Physics Education Research: Education or Physics?

Sydney University Physics Education Research Group *

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Abstract

At the University of Sydney, a number of physicists have come together to form a group whose aim is to carry out research into tertiary physics education. This move has prompted the question to be reconsidered: what should be the influence of educational research on teaching in a university physics department?

Experience suggests that the kind of research done in Education faculties is not much heeded by physics lecturers, even those with genuine concern to improve the standard of teaching and learning of their students. Yet there are many insights to be gained from the results of mainstream educational research which could improve university physics teaching. This paper argues that an excellent way to achieve this end is to locate centres of research into physics education within physics departments, and for that research to be carried out by physicists.

[0]The group consists of: I.D.Johnston (leader), I.J.Cooper, K.Crawford, P.W.Fekete, P.R.Fletcher, M.A.Oldfield, B.A.McInnes, R.M.Nillar, I.M.Sefton, M.D.Sharma and P.J.Walker; together with other associated members.

1 Background

In today's university milieu, the job description of academics includes both research and teaching; and while the ideal is that all should be equally interested in both activities, in reality there is a wide spectrum of commitment to either. On the one hand there are those who prefer to spend all their time in research, in pushing forward the frontiers of knowledge in their subject. By and large our university system is tolerant of such people, drawing comfort from the fact that some of the world's most productive scientists have been indifferent teachers. Examples quoted usually include Kepler and Einstein. On the other hand, there are those who are more interested in teaching, in exploring ways to communicate this knowledge to students. Our university system is less comfortable with such people: there seems to be something of the "those who can do; those who can't teach" attitude. Yet increasingly many academics believe that the process by which our subject is codified and passed on to the next generation is a worthwhile field of research in its own right. It is the purpose of this paper to make that argument, in the context of physics.

In the department to which the authors belong, a group of individuals have come together to form a research group, with the acronym of SUPER — the Sydney University Physics Education Research group. Its aim is to strengthen work being done in this area by pooling knowledge about research methods used in other educational disciplines. But the formation of such a group does not, of itself, confer legitimacy on the enterprise. Two questions should be asked, and answered with as much rigour as possible.

- Is such an activity useful to university physics teaching? and
- If it is, is it best done within a Physics department, rather than within an Education faculty?

In this paper we will seek to answer both of these questions by focussing on

- the apparent indifference of many tertiary physics teachers to the results of research carried out in Education departments, despite
- the apparent benefit that physics teaching and learning could gain from that kind of research, and
- the resolution of that problem which is possible by locating such research effort within physics departments.

2 There seems to be a conflict between Physics education and mainstream Education research.

Many, if not most, academic physicists would contend that the kind of educational research carried out in mainstream Education faculties has little impact on the teaching of physics in ordinary universities. There are several reasons usually advanced by physicists in support of this contention.

1. Many Education faculties devote most of their attention to the problems of pre-tertiary education, for the obvious reason that that is where most of their students will end up as teachers. Unfortunately the perception is that the insights gained by researching in this area are of limited usefulness in the tertiary scene where most practitioners believe the relationship between teacher and student is fundamentally different, falling into the master-apprentice model.

   There have been many innovative teaching methods developed over the past few decades — for example, Keller plan[1], Computer Aided Learning, Workshop Physics[2] to name but a few. These have been tried in isolated universities, with varying degrees of success. Nevertheless, the majority of Physics departments throughout the world still teach by the lecture/tutorial/laboratory model.

2. There is mistrust of the methods used in Educational research. In the social sciences, research is done by seeking opinions, analysing questionnaires, interviewing subjects. The outcomes are often context dependent and will vary with the particular group chosen. Such methods are perceived by physicists to be "soft" and their results unreproducible. This is in opposition to the "hard" sciences in which results and opinions which cannot be validated are (at least in theory) ignored.

   This lack of trust can be most clearly discerned by observing practising physics teachers. Many of those who care about their teaching have heard of research results which suggest that, for example, ordinary lecturing is not, in general, a successful technique for helping students to learn physics. Yet they continue to conduct their classes in the traditional manner. When it comes to the crunch, they seem prepared to ignore the research findings, and adhere to the "it worked for me" philosophy.

3. An important issue is one of *ownership*. Academics have grown up with the belief that science is that which is done by scientists, and the only way it can be learned is by modelling oneself on a scientist. Such a model is, by its very nature, highly personal, and most scientists are uncomfortable with

the idea of using someone else's materials and approach in their teaching. Many an attempt at teaching reform has foundered on the "not-invented-here" syndrome.

Perhaps the best example occurred during the 1970s when departments all over the world were making televised lectures in the then fashionable belief that that was the way of the future. Remarkably few departments were willing to use programs made at other institutions, and much effort was spent duplicating materials being made elsewhere. The result was that the whole effort was soon deemed too expensive and fell into disuse.

4. However the most important issue seems to be whether the *process* of teaching, at a tertiary level, can be divorced from the *content*. Irrespective of how they think students learn, most tertiary physics instructors believe that anyone who wants to teach the subject effectively at this level must have a deep understanding of the material. An outsider's views about how the subject should be taught may not be useful if they do not understand intimately what has to be learned and why.

   There are many obvious examples within physics. As Feynman has pointed out[3], even so basic a concept as energy is full of unresolved difficulties. What then is the answer to the question: how can one best help students learn about energy? It is hard to see how anyone could give other than very general advice on that question, unless they knew exactly what those difficulties are.

Whether or not these four arguments would stand up to rigorous analysis is debatable, but that is not the point. They are widely held, and it needs to be appreciated that they stand in the way of a possible source of improvement in our teaching practices.

In many academic departments, approaches to teaching, particularly at the upper levels, are rarely sophisticated and sensitive to the needs of students. Improvements do not accumulate, and each new lecturer starts afresh. However there is much education research from all over the world, which suggests that this need not be the case. Like other forms of teaching, physics teaching is an activity that can and should be researched in order to improve its effectiveness.

3 Physics teaching has a lot to gain from mainstream education research.

In the current mainstream education literature many issues are discussed which have obvious relevance to physics teaching. As just some examples, the following may be singled out.

1. **Learning theories**
   Within that branch of education which deals with the process of learning, a recent shift in theoretical perspective seems particularly relevant to physics. Previously the most widely held models of learning were transmissive: absolute knowledge was seen as being passed from expert to novice. Currently, the social origin of learning it is more widely appreciated, and recent theories suggest that students' (and all human) thinking is construed through previous experiences, that is, that the mental models they evolve in order to explain what they observe are constructed from what they know already, as well as what they are being taught. This model is known as *constructivism*[4].

   These ideas have already shown important results in research carried out by many different workers within the mainstream education research community. The general idea under investigation is that the point of view of students may be different from that of course designers, which cannot help but influence how they learn. Some phenomenological analysis of results suggests that many students' experiences have resulted in learning outcomes quite different from what their teachers intended[5].

   This work has obvious relevance to the university scene. A fundamental assumption that universities make is that the learning experiences provided for their graduates make a difference to their knowledge and capabilities. It is entirely possible that this is not true. We really need to understand the relationship between the way education is experienced by university students and the outcomes of their learning.

2. **Teaching strategies**
   One of the key thrusts of research and development in mainstream Education faculties is in the area of teaching (and assessment) strategies. In the recent literature will be found discussion of research into, for example, the value of discussion in small tutorial groups, the effectiveness of formal and interactive lecture delivery, the feasibility of guided and open forms of enquiry and questioning strategies as a progressive evaluation tool.

   At the university level, much of the teaching community seems unaware of these discussions. Farr and Brown[6] capture the essence of the problem:

   > "Most intructional decisions are made by forfeit; that is, by not recognising that a decision can be made or by not being aware of possible alternatives. The usual forfeit 'decision' involves continuation of a practice whether or not it is the most appropriate procedure for the situation."

While it is true that there always have been, and still are, good university teachers who do not seem to need to change the way they teach, surely it is without question that, in general, university physics teachers should be willing to try the results of this kind of research. At the very least, there should be systematic investigation of how effective such teaching strategies are in a physics context.

3. **Research methodologies**

   The widespread mistrust of the education methodologies mentioned above cannot really be justified and must surely be mere discipline chauvinism. Mainstream education workers have developed and categorized a wide range of proven research methods: descriptive methods such as surveys, interviews, observational studies and analysis of examination results; developmental methods investigating patterns of change as a function of time; case and field studies, to name but a few. This is not to imply that all these constitute a monolithic whole. As in all disciplines, a climate of change spawns different schools of thought. Recently, for example, there has been an increasing acceptance of a *qualitative* as well as the more usual quantitative approach[7]. The researcher interested in using these methods must understand what compromises exist in their internal consistency and external transferability.

   Each qualitative approach has its own standards and evaluation criteria, and the unwary researcher who chooses to mix elements from different approaches in a single study may not realize this difficulty. Those wishing to undertake research in physics education therefore have the double responsibility of learning what mainstream research methodologies are available, and applying them in such a way as to ensure external and internal credibility and validity for their research findings.

4. **New technologies**

   New technologies are having a large impact on learning everywhere. Most of the research carried out into this area has been done at the school level, for the simple reason that there are more students available on whom the research can be done. Preliminary research already shows that there are real differences between the representation and use of knowledge learned through traditional teaching methods, and that gained in, for example, computer based environments[8]. Information technology presents a fundamental challenge to older notions of human knowledge as memorized information and the capacity to carry out routine procedures.

   Here too, those investigations could and should be extended more widely into the tertiary domain. Already many physics departments the world

> over (and indeed all other departments as well) are changing their teaching practices in order to take advantage of the many benefits they see the computer bringing, as is evidenced by papers at several conferences[9] [10]. But this is often done without apparent recognition of the fact that these new approaches may involve radical changes in old conceptions for both staff and students. If the new technologies are to be used effectively there is a need for research on the impact of these new experiences on students' learning within the actual disciplines.

There seems no doubt that issues like these are of relevance to physics teaching, and there are many in our physics teaching community who believe that, in answer to the first question posed at the beginning of this paper, this kind of research is useful, and that the methods used in the social sciences are valid. For them the real question is: where and how should such research be done? The worry about divorcing learning from its context still remains, and it is worth noting that this worry is shared by educational researchers themselves.

The founder of phenomenography, Ference Marton, puts it like this:

> "All that is psychological includes consciousness but refers to something beyond consciousness itself. For example, we do not merely love, we love someone; we do not merely learn, we love something; we do not merely think, we think about something. . . . By changing that which has to be laerned or understood, we change the relationship between the object of learning and the individual."[11]

4 Physics education research can usefully be done in a physics department.

Many groups throughout the world have adopted the philosophy that this kind of educational research should be placed within Physics departments and conducted by experienced physicists — examples are those groups led by McDermott[12], Goldberg[13], Niederer[13], Redish[14], among many others. Whether this philosophy is appropriate is argued on several grounds. Basically they come down to the contention that university education in general, and university physics education in particular, must be considered to have their own unique needs and difficulties. Examples of these may be observed in the four areas of research already mentioned.

1. **Learning theories**
   When theories of learning are applied to the practical business of teaching, they need to be interpreted in the light of the context, particularly of the

purposes for which the material is being taught. Epistemological issues are of fundamental importance in physics (perhaps more than any other branch of science). Physics claims to discover not only things about the 'objective' world, but also subjective aspects of how these things are understood. Ideas of modelling, interpretation, and the use of language are of key interest to the physicist. How students learn these ideas are therefore of crucial importance.

Physics has always prided itself on being the cutting edge science, of developing genuinely new concepts and ways of looking at the world. The remark attributed to Lord Rutherford that "only physics is science, all else is stamp collecting", while perhaps facetiously meant, represents a genuine feeling on the part of many physicists. Yet such concerns are rarely explicitely thought about in teaching. Physics education research is one way of grappling with those kind of underpinning issues which are normally taken for granted by practising physicists.

It is also true that the mission of physics teaching in the eyes of its clients seems to be changing. There is continuing pressure from Engineering faculties, for example, to drop physics and to give their students more professionally oriented courses. Then again, falling enrolments in mainstream physics classes suggests that the younger generation no longer see physics as the grand adventure of the human spirit. It is as though they no longer feel the need to understand our subject in the same way we do — particularly with its traditional heavy emphasis on mathematics. Again physics education researchers are in an ideal position to re-evaluate the link between what we teach and how we teach it.

2. **Teaching strategies**
   Teaching strategies developed for other contexts, for example for secondary schools, may be tried in the tertiary sphere, but they need to adapt to the different nature of university education. Those who teach in a university have a responsibility to their subject as well as to their students. Despite constraints, financial or otherwise, imposed on universities from outside, most academics would feel obligated to teach their subject even if very few students were interested in learning it. Scholars want their discipline to survive.

   The university tradition is that the subject is taught by practitioners in the field. Those practitioners are responsible for choosing up-to-date curriculums, and choosing educational methods which will promote learning by students. It follows that teachers of physics have a professional responsibility not only to present the subject matter of physics in order to ensure a new generation of practitioners, but to do so in the most effective way. This also implies that there should be a clear idea of what students ought to learn and understand as a result of teaching, and of ascertaining whether the knowledge and understanding have been gained. Determining the relationships between teaching goals, teaching methods and learning outcomes is the role of educational research, to which the physics community itself can and should make a significant contribution

3. **Research methodologies**
   It has already been pointed out that education research has its own ways of doing things. When these are transferred to a different context, they need to take account of the level of sophistication of the material being taught in the university context. Physicists have always objected to physics being taught by non-experts, because they believe that the depth of the subject will be missed by others. The only people qualified to analyse and specify the appropriate knowledge, skills and attitudes are most likely to be working within physics. Whether or not students are learning to build appropriate mental models of physics can really only be judged by those who understand, as porfessionals, what those mental models are.

4. **New technologies**
   Computers are used in physics teaching in a way which seems completely different from most other disciplines. While there are some physics departments around the world which use Computer Based Learning (where the computer simply *presents* the material), the relative number is not large.

   On the other hand, computers have, in the last generation, changed how physics is done professionally, and this change is entering its teaching. One example is that computer simulations play an increasingly central role. (Note that the word "simulation" is used here to describe a computational modelling, rather than a simulacrum of what might be observed in a laboratory.) For physics, computation is part of the subject itself. There is an urgent need for work to be done on the effectiveness of this kind of use computers in physics teaching, and it can far best be done in a physics department.

5 Conclusions

To summarize, we have argued that there are problems involved in teaching physics to those who might be the next generation to which answers are not known, and which need elucidation. We have also argued that the solution of these problems is the proper concern, and indeed the responsibility, of practising physicists. We believe the answers to the questions posed at the head of this paper to be unequivocally “yes”, i.e.

1. physics education research can be very useful to our teaching, and

2. there are cogent reasons why it should be done within a Physics department, rather than within an Education faculty.

Not the least of those reasons is the time-honoured one of intellectual curiosity. We practising physicists have spent a long time learning our subject. We may or may not have found it difficult; we all found it rewarding. Why then do so many of our students find it hard and dull? We can only answer this by thinking deeply about physics and pedagogy at the same time. And, as the work of Aarons has shown[15], the payoff is that we can deepen our own understanding of our subject and possibly come up with new methods of passing it on to those who follow us.

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