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Practical teaching in secondary level certificated physics: a view from Scotland

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Abstract
This study reports on a survey conducted in the Scottish physics education context focusing on practical work within National 5 certificated classes. The online survey was open to all practising educators and technicians in Scotland's secondary schools and further education colleges. Descriptive statistics were used to analyse the results, alongside basic thematic analysis of text responses. The results indicate a decline in practical work in the classroom but suggests this is not due to the COVID-19 pandemic. Instead, cost and availability of equipment alongside a perceived lack of time for experimental work are cited as the major difficulties. The resulting recommendations are improvements to the curriculum and support for educators to develop best practice.

Keywords: practical, equipment, secondary, teachers, technicians

1. Introduction

Anecdotal evidence suggests there has been a reduction in hands-on activities since the COVID-19 pandemic. Additionally, there continues to be reporting of 'no money' which continued cuts to public spending can only exacerbate. Replacing broken equipment is expensive, especially in physics, so the apparent lack of resources is understandable. A further issue is the need for technical support in the setting up of the equipment (again physics tends to require more of this nature of activity), but technician numbers have been cut substantially [1], resulting in a reduced service and a likely contribution to the lower incidence of practical work. Technicians are frequently responsible for purchasing, installation, and maintenance of equipment [2]. They are key contacts for advice on practical work where collaborations

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with teachers can provide an invaluable source of new ideas.

Experimental work is used to aid discovery and investigation and to support the understanding of theory [3]. The challenge and freedom when designing and conducting hands-on activities, and the moment of excitement when results are achieved are often core to the enjoyment of science. At times there is no right or wrong outcome, instead there is understanding why something has happened, even if it was not expected. This extends into the classroom where educators bring knowledge and expertise to devise practical activities which bring scientific concepts to life whilst also developing learners' knowledge and skills in an invaluable manner. Practical work encourages interaction with science subjects often bringing difficult concepts from the abstract to the well understood through linking between ideas and observations [4], though it is also clear that it must be supported with prior knowledge [5]. This research is written from the view that practical work is a vital part of the learning process for young people, but more than being a key method to encourage children and young people, it is an important element of teaching for practitioners.

This research will examine the impact of the barriers and challenges facing educators' use of experiments in the classroom, specifically factors such as availability of equipment, technical support, staffing and teacher experience. It is hoped this can guide future work to improve practice, and act as the first step in assessing the current landscape in Scottish secondary physics education with particular emphasis on practical work.

2. Background

The importance of practical work in science subjects is well documented and highlights the benefits such as consolidating concepts, encouraging natural curiosity, and adding an interactive element [6–8]. A recent Royal Society report [9] suggests practical inquiry encompasses all hands-on activities from closed teacher-directed experiences to open-ended student-centred investigations, including simulations. Studies into pupils' perceptions show a preference for hands-on activities and a belief that they benefit from seeing the theory in action. Enjoyment is also of importance, as is the opportunity it gives for personal autonomy and social interactions with peers [10]. A scientific inquiry method develops skills such as data analysis, argument formation and presentation of findings, while incorporating a component of project work outside the classroom can link science to the real world and help pupils understand how to question the information they encounter from other sources [11].

There are multiple reasons to ensure that practical work is included in science lessons, but there is a shortage of research into which methods are considered ideal for specific teaching points. For example, which equipment is best suited to explaining Newton's second law of motion. Existing guidance on practical work tends to be more generalised and leans towards a promotional viewpoint. The Education Endowment Foundation report 'Improving Secondary Science' [12] and Gatsby's 'Good Practical Science' report [13] indicate the value of practical and investigative work but have little direct guidance as to best practice for individual curricular outcomes. While they give strong guidance for practical elements overall, they do not give research-based understanding of why a certain method for a specified teaching point may be a good idea. These concerns are somewhat addressed in work by the Institute of Physics in collaboration with the Nuffield Foundation as part of the 'Practical Work for Learning' project [14]. This has some excellent suggestions, however there is a need for comparison of methods, especially as apparatus has changed and new innovations have become available. Many of the activities described on those pages will still be one of the good or best methods available, but regular reviews are required to ensure the evidence is up to date.

The need for a more in-depth examination of how practical work supports the concepts of each science subject, with additional topic-level detail, is highlighted in a recent study of pre-service teachers in England [15]. They explain the need for better guidance on the types of practical work as well as examples and how they can be incorporated. They suggest further research into experienced teachers' views on the subject could provide additional data to inform the support required to ensure practical work is utilised to its full potential. Building on the general views of the importance of practical work, teachers need opportunities to reflect and discuss at a more detailed level.

Providing guidance may help to address some of the challenges facing school staff in this area. There are concerns regarding ‘time lost’ for pupils of the current generation due to COVID-19 pandemic disruption [16] and significant constraints on school budgets [17] which, when combined, may have resulted in a decrease in the frequency and depth of practical science. The impact of financial restrictions has also resulted in technician numbers per school having fallen, and a looming crisis due to an aging workforce [1]. This reduction in support combined with a requirement for subject-specific professional development are two of the reasons cited by the UK government and stakeholders for pupils receiving less than the recommended quantity of practical work in science [13, 18]. These issues alongside poor equipment provision (insufficient quantities/out of date/faulty) were highlighted ten years ago [19], and anecdotal evidence suggests there have been no improvements since indicating a need for further investigation.

Discussions with school colleagues suggest it is not uncommon for equipment which is more than twenty years old to still be in use. Advances in technology have resulted in new methods of performing some typical science experiments, for example, mobile phones have the capacity to measure acceleration and the literature has been referring to their use for over a decade [20]. Given this, it may be expected that survey responses will identify smartphone use in classrooms. The apparatus sold by science equipment suppliers mirrors this move towards technologically superior kit, but schools are not always able to replace old for new. This may be due to the tendency for these items to be expensive and the cutbacks that local authority budgets have experienced [21]. As a result, the method for a particular concept can vary depending on establishment and equipment available. There is a need to draw them together to allow practitioners to make informed choices.

There is a lack of research within the areas we are proposing. The importance of practical activities in science features regularly, however, there is little to support teachers and technicians with the implementation of this. Developing an understanding of current resources and methods will allow us to create resources for sharing best practice. By doing this we form a community of teachers and technicians where collaboration is central in discussions regarding the cost of equipment, ease of use, likelihood of widespread adoption, and, most importantly, the effectiveness of the teaching method.

3. Methodology

The initial stage of our research into practical methods in physics required participants to complete a voluntary and anonymous short questionnaire. There were a mix of closed and open-ended questions with the intention to gain information on the current landscape of the practical work being used, the reasons behind these choices, and any changes which have occurred in the quantity or quality over participants’ careers. National 5 physics is a nationally governed qualification taken by students who are normally between 15 and 18 years and has approximate equivalence with GCSE [22]. This level was chosen for the survey due to it being the most widely taught physics course by candidate number in Scotland [23].

To obtain a representative sample from the wider population we used simple random sampling [24]. Potential participants were contacted through teacher and technician mailing lists and social media. All messages included a request to share the information with interested parties. These links to a broad range of educators ensured the diversity of the population was captured. There was a clear emphasis on our desire to have school technicians involved. Their views on the practical and health and safety aspects are vital to the decisions teachers make on the implementation of new experiments [25]. The purpose of including a variety of staff was to achieve a rounded assessment of the practical and pedagogical aspects of the activities we are proposing to trial.

Data was collected through Qualtrics [26] and analysed in Excel. Some data analysis was conducted in IBM SPSS statistics (Version 28); however, it was felt that the data was most appropriately analysed using descriptive statistics [27]. A simple manual thematic analysis was conducted on text answers to give a broad understanding of important ideas [28]. The sample size was conducive to using mixed methods of analysis, and this allowed for full capture of the nuance of the data [29].

From a population of 821 physics teachers [30] and 890 FTE technicians as estimated from Scottish Government figures [31], we received 42 completed questionnaires [32]. Due to the methods of dissemination, it is possible that not all potential participants received notification of the survey. Thirty-eight incomplete questionnaires were discarded. The sample was geographically representative and had a 45%–55% balance of female to male respondents. The age range was broad, as was experience. 5% of respondents listed an independent school as their place of work, which is close to the level expected in this sample [33]. There was, however, an imbalance of teachers (90%) to technicians (10%). Of the teaching staff, 29% were in leadership roles (curriculum, subject, or whole-school remit) who, in Scotland, remain class committed, and one person (3%) was a supply teacher. The remainder were physics teachers (who may also teach other science classes). Two technicians reported being science technicians, one a senior technician and the other responded as a technician. This is an important element as, in recent years, there has been a move by some local authorities towards whole school technicians where their specialism is not reflected in their job title.

4. Results and discussion

Respondents were asked a range of questions pertaining to classroom practice. These questions aimed not only to find out about what is happening in Scotland's physics classrooms, but to understand how this has changed over time. The results are presented in this section and are set out based on the analysis performed. Discussion is given alongside each question where pertinent, with a fuller discussion at the end of this section.

Respondents were asked to give an approximate percentage of the methods used to teach National 5 Physics (N5). The box whisker plot, see figure 1, indicates the responses. One respondent indicated that they were unable to give an accurate answer due to lack of teaching, so the plot is based on 41 responses. Of note is the relatively high percentage of time indicated as either teacher led without practical work, or book work. Whole class practical work is indicated next, but the median is some way lower than that for teacher led.

Looking at comments associated with this question it becomes clear that examination preparation and a general lack of time in the course are seen as significant barriers to completing practical work. This is further developed by a comment indicating that students are not assessed on their practical abilities which seems to make it less important as part of the teaching process. Other comments in this section highlight that certain topics allow for more practical work than others, for example dynamics and electricity. Overall, there is a sense that it is difficult to warrant significant class time for practical work due to old, insufficient, and expensive equipment. Comments show this is exacerbated by the constraints of a very 'full' curriculum. Interestingly, there is no mention of the use of students' mobile phones as an alternative to expensive equipment.

Respondents were asked to suggest how practical work has been impacted over time. They were asked to consider the period since the COVID-19 pandemic, but also consider their career, see figure 2. The plots were found to be similar whether they included or excluded those staff who have only been in position since the pandemic.

Here we see similar themes coming from the qualitative data as for the previous section. Time, money and exam preparation are significant barriers to effective practical experiences. There are, however, others which feature in this section. Lack of confidence is mentioned, as is the reduction in technical support. Two elements of the current curriculum are highlighted. The first is the 'assignment' which is seen as taking a significant amount of time away from both class teaching and potential practical work. The second being the move from the Standard Grade system to the national qualifications in 2013/2014 [34], with the current course seen as less conducive to practical work. It is described as a 'cluttered curriculum' with experiments considered an extension, not core work. Simulations are suggested by one

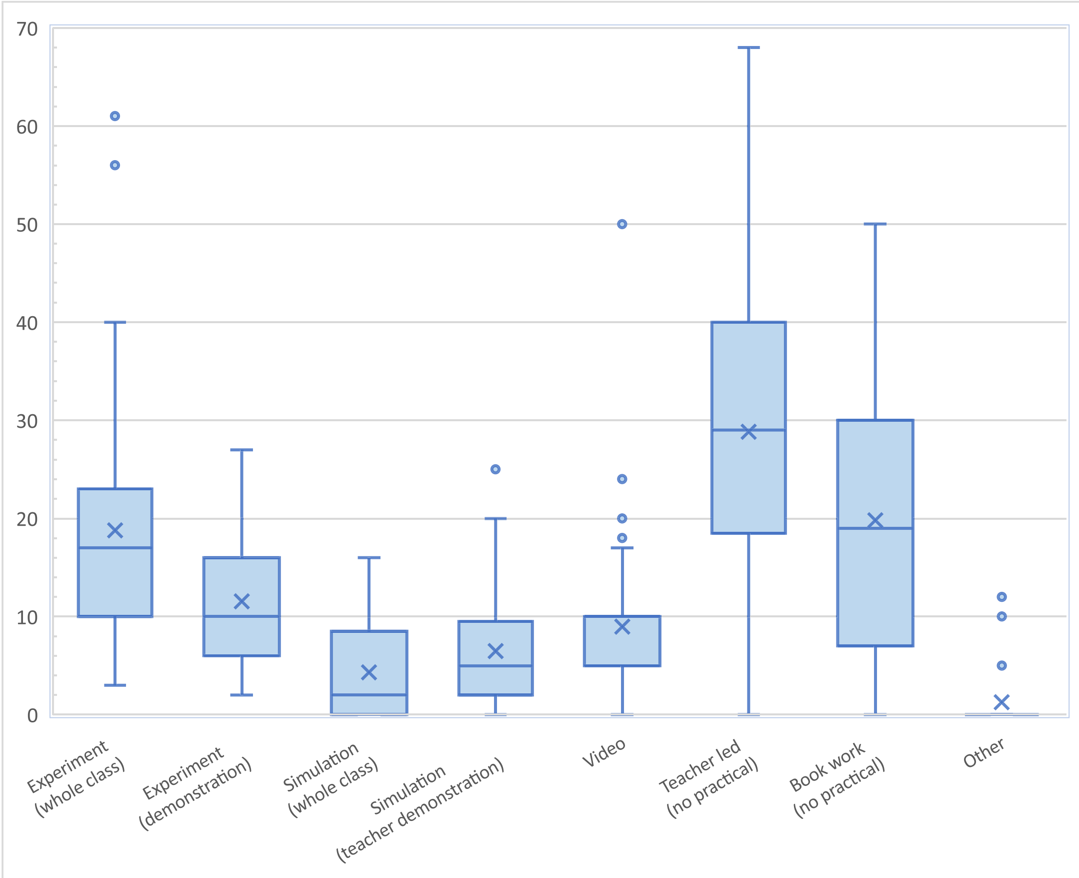

Figure 1. Percentage of time spent on each activity ($n = 41$).

respondent as a way to avoid confusion, potentially alluding to inaccurate results from practical work which can be avoided with simulations. Similarly, demonstrations are increasingly seen as a good alternative due to the lack of equipment.

As the research initially hypothesised that the more significant change would be in the years since the COVID-19 pandemic, respondents were asked to indicate the change since COVID-19, however, this should be regarded as an issue with the survey as figure 3 would suggest that significant change has occurred over a longer period. Despite this, the results are stark in that they indicate a clear difference in pupil led experimental work over the past 5 years. The graph includes all respondents, even if they have not identified a change in practical work. There is a clear trend amongst those who noted a change that student led practical work has decreased whilst other forms of teaching practice have increased. Similarly, it aligns with the main change in activity being a permanent feature rather than one associated with COVID-19.

Respondents were also asked to comment on their reasons for choice of practical equipment. The mean and median response indicated that cost, quality, quantity and time were all rated as very important, with ease of setup moderately important and preference (for a particular make) was only slightly important. In terms of factors which are mentioned in the open answers, cost is the major theme. Simulation comes out as a time and cost-efficient option. There is a feeling that other sciences receive more money, potentially as a result of the lower individual cost. Concerns are raised for aging 'ecosystems' where support is

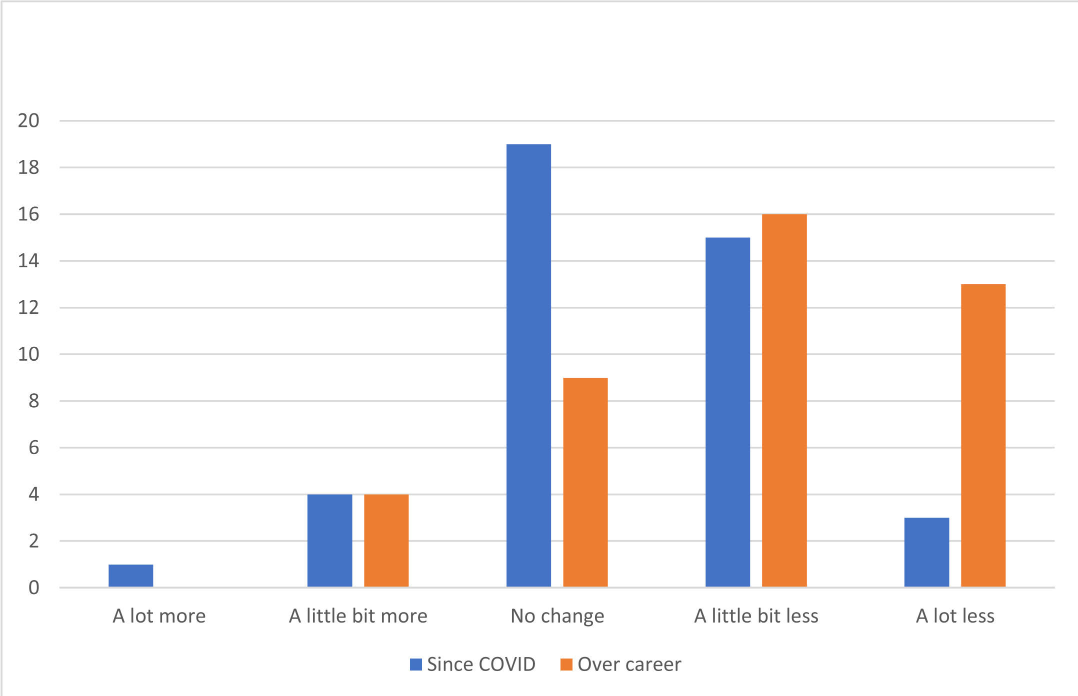

Figure 2. Respondents view of the quantity of practical work compared over their whole career or since COVID ($n = 42$).

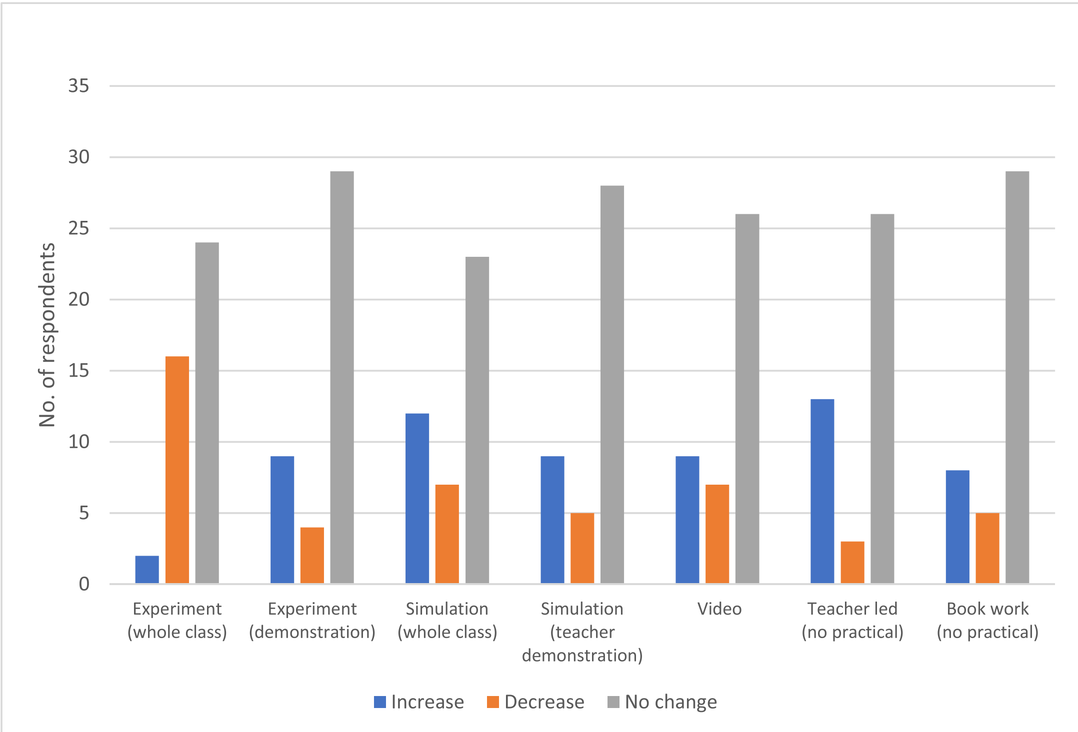

Figure 3. Change in individual teaching activity since COVID ($n = 42$).

increasingly limited, and one respondent regarded the situation as 'making do.'

Important issues to raise are those of technical support and the reduction in institutional knowledge as experienced education professionals leave the profession. Staff who have both supported practical work through technical proficiency or through seeing it as core to their practice are, in some cases, reaching the end of their career. In fact, the data indicated a potential link between length of service and increased practical work, though more significant research is required to give statistical confidence to this idea.

5. Conclusions and recommendations

This research indicates a worrying trend in the reduction of practical aspects of physics. While it is noted that other elements are also important, practical skills learned through school are an essential part of the development of scientific abilities which are important across the sciences, engineering and in general life. Equipment challenges were identified in terms of current quantities, quality due to deterioration and cost of replacement. This, and time to perform practical work in class, are cited as major impediments. It is imperative that we look at methods to counteract this.

This particular study is focussed on Scotland, in part because of the strong network of support amongst colleagues, however the ramifications of increased costs and decreased practical work will be of note across secondary physics education globally. There is clear consideration for policy makers and budget holders, and given the view of the curriculum as cluttered, it may be that alterations to assessment and curriculum are required. Similarly, improved technical support and ensuring consistency of knowledge and understanding of practical work are essential.

Finally, a better understanding of which methods and equipment allow for best coverage of the material and skills required is essential. To this end, research is required into current methods with an analysis of what can be seen as good or even best practice. This research should consider what is available, the support required, the time it takes to both set up and complete the tasks and, most importantly, the effect on physics learning for students, both in terms of preparation for later work and understanding of the current topics. This can be pursued by engaging teachers and technicians to share knowledge and practice.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/10.15129/cff1897f-78c3-4d9c-83aa-2a4189840420.

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