Working towards evidence-based practice in science teaching and learning

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ABSTRACT High-performing international education systems integrate evidence-based practice into their initial teacher education programmes. It is the authors' experience that the usefulness of education research to education practitioners is not always easy to judge and this leads to a justifiably cautious approach to evidence-based practice among trainee science teachers and their mentors in schools. An example of informal practitioner research is described and discussed. This involved using a science in society or socio-scientific approach to deliver a science subject knowledge module to two different cohorts of intending science teachers. The module was taught separately to 22 undergraduate students in their final year of a Primary/Secondary Education Honours degree with Qualified Teacher Status, and to 50 students following Graduate Diploma Subject Knowledge Enhancement courses in chemistry and physics who were preparing to take up places on science Postgraduate Certificate in Education courses. The aim was to demonstrate strategies for facilitating the development of critical thinking and scientific literacy in school science lessons. The use of anonymous voting devices during sessions indicated a polarisation of opinions among participants, rather than a more considered or critical response to the scientific questions. This discussion seeks to illustrate the value and drawbacks of informal practitioner research and how this evidence-based approach might be beneficial to teaching and learning in science.

Introduction

The interim report (BERA-RSA, 2014) of the joint enquiry by the British Educational Research Association (BERA) and the Royal Society for the Encouragement of the Arts, Manufactures and Commerce (RSA) seeks to establish a clear link between school improvement and research-based activity during initial teacher training and continuing professional development (Mincu, 2013). Burn and Mutton (2013) have surveyed the range of relationships between research and initial teacher education in selected international education systems, seeking links between pupil performance and evidence-based clinical practice in education. The report identifies some common attributes shared by high-performing international education systems. These include the provision of high-quality teacher education that progressively develops research skills and the ability to engage critically with evidence. However, the published requirements for qualified teacher status across the UK indicate a difference in attitude towards the role of research in teacher education (BERA-RSA, 2014). Whereas in Scotland and Northern Ireland the importance of research and evidence-based teaching is explicitly emphasised, in Wales and England this is only implied (Department for Education, 2011a; General Teaching Council for Northern Ireland, 2011; General Teaching Council for Scotland, 2012; Welsh Government, 2011).

Ben Goldacre, who is well known for the *Bad Science* column in the *Guardian* and his blog at www.badscience.net, responded to a request from the Department for Education to produce a discussion document (Goldacre, 2013) on the need for teachers to understand the importance of evidence-based teaching and learning and the strengths and limitations of quantitative and qualitative research methods in education. With some success, Goldacre has advocated (Department for Education, 2013) the increased use of randomised controlled trials in education in order to generate high-quality quantitative data to answer questions about what works in schools and what does not. Among Goldacre's considerations is that teachers should be encouraged to participate in large-scale quantitative research, while using their own

small-scale qualitative research to help identify the ideas that need examining. Goldacre argues that this is necessary to counter the current state of affairs in which education policy and practice is vulnerable to the influence of senior, sometimes charismatic, people who claim to have answers to challenges in schools, even when these are not based on significant evidence. Also, much of the small-scale qualitative research referred to by Goldacre (2013; Department for Education, 2013) is currently undertaken as part of professional development programmes of one sort or another. There is no infrastructure for following up research aimed at qualifications with larger scale studies that have more scope to inform and influence practice. As this article is concerned with a small-scale and informal piece of practitioner research, it illustrates many of the arguments raised in Goldacre's paper.

The learning, teaching and assessment strategies investigated

Science in Society, a subject knowledge module, was taught to 22 undergraduate students in their final year of a Primary/Secondary Education Honours degree with Qualified Teacher Status. Later during the same academic year, this module was also taught to a cohort of 50 postgraduates as part of Graduate Diploma Subject Knowledge Enhancement courses for intending teachers of chemistry and physics. The module was designed to enhance science subject knowledge and understanding and also place it in a technological and social context. The informal research was carried out during the topic, Genetically Modified Organisms (GMO). Learning, teaching and assessment (LTA) strategies that students were likely to need while on school experience placements were modelled in the teaching. This acknowledged the role of pedagogical content knowledge (Shulman, 1986) as a component of subject knowledge for teachers.

The format for each topic in the module was similar in that a lecturer introduced the scientific concepts involved and then set group tasks that required further research in preparation for the next session. For the GMO topic, groups were allocated and then assigned to one of a range of stakeholder roles. Each group then had a week to research GMO from that particular perspective and make the case for or against the genetic modification of organisms for agricultural or medical use during a mock public enquiry debate in the second session. This strategy was intended to facilitate skills involved in the explanation, feedback and dissemination of group research outcomes to the whole cohort and to allow the student teachers to experience strategies that could improve scientific literacy and develop critical approaches to evidence in secondary school learners.

Some specific benefits of using role play and debate as a group activity with pupils were proposed by Simonneaux (2001), whose work suggested that developing critical thinking and scientific literacy are reasonable learning objectives for this strategy:

- understanding the complexity of decisions involving social issues;
- understanding relevant scientific principles;
- expressing, defending and/or criticising viewpoints;
- distinguishing between statements based upon evidence and those based upon values;
- evaluating evidence.

In his meta-study of 54 articles, Cavagnetto (2010) identified three main approaches to teaching pupils scientific argumentation in order to improve their scientific literacy. The structural approach included activities that emphasise the structure and practice of scientific argument and debate in comparison with other sorts of argument, such as political or legal. Immersion approaches included all activities where the emphasis was on scientific method and investigation, and learners were encouraged throughout to talk about the scientific process and evaluation of its outcomes. The use of group work and role-play debate, described above for the GMO topic, fell easily within the scope of the third, science in society or socio-scientific, approach, with activities that set scientific arguments in moral, ethical and political contexts.

Hand-held voting devices known as 'clickers' were used in conjunction with *TurningPoint 2008* software (Turning Technologies) to survey attitudes and display the results at various points during the topic. Compared with a show of hands or an assessment for learning (AfL) strategy such as 'traffic lights' or 'wipe boards', mobile voting devices have the perceived benefits of engaging students and being anonymous. Anonymous voting can encourage participation and honest

attempts to answer questions. Another pedagogic advantage for the teacher is that the results of the survey can be displayed instantly as a chart for discussion and can be saved for future reference. It is the authors' opinion that this addresses one issue associated with many less technology-dependent strategies: how to record formative assessment outcomes for diagnostic use and so inform future planning.

Voting occurred at the start and end of the topic for the undergraduate cohort but, for the postgraduate group, opinions were also sought just before the group work began. The same Likert-type items were used on every occasion. Using a 5-point scale, voters were asked to submit anonymously their level of agreement or disagreement with three statements. These were about the safety of GMO technology and its use in the fields of agriculture and health. The authors' intuition was that increased scientific literacy and critical thinking skills might be reflected in the students' anonymous voting behaviour through fewer voters expressing strong agreement or disagreement and more neutral votes.

The possible implications of the survey results for refining science pedagogy were discussed with the student participants and colleagues. A limited literature search was also conducted within the time constraints allowed. This is consistent with a systematic approach to critical reflection using Brookfield's Four Lenses (Brookfield, 1998, 2002).

Concerning methodology

The various guises that practitioner research can take are set out and discussed by Burton and Bartlett (2005), for whom a working definition of educational research would be research motivated by the need for improvements in LTA rather than to make advances within a subject discipline. The informal investigation described briefly above demonstrates elements of action research and case study, but satisfies neither approach completely.

Action research in the classroom consists of repeated cycles of planned interventions based upon previous observations. Each intervention is evaluated for its impact to inform the planning for the next (Baumfield, Hall and Wall, 2008). In the GMO topic, the intervention can be considered to be the use of role-play debate. Analysis of the data gathered when using the clickers provided an indication of the impact of the LTA strategies adopted on student engagement with the topic and their attitudes to the use of GMO. This also gave clues to their use of critical thinking and demonstration of scientific literacy skills. This allowed an evaluation of the effectiveness and fitness for purpose of the role-play debate approach and informed future refinements to the LTA strategy. An extra opinion survey was conducted with the second cohort before the start of the role-play debate, so that, if the change in voting pattern was repeated, it might be pinpointed more closely to the first or second session activities.

Using Bassey's (1999) reconstructed approach to educational case studies, the authors believe that the investigation meets the criteria for an educational case study in the following ways:

- The research can be described as educational because it investigated a specific LTA strategy and evaluated its fitness for purpose;
- It was empirical and natural because it used anonymous cohort data collected in contact sessions during the planned LTA activities associated with the topic;
- It was concerned with a singularity involving a set of instances clearly limited by time and locality;
- The area had relevance for practitioners and students and was of interest to them;
- The study was informative and generated cautious conclusions and recommendations for future improvements in the LTA strategy.

However, also using Bassey's (1999) guidelines, it should be noted that, as a case study, the investigation could be questioned in a number of areas. Was there sufficient data to have confidence that all the significant features of the case were identified? Plausible explanations could be constructed based upon the data but, without further qualitative data-gathering, they can be considered as neither fully trustworthy nor fully convincing.

Results

The undergraduate group vote at the start of the topic demonstrated a range of opinion skewed towards caution with respect to the potential safety of GMO (Figure 1), but also in favour of making GMO foods available to the public (Figure 2). The use of GMO for medical purposes was strongly supported (Figure 3). After the topic

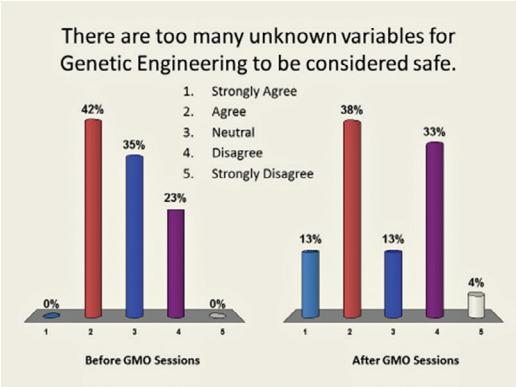

Figure 1 Confidence in the safe use of GMOs: voting results slide for the undergraduate cohort ($n = 22$) before and after the topic was taught

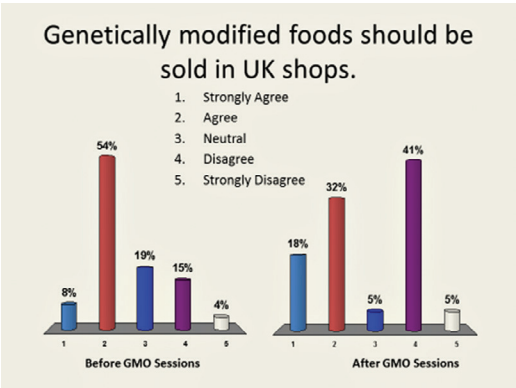

Figure 2 Use of GMOs in the human food chain: voting results slide for the undergraduate cohort ($n = 22$) before and after the topic was taught

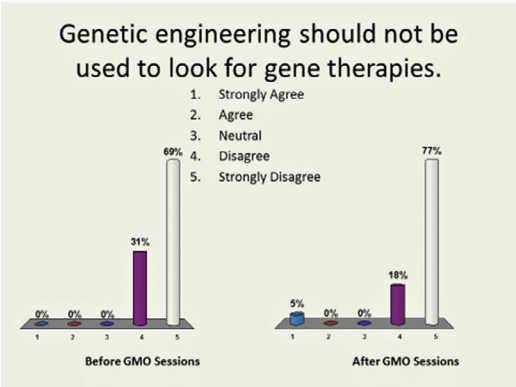

Figure 3 Use of GMOs for medical purposes: voting results slide for the undergraduate cohort ($n = 22$) before and after the topic was taught

was completed, the distribution was bimodal for the first two questions, apparently due to more 'neutrals' choosing a side (Figures 1 and 2). Attitudes to the medical use of GMO remained positive, apart from a small number now expressing strongly opposing views (Figure 3). Experiencing the activities associated with this topic had apparently polarised the opinions expressed by the group.

The teaching of this module and topic to a second cohort provided an opportunity to amend the delivery slightly, by adding another opinion survey point midway through the topic before group work began. Opinions did change during the first, information-based session, but the number expressing neutrality was much reduced after the group work component and debate and even reversed the trend demonstrated by the first two surveys (Figures 5 and 6). In short, the same polarisation of viewpoints after the group work was observed at different times with both cohorts (Figures 4, 5 and 6).

The voting results were discussed by the students during plenary sessions and the effect of rational and irrational influences on decision-making was an issue raised. One irrational influence noted by the students during group work was conformity to group aims and values. However, it was not clear how this might affect anonymous voting. These are the strategies that students observed during debates and additional ploys suggested later in discussion: ignoring contrary evidence and only reporting supporting evidence, distorting evidence, misrepresenting the opponents' cases, ignoring established causal relationships or reporting fictitious ones, and deliberately mixing up cause and effect.

Discussion

Most teachers routinely conduct informal research. In order to improve their pupils' learning, they observe the impact of what they do on their learners' progress, consult their pupils, question trusted peers and read up on areas of interest. In this way, they are applying the principles of critically reflective practice (Brookfield, 1998, 2002) and conducting informal research (Burton and Bartlett, 2005). They have little time to allocate to more formal research involving formal publication or to contributing to large-scale research projects.

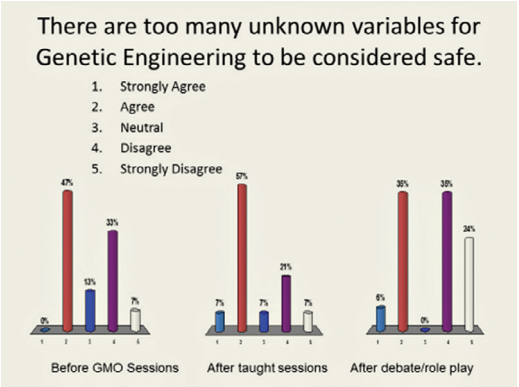

Figure 4 Confidence in the safe use of GMOs: voting results slide for the postgraduate cohort ($n = 50$) at the start of the topic, before group work and after the topic

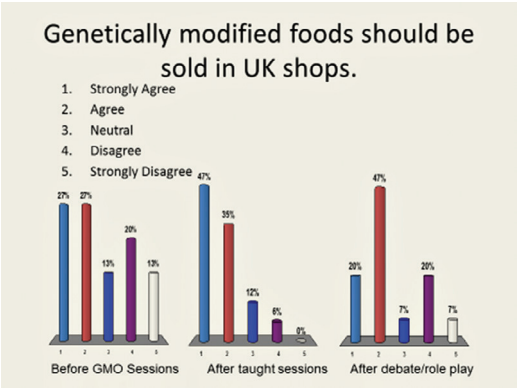

Figure 5 Use of GMOs in the human food chain: voting results slide for the postgraduate cohort ($n = 50$) at the start of the topic, before group work and after the topic

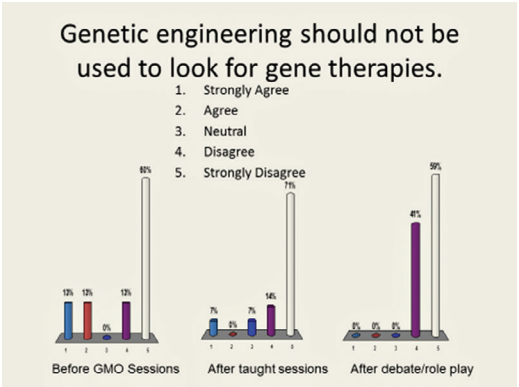

Figure 6 Use of GMOs for medical purposes: voting results slide for the postgraduate cohort ($n = 50$) at the start of the topic, before group work and after the topic

Concerning Likert scales

This research used a 5-point Likert scale to indicate the direction and intensity of respondents' opinions. The issues surrounding the use of such scales have been much researched and discussed. Arguments that Likert items cannot be used as interval scales and should be considered unsuitable for use with parametric statistics were robustly countered by Norman (2010). Leung (2011) recommended that social workers and teachers use 11-point scales mainly to increase sensitivity. Cummins and Gullone's (2000) earlier influential work explored the use of different Likert scales and favoured a 10-point scale. However, Leung's study (2011) found little difference in the psychometric properties and statistical behaviour of different-sized Likert scales. Leung (2011) also considered briefly the argument over odd- or even-numbered Likert scales. Even-numbered Likert scales have no neutral category. This may reduce certain sorts of bias, but may also distort the data in other ways. For instance, forcing neutral voters to choose a directional response can hide true opinions about complex or sensitive issues.

This study made use of the visual presentation of voting behaviours based upon a smaller, odd-numbered Likert scale with a neutral point. Future data gathering could be planned to include statistical analysis and more interval points, but an odd-numbered scale is probably still recommended for surveying opinion on complex topics such as GMO. However, as the same questions were used on each occasion, the possible questionnaire effects caused by the Likert scale or item wordings selected were common to each survey. It is, therefore, a reasonable step to question the assumptions made about the participants' voting behaviour and/or those concerning the expected learning outcomes for the LTA strategy.

Concerning the LTA strategy

In Cavagnetto's (2010) view, all approaches to teaching science that develop science argumentation skills will lead to improvements in pupils' communication skills, metacognition and critical thinking. However, Cavagnetto's study suggested that, while a socio-scientific approach can provide authentic contexts for science learning, adopting approaches with activities emphasising immersion in the process of science may be the most effective way to develop all the aspects of scientific literacy. Cavagnetto (2010)

also highlighted the unique competitive but collaborative nature of scientific argumentation. In role play, participants can adopt more adversarial styles of argument in order to win the debate. The polarised voting viewpoints observed at the end of the second session might indicate responses to individual and group debating performance rather than a more critical evaluation of the evidence provided. The students observed that the competitive nature of debates had led some participants to employ unscientific tactics and strategies in order to secure 'a win'. This increased the levels of engagement for participants, but the implications for the teacher running the activity are to be aware of these debating strategies in advance and how to manage them. Depending on the learners involved, unscientific styles of argumentation and debating ploys could either be disallowed during the debate, or allowed and discussed fully during subsequent debriefing. Trying out these alternatives would be future planned interventions in the action research cycle.

Concerning methodology

One cycle of action research was completed with each cohort and, to date, there have been no further opportunities to test the future interventions suggested above to improve the use of socio-scientific LTA strategies and evaluate them.

Taking a socio-economic approach to complex scientific issues such as GMO requires learners to consider multiple perspectives using background knowledge and understanding of a range of scientific concepts. For both cohorts of aspiring teachers, it arose independently that the group work and debate were associated with a marked polarisation of views during anonymous voting. This was made more apparent by the instant visual display of the voting results within the *PowerPoint* presentation and the ability to compare responses over time using previously saved results. The results of the voting provided a stimulus for lively discussion about the use of role-play debate as an LTA strategy, together with a consideration of the assumptions that practitioners made about the purpose and outcomes expected from this style of group work. This reminded us that accepted pedagogical practice is often based upon assumptions that may or may not appear to agree with practitioners' observations.

Our observations were gathered during teaching and learning activities with intending teachers and were used in the discussion of science pedagogy and its fitness for its intended purpose. The voting response data were examined informally during student feedback discussions and our explanations were later found to be plausible in the context of the peer-reviewed studies consulted. To some extent, this is triangulation of evidence and at least consistent with the aim of developing critically reflective evidence-based practice envisaged by Brookfield (1998, 2002). As such, the findings had considerable utility at a local level. However, in terms of more formal research considerations, further planned investigation would be needed in order to evaluate the reliability (repeatability) of the data gathered, their validity and whether any generalisations could or should be made from them.

The survey results raised many questions, opening up several avenues for possible further work. It would have been interesting and informative to investigate links between short-term voting behaviours and long-term learning and the individuals' reasons for maintaining or changing their opinions. Whether voting behaviours in the same context would be similar or different in other groups of adult or school-age learners could only be answered by systematic observations on a much larger scale beyond the resources of practitioner researchers.

Implications for action research in schools

In applying Brookfield's Four Lenses (Brookfield, 1998) with two groups of aspiring science teachers, this informal research may or may not have indicated something worthy of further investigation. However, given the time constraints placed upon educators, it is unlikely that this or similar informal research in schools will be taken forward in a more formal context. Formal and informal small-scale research can be powerful improvement tools in schools for responding to issues and opportunities quickly and effectively, but does not provide the large-scale quantitative data required by centralised policy-generating bodies. Goldacre would argue (2013; Department for Education, 2013) that this means that greater emphasis needs to be placed on schools participating in large-scale quantitative studies, preferably in the form of randomised controlled trials.

In the drive for school improvement, Masters-level study and schools' engagement with evidence- and research-based learning and teaching

continue to be highlighted and encouraged as important components of initial and continuing teacher education (Department for Education, 2011b). The small-scale practitioner research associated with this has great potential to inform and guide large-scale research. The international evidence appears to indicate that both approaches are needed to inform practice with research-based evidence:

> *That research – be this delivered or stimulated by external interventions or through on-site collaborative inquiry processes – is a vital component of a school's capacity for self-improvement, and that such research is likely to play a vital role in ensuring that effective teaching and learning processes are in place.* (Mincu, 2013: 2)

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