the career prospects of those working within the field and to the perceived value of discipline-based educational research among physics teaching staff. We note that the emergence of PER as an established academic field which could impact undergraduate teaching in the US followed strategic advocacy by the US PER community. We further note that professional bodies played a particularly important role in validating the field and promoting adoption of evidence-based teaching innovations among physicists.

> *We recommend strengthening existing networks to develop a cohesive academic community for UK PER that has the ability to work toward common priorities and coordinate advocacy for the field within the country.*
>
> *We suggest that both informal promotion through local and national networks and formal lobbying – e.g., seeking endorsement from national bodies – would be of benefit in raising the profile of the field.*

5.2 Funding for UK PER

We note that funding for PER is a necessary but not sufficient condition to ensure impact and emphasise that the scale of impact does not necessarily scale with the level of funding. For example, challenges around dissemination and adoption of evidence-based techniques remain even where levels of financial support for PER are high. However, a threshold level of funding is essential to allow PER to develop as an academic field. In addition, it is necessary to make funding available for longer durations, in order both to train individuals in PER, and to allow for the rigorous evaluation of PER-informed developments to teaching practice. This is not currently achieved in the UK, where most PER is funded through one-off, low-value, teaching development grants at institutional level.

> *We recommend that stakeholders concerned with undergraduate physics education work to identify funding streams for PER which support basic research and allow for the development of researchers and research projects over time. Specifically, funding should be sought for PhD studentships and postdoctoral research positions in PER, and multi-year research projects.*

We note that funding from a well-respected national body may also serve to validate PER within the physics community and to promote research topics that address national priorities.

5.3 Addressing common teaching challenges

While the factors supporting high-quality undergraduate physics teaching are perceived to be specific to individuals or departments, the factors challenging it appear to be strikingly similar across the UK. Some of these challenges – such as addressing perceived deficits in mathematics among incoming students, engaging students in large classes, and effective teaching of mixed-ability cohorts – could be usefully informed by PER which is focused on UK priorities. We note that at present many of the evidence-based innovations in undergraduate physics teaching are imported from the US and may not be optimised for UK students and teaching staff. PER leading to teaching enhancements that address the common challenges in UK physics education would have widespread usefulness and may be more clearly relevant to and more readily adopted by UK teaching staff. In other international regions, targeted funding at a national level has successfully defined national research priorities for PER. It is also evident that there are numerous challenges, both in the UK and internationally, that limit widespread adoption of PER-informed enhancements by the teaching community, both within individual departments and more broadly. Thus, more work is needed to develop effective ways of disseminating, embedding and maintaining teaching innovations in UK undergraduate physics curricula.

We recommend that the PER community prioritises some of its research effort in areas that have the potential for widespread impact across UK undergraduate learning and teaching of physics. We note the value of cross-institutional collaborations in this area.

We further recommend that those developing funding strategies for PER take a portfolio approach which supports both fundamental research and 'roll-out' projects aimed at embedding sustainable teaching enhancements.

5.4 Developing teaching practice

While most physics teaching staff undergo training intended to develop their teaching, they report high levels of dissatisfaction with the generalised training which is most commonly provided. Generic training courses are, in the main, not felt to be relevant to the issues faced by physics teaching staff, who report learning more usefully from colleagues and from their own experiences as learners and teachers. In addition, some staff form a negative impression of the educational research 'jargon' they encounter in generic training courses which extends into scepticism about PER. There is a clear opportunity to provide more relevant training to physics teaching staff which is subject-focussed, delivered - at least in part - by colleagues with a deep knowledge of both physics and physics teaching, and informed by evidence gained from PER. We favour a development model in which teaching staff, PER practitioners and education professionals work in partnership, preferably over a sustained period with opportunity for reflection and feedback. We highlight the AAPT New Faculty Workshop as an example of a nationally organised training scheme which has achieved widespread impact on physics teaching in the US.

We recommend departments, institutions and professional bodies consider provision for initial and continuing professional development for UK physics teaching staff which is both subject-focussed and evidence-based. We further *recommend that this should be based on a partnership model including physics teaching staff and PER practitioners as well as teaching and learning development professionals. We note the potential value of PER in this area.*

5.5 Valuing excellent teaching

In general, UK physics undergraduates benefit from being taught by staff who feel positively about teaching and are dedicated to doing it well. Development of excellent teaching is hindered, however, by intense time pressure within a professional culture that is often perceived to value teaching less highly than other academic job functions, in particular research. Hence within departments, limited time and resource for teaching are more often directed to remedying problems than to teaching enhancement and sharing of good practice. At an individual level, many staff report lacking the time to teach as they would like to, and spending a great deal of time on teaching is widely felt to be harmful to career progression. This finding applies equally to staff who choose to conduct PER and may be compounded by a lack of legitimacy resulting from the 'cottage industry' dynamic discussed above. While the situation is felt to be improving at some institutions, in many cases reward and recognition structures that aim to support teaching are not seen to do so in practice. Challenges also exist in evidencing excellent teaching. Most commonly used measures – such as student surveys and course results – are felt to be problematic, and there is often little shared understanding of teaching excellence among institutions and teaching staff.

We recommend that institutional management, departmental management and teaching staff work to develop a shared understanding of teaching excellence and workable measures of teaching quality. We note that relevant studies in PER may usefully inform this process.

We recommend that institutions work to counter the widely held view that there is a disconnect between reward and recognition policies and practice in relation to teaching. We urge greater transparency regarding promotion decisions based on teaching contributions.

We recommend that institutional and departmental management ensure staff have adequate time for reflective teaching, teaching enhancement and sharing of good practice. We further recommend that they provide an infrastructure and promote a culture in which teaching is afforded legitimacy and prestige equal to other academic functions.

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Appendices

Appendix A. PER in the United States

The majority of the seminal results described in Section 3 stem from research done in the United States, where PER first emerged in the 1970s and where it is now most firmly established as a sustainable field of academic research. According to the report *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering* (National Research Council, 2012), PER research staff are currently active in 79 higher education institutions in the US. A recent funding census attracted 237 respondents who self-identified as US-based PER practitioners (Henderson et al., 2012). The US PER community is largely, though not exclusively, comprised of physicists who are based in physics departments. 70% of the Henderson et al. (2012) sample worked in physics departments, 43% held PhDs in traditional areas of physics and 33% held PhDs in PER. Other respondents were based in education departments or held joint appointments. Underscoring the multidisciplinary nature of the field, roughly half the reported PhDs in PER were granted by education departments.

Notably, there are established career paths for researchers in PER in the US. About a dozen institutions grant doctoral degrees in PER (National Research Council, 2012) and job opportunities for new PhDs appear to be plentiful. Beichner (2009) describes a job market in which '*most PER graduates take faculty positions immediately upon graduation*,' leaving PER postdoctoral positions undersubscribed. An average of 55 jobs per month were listed on a blog of jobs suitable for PER graduates (http://perjobs.blogspot.co.uk) in the second half of 2013, and the vast majority were based in the US. While appointment of a PER scholar to a tenure track position at a major research university is still rare (National Research Council, 2012), more than 75 tenured or tenure-track faculty are currently active in PER (Cummings, 2011). Describing successful career trajectories of PER PhD graduates from 2000-2002, Cummings (2011) states that most went directly into tenure-track positions and had been granted tenure based on their PER work within ten years. Half of the small sample of postgraduate and postdoctoral scholars interviewed by Barthelemy et al., 2013) aspired to continuing careers in academia.

A cohesive professional community supports US PER. There are several national meetings for PER each year (National Research Council, 2012) and the largest of these typically attracts more than 200 delegates and produces an average of 70 associated proceedings publications (Cummings, 2011). There are also three peer-reviewed journals – *The American Journal of Physics*, *The Physics Teacher*, and *Physical Review Special Topics: Physics Education Research* –which provide avenues for publication of work in PER. A PER Topical Group within the American Association of Physics Teachers (AAPT) is open to all PER practitioners. This group in turn elects a Leadership and Organizing Committee which coordinates strategic decision-making for the PER community. In addition, there is an active online forum, provided by the AAPT and partly funded by the National Science Foundation (NSF), for resource and information sharing at PER-Central (http://www.per-central.org). The site attracts both US and international PER practitioners and, among other services, coordinates groups of graduate students and of individuals working alone in PER to allow networking and community building.

Most US PER practitioners study teaching and learning of undergraduate physics, with the majority of grant funding going towards research at the introductory undergraduate level and much smaller amounts devoted to work focusing on more advanced undergraduate or school-level learners (Henderson et al., 2012). Cummings (2011) notes a general diversification of PER research interests as the field grows and, in particular, a move away from research which is directly applicable to teaching. She quotes one researcher as stating that '[PER research] seems to have become more and more fragmented, quite divergent' and that 'there seems to be a lack of consensus on priorities and goals of the field'. A comprehensive report for the National Academy of Sciences, *Adapting to a Changing World: Challenges and Opportunities in Undergraduate Physics Education* (National Research Council, 2013) summarizes current and emerging areas of emphasis in US PER studies which include topics which are directly applicable to classroom challenges (e.g., the promotion of reasoning abilities), topics which are more theoretical in nature (e.g., the nature and origins of conceptual difficulties), and topics relating to strategies to engender change (e.g., optimizing dissemination routes for PER-based innovations).

Unsurprisingly, funding levels for PER are highest in the United States. Based on an on-line survey of PER practitioners and an audit of relevant funding bodies, Henderson et al. (2012) estimate a total funding base for US PER in the years 2006-2010 of $72.5m (£44.8m). In this study, 55% of survey respondents reported having been funded to conduct PER and the average grant size was roughly £160k. To allow comparison across international regions, we divide the total funding reported by survey respondents by the time period covered by the survey and the number of PER practitioners in the full survey samples. We find annual funding levels per respondent are 50%-100% higher in the US than in any other region covered by our study.

Henderson et al. (2012) report that the majority of funding for PER in the US comes from the national government through NSF programmes run by the Directorate for Education and Human Resources. Additional sources of support include the US Department of Education, private foundations and grants provided at state and institution level. Grants from governmental sources averaged $368k (£224k), while institutional grants averaged $17k (£10k). Henderson et al. (2012) also investigated the nature of funded projects in the US. While grants were awarded for studies of physics learning at all educational levels – from elementary school through to postgraduate study –the largest amount of funding by far supported work on undergraduate learners, particularly those in introductory classes. Funded projects most often focused on curriculum development, though substantial fractions of the funding pot also went to basic research, dissemination and outreach.

Henderson et al. (2012) also note that the primary purpose of the NSF programmes that fund 75% of US PER is to support educational practice, rather than to subsidise basic research. They further note that very little PER work is funded through programmes housed in the NSF Division of Physics and that there is no dedicated funding line within the NSF or elsewhere to support PER. They argue that these deficits in combination with the often short-term, project-by-project basis of much of the available funding complicates efforts to build sustainable research programmes in PER.

Appendix B. PER in the European Union (outside the UK)

In the European Union outside the UK (hereafter 'EU'), our survey attracted 85 responses from self-identified PER practitioners based in 41 institutions and 19 countries. We note that different types of researchers may identify as PER practitioners in different regions and that, especially within the EU, this may lead to considerable diversity within the sample.

In general, those who identified as PER researchers in the EU were less likely than those in other regions to be tightly connected to physics departments. Only 60% of respondents were based in physics departments and just 25% held PhDs in traditional areas of physics. A third of the EU sample were based in education departments. A similar fraction was found by Vollmer (2003), who surveyed experts in PER from 21 EU countries and published responses averaged by country. While Vollmer (2003) states that very few PER experts have a lot of contact with colleagues in traditional areas of physics, roughly half the respondents to the FLIP survey who were based outwith physics departments reported working with them regularly.

Our survey suggests that, compared to other regions outside the US, PER may be relatively well established as an academic field in the EU. Research in PER appeared to be a primary job role for many EU respondents, who were more likely than those in other non-US regions to hold PhDs in PER (33%), to spend at least half of their non-teaching time on PER (53%) and to publish PER results at least every year (78%). They were also more likely to work at an institution which had a PER group (65%) and offered PhD studentships in PER (67%). Just under a third of EU respondents felt there were well-defined career paths for PER in their countries.

Perhaps unsurprisingly, given the large number of countries represented in the sample as well as the academic diversity of the respondents, there was less evidence of a cohesive professional community of PER researchers across the EU. While the vast majority of respondents reported keeping up-to-date with PER knowledge by reading the research literature and attending conferences, there was little consensus around preferred publications or conferences. The most common place to publish PER for EU researchers was in national-level journals and no more than a quarter of respondents published work in the most commonly cited international journal (*The European Journal of Physics*). The most frequently mentioned PER conference (GIREP-EPEC) was attended by no more than a third of respondents.

European researchers were much less ubiquitously interested in studies at undergraduate level than those in other international regions. A greater number of respondents reported studying learners at secondary school level (72%) than at HE level (65%). Many practitioners studied physics education at multiple educational levels, and many reported playing a role in the training of physics schoolteachers. In keeping with this broader scope for PER, there was no clear consensus among EU respondents about prominent and/or influential research areas. Among the most commonly cited were problem-based learning and technology-assisted learning, which were also common responses in other international regions. Notably, when asked to consider how PER activity could foster learning improvements in undergraduate physics and to provide examples of widely-disseminated PER-based innovations, the most common response among the EU respondents who chose to answer was that they didn't know. This may reflect both the greater emphasis in this region on study outside of HE level and/or a lesser focus on applied research that directly aims to impact student experiences.

EU survey respondents identified 71 grants worth a total of €16.6m (£13.5m) over the ten year period to 2013. We note that this total is a lower limit on the funding actually received for PER over the period, as some respondents listed grants but did not provide their value and some respondents explicitly stated that listing their funded projects would be too time consuming. The value of reported grants yields an average annual funding per respondent within the EU which is 50% lower than that in the US and 25% higher than that in Australia and the UK. The fraction of respondents who were grantholders was lowest in the EU survey, with just 38% of researchers reporting that they were principle investigators of a funded PER project.

The largest fraction of reported EU funding came from a small number of very large grants from the European Commission. While these projects comprise only 11% of the reported grants, they have an average value of €1.8m (£1.5m) and contribute 46% of all reported funding. The second largest contributor to the reported funding, both by number of grants and total value of funding, were national governments which averaged €203k (£166k). Among grants where differentiation by the type of government body was possible, lower value awards from ministries of research outnumbered higher value awards from ministries of education. A quarter of the reported grants came from institutional sources, but with median award values of €17k (£14k) they were worth just 4% of the total funding reported.

While we did not specifically query the aims of funded projects in our survey, the titles and/or descriptions of reported grants suggest that, as in other regions, many are focused on the development of teaching practice, often at pre-University level. In addition, many of the largest grants – for example two multi-million Euro awards from the European Commission – focused on improving teaching and learning of science in general rather than physics specifically. Funding levels for studies of undergraduate physics teaching and learning and, in particular, basic research in this area, are substantially lower than those reported above.

Appendix C. PER in Australia

We received survey responses from PER practitioners at 21 institutions in Australia, which suggests a very high fraction of institutions with undergraduate physics departments in Australia have staff involved in PER. 75% of all departments that produce research in the physical sciences in Australia are represented, as well as three institutions with no research units in physics (Australian Research Council, 2013). The majority of respondents were based within physics departments (80%) and held PhDs in a traditional area of Physics (76%). Very few respondents held PhDs in PER (6%).

The Australian survey attracted an older and more experienced demographic than those in other regions. Just 8% of respondents were under the age of 35 and two-thirds had more than ten years' experience in PER. There are correspondingly fewer early career researchers and more mid-career researchers in the sample compared to other regions, though with no higher fraction of full professors. Given how common PER staff appear to be and how long many have been active in the field, it seems likely that Australian PER emerged fairly soon after the field became well established in the US. If the group of respondents who have participated in our survey provides an unbiased sample of the PER community in Australia, the lack of early-career researchers may suggest that growth of the field is now waning.

Many of those doing PER in Australia appear to do so within a job focused on another area. Only 18% of respondents stated that their primary professional activity was research of any kind, a significant fraction reported doing research outside of PER, and just 11% spent more than half their non-teaching time on PER. However, roughly 40% of the sample reported being based in PER groups, publishing PER more than once a year, and working in institutions which offered PhD studentships in PER. Roughly a quarter of the respondents felt there were well-defined career paths in PER in Australia.

PER researchers in Australia showed the lowest level of consensus over publication routes of all the regions we studied. No more than 1 in 5 respondents submitted work to either of the most commonly cited journals, *The International Journal of Science Education* and *The International Journal of Innovation in Science and Mathematics Education*. These journal choices are also outliers internationally, as most PER researchers choose to publish work in physics-specific publications. Australian respondents show a somewhat higher level of cohesion with respect to conference choice, with over half attending congresses of the Australian Institute of Physics. However, they were significantly less likely than respondents from other regions to report keeping up-to-date with PER knowledge through conference attendance, with just over half stating that they did this.

As in the US, the majority of Australian PER researchers studied undergraduate level learners and substantial minorities studied learners at school level. Among the international regions studied, Australian respondents showed the highest level of agreement over which areas in PER were 'hot topics', with nearly half citing technology-assisted learning. Australian respondents also had the highest level of consensus over which factors set the PER research agenda, with two-thirds of respondents suggesting that PER research topics came into prominence due to national priorities. This serves to highlight that strategies at a national level can effectively influence the focus of PER research within a region.

Within Australia, it is likely that this influence is a direct result of a funding base for PER which appears to be dominated by grants from national-level bodies such as research councils and the Department of Education. Nearly 60% of the grants reported in our survey, accounting for over 90% of the total reported funding for PER, were publically funded and worth an average of $AUS194k (£105k). Nearly all the remaining reported funding was comprised of much smaller institutional awards with an average value of $AUS20k (£11k). Judging from project titles and descriptions where possible, funded projects in Australia seem to be a reasonably balanced mixture of research studies, development work and implementation schemes.

Being funded for PER seems relatively common within Australia. Over half (56%) of the respondents to the Australian survey reported holding grants for PER and the average number of grants held per grantholder was two. However the average grant size of $AUS122k (£66k) was smaller than in any other region and the annual funding per respondent was lowest of all the regions studied. That said, the number of Australian survey respondents relative to the national population was extremely high, almost three times that of the US. Australian funding levels are therefore low for the size of the PER community, but second only to the US relative to the population of teachers and learners of physics.