The I files, the truth is out there: science teachers' constructs of inquiry

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Introduction

Inquiry in the science classroom has been the centre of debate among education researchers for many years. The extant literature shows a large number of studies indicate that classroom science, which encourages knowledge and skill development through inquiry, can provide school students with opportunities to develop conceptual and procedural knowledge which reflects, as much as is possible, the spirit of professional science (Atkin and Black, 2003; Osborne & Collins, 2000; Sjoberg, 2004; Authors). Supporters also suggest that inquiry approaches tend to be inductive rather than deductive and student centred (Deignan, 2009), requiring students to identify and pose questions, design and carry out investigations and experiments, and communicate their findings (Windschitl, 2003; Linn et al*.,* 2004). All in all, much of the existing literature in the field suggests that inquiry based approaches offer students a classroom science experience that seeks to promote an understanding of the nature of science which is grounded in a culture and spirit more in tune with science practices than more traditional approaches are(Hofstein & Lunetta 2003). However, our conversations with classroom science teachers during professional development activities have led us to detect an interesting tension—that teachers appear to find it difficult to deploy inquiry approaches on a sustained basis. This is also highlighted by some existing literature. For example, some authors suggest that time constraints and over-burdened curricula may impede science teacher's use of inquiry (Kirschner et al., 2006) while others state that it is often the case that science teachers' have limited experience with '*inquiry in a formal scientific sense*' (Crawford, 2007, p. 323) and therefore, may have limited understanding of how using an inquiry approach in the science classroom works and of its potential benefits to students. Our data does not indicate a lack of teachers' understanding of inquiry but we have found that there are issues concerning teachers' belief that it will deliver the examinations' content requirements effectively and that the time to design and deploy authentic inquiry is excessive in content-dominated systems. The tension we identify highlights the importance of listening to teachers' constructs of inquiry as we attempt to understand potential problems further and identify the salient issues which may inhibit science teachers from effectively deploying inquiry in the classroom. Hence, the main focus of this paper is to report science teachers' constructs about inquiry in the science classroom.

Inquiry in the school science classroom

Prior to the recently introduced curriculum (2017) in England, the 2007 National Curriculum (NC) emphasised the need to develop students' 'scientific thinking', 'practical and inquiry skills' and 'critical understanding'. However, one of the principles of the 2007 NC was that it specified the content to be taught rather than how that content should be taught. Additionally, its content-laden nature, with a focus on high stakes testing, did little to support teacher's use of inquiry as an effective approach to supporting the development of the skills and understanding mentioned above. The traditional school science culture in England still places emphasis on high stakes assessment which shrinks classroom science inquiry to fit a rigid assessment model. Students are trained to participate in recipe-style investigations that suit the requirements of the mark scheme (Authors). There have also been concerns that GCSE (General Certificate of Secondary Education) examinations in England focus on recall of information and are not sufficiently challenging, particularly at age 16, as they reveal little or nothing about the thinking required to describe the importance of processes, ideas and evidence. The Office of Qualifications and Examinations Regulation (Ofqual) noted that the assessment instruments used 'provided insufficient opportunity for more able candidates, particularly those at higher tiers, to demonstrate the extent of their scientific knowledge, understanding and skills.' (Ofqual, 2009).

Given the condemnation of the 2007 curriculum above it is worth noting that the reported vision of that curriculum was—to develop skills and knowledge through inquiry. Yet in reality it all but inhibited that vision. However, at least the emphasis on inquiry echoed a significant body of evidence accumulated over the last two decades which claims inquiry is a highly effective approach to teaching and learning science (Sadeh and Zion, 2009). Proponents of this view suggest that it deepens students' understanding of the Nature of Science (NoS), develops critical and higher order thinking skills, and promotes autonomous learning (Sadeh and Zion, 2009; Kaberman & Dori, 2008; Carter 2008). However, science teaching still seems to be dominated by deductive pedagogies throughout many countries with inquiry approaches largely seen as an add-on and used during non-curriculum time such as after-school science clubs (Directorate General Education and Culture, 2005). **For example, Ramnarain (2014) found that teachers of chemistry and physics in townships and rural areas of South Africa favoured more traditional approaches to inquiry approaches. However, the author identifies that a lack of resources, limited teacher experience in using inquiry approaches and large class sizes are significant factors influencing the teachers' perceptions.**

However, recent changes to PISA, which highlight collaborative problem-solving skills in students as well as more traditional factual knowledge in an attempt to better represent knowledge and understanding rather than just memory recall, may change this (PISA, 2015).

Existing literature indicates a general consensus regarding the main aim of an inquiry approach which is to support students' independent learning through facilitating the construction of their own knowledge (Palmer, 2009; Krajcik, *et al*, 2002; Germann, *et al*, 1996). Hand, *et al*, (2004) suggest that teachers who encourage students to ask their own questions and design their own methods of gathering evidence to answer those questions can expect positive participation from their students during science lessons. This indicates that, as students become accustomed to inquiry based approaches, their capacity to correlate questions and claims with evidence is enhanced alongside their interest in scientific topics.

We view inquiry as a learning strategy for students to learn specific processes such as questioning, designing and conducting investigations, identifying patterns in gathered data, and supporting claims with evidence. This can help the development of the spirit of scientific investigation as well as knowledge and understanding of science (Bybee, 2004). Depending upon the level of teacher intervention and student autonomy, the approach can be 'structured', 'guided' or 'open' (Zion & Mendelovici, 2012):

Structured - students adopt a question provided by the teacher and follow a set of prescribed procedures to investigate it leading to a predetermined outcome

Guided - Students decide the processes to be followed and the results are not always known in advance. This approach affords students slightly more autonomy than structured inquiry even though they investigate questions set by the teacher

Open – students locate their own questions, approaches and develop their own outcomes even while the teacher offers a context or broad topic for the inquiry. This approach offers considerable autonomy for the student with consequently different demands on the teachers' roles.

Much of the existing literature tends to focus on structured or guided inquiry with limited reports on open inquiry. We suggest that this is because both structured and guided approaches are relatively process-driven or, what (Authors) refer to as, 'procedural' (p.5). This affords teachers a large degree of control and, therefore, is easier to manage in the classroom than open inquiry which requires the teacher to relinquish control in significant areas to the students in order to encourage them to take complete ownership of the inquiry and engage in continuous decision-making. This point brings us back to the 2007 science curriculum in England. While recognising and suggesting commitment to the key principles of inquiry it, essentially, offered little more than lip service to its deployment. We now go on to describe the methods we employed to gather and analyse data as well providing detail of Personal Construct Theory which we used as a methodology to underpin our study.

Methods

Personal Construct Theory (PCT) (Kelly, 1955) was used to underpin this exploration of science teachers' constructs of inquiry. Kelly believed that we attempt to make sense of the world in much the same way as scientists attempt to understand phenomena by making predictions and developing theories to understand people, objects and events. He suggested that we begin by developing a set of personal constructs. Constructs are mental representations and what we use to construe and interpret people, objects and events and are based upon our experiences and observations. Constructs are bipolar dimensions and represent a lens through which we interpret our world (Pope & Denicolo, 2001). Therefore, the elicitation of a person's constructs is important in understanding their personal view of their world.

We conducted personal construct conversations with ten science teachers **identified through their participation in an ongoing professional development project** designed and delivered by the authors. The teachers' career experience ranged from three years to twelve years and their use of inquiry in their classrooms varied greatly and all ten teachers were from **state secondary** schools in the Yorkshire and Humber region of England. **We acknowledge that the sample is small and therefore, do not claim that these teachers are representative of the wider science teacher community. However, the rich insight and understanding that these ten teachers provide has merit as it is potentially 'relatable' to other teachers and educators (Bassey, 1990). An important criterion for judging the worth of a specific case is the degree to which the details are appropriate for a teacher working in a similar context and situation to relate his/her own understanding and experiences to that described in the reported specific case. This relatability is, at least, as significant as generalising across a larger sample. Furthermore, the teachers were not an unusual group as they were all working within standard state secondary schools with typical KS3 students from a mix of socioeconomic backgrounds.** University ethical procedures were followed at all times and the teachers were made aware of their rights within the study when invited to participate.

The duration of the Conversations was approximately one hour and conversations were audio recorded and transcribed to aid analysis and to provide illustrative material. For the purposes of the current study the authors adopted the triadic technique for eliciting the teachers' constructs (Epting, *et al.*, 1993; Authors). This involved presenting the teachers with nine elements (see table 1) and asking them to choose two elements which they felt were similar to each other but different from a third which they also selected. **Elements can be people, events or objects that are significant in the field of interest and meaningful to the participants (Kelly, 1955). The elements were chosen to include aspects of self that would elicit positive and negative constructs in a real and an ideal situation giving an indication of the yardstick by which teachers understand inquiry in their situation.** In this way, the authors were able to elicit the teachers' constructs through conversations that focused on each triad of elements. **Kelly's use of the word 'conversation' rather than 'interview' indicates that while the researcher bears considerable responsibility for the conduct of the interview (timing, tone), it is the subject of the interview that supplies the content *(*their selection of elements leading to the elicited personal constructs*)*. PCT conversations are not a simple series of preset questions developed by the researcher and delivered respectfully in an engaging manner. The locus of control resides predominantly with the participant who is sorting the elements according to their personal constructs. Therefore, teachers were encouraged to talk freely after selecting their three elements, although researchers did sensitively probe and gently direct the conversation back to the field of interest if the teachers began to diverge into other areas.**

Table 1 approx here

Analysis: from conversations to constructs

Transcripts of each conversation were systematically coded to identify emergent and contrast poles (line-by-line and focused). This inductive process enabled the development of descriptive labels which illustrate the teachers' constructs as well as what values and structures influence them. We analysed data from all ten teacher conversations and developed a list of the constructs which we shared to test for inter-rater reliability. All authors analysed each construct to measure its validity. At all times we used an inductive method in an attempt to identify what can be elicited from the data rather than an attempt to recognise pre-existing constructs in parts of the transcript.

Once agreement was reached the participating teachers were consulted in an attempt to gain participant validity and identify a level of agreement among the constructs.

Twenty-three constructs arose from the conversations which underpin the teachers' understanding of their experiences of professional development and of inquiry in the science classroom and are consistent across all of the participating teachers. Ten directly relate to 'inquiry' and are reported within this paper. The remaining thirteen constructs, which are not discussed here, are more relevant to the specific professional development project the teachers were involved in and therefore, not useful within the context of this paper. Table two lists the ten constructs:

Table 2 approx here

Each construct was placed in a single category based on the central issue it seemed to address. This was an iterative, inductive process involving constant comparison (Thornberg, 2012) between the emerging categories and the constructs until a satisfactory classification was available. The categories grew out of the constructs rather than being provided in advance or developed from the relevant literature about inquiry. The reason for choosing an inductive approach was to allow the participating teachers' insights to appear in the final analysis rather than classifying their contributions into pre-existing groups. While a characteristic of Grounded Theory (Glaser and Strauss, 1967; Charmaz, 2006), this approach is also suitable for use in a Personal Construct Theory methodology (Kelly, 1955) with its insistence on the personal nature of understanding. The sorting was done independently on two occasions, by the authors, and then a final classification was created by comparing the two versions and checking with the original transcripts. While the suggested categories changed somewhat during this process the wording of the constructs were left unchanged as they had been previously agreed by the teachers in the study. The eventual four categories were checked by a colleague outside of the reported research to produce a final agreed classification. The eventual four categories are listed in the table below:

- ***time* - pressures of curriculum coverage and project work**
- ***environment* - classroom, creativity, student groups**
- ***confidence* - teachers' confidence in using an inquiry approach**
- ***student ability* - suitability of an inquiry approach for students**

Findings

Time

A requirement to cover subject content knowledge to fulfil curriculum demands and prepare students for examinations offsets the teachers' belief in the effectiveness of inquiry. Because of curriculum demands their current classroom approaches tend to be of a more traditional, deductive type which allows easier coverage of the necessary content. This issue is also highlighted within existing research on inquiry (Kirshner, et al, 2010) and suggests that what is practised in classrooms can lack parity with visions of inquiry announced in policy documents such as the 2007 NC in England and teachers are often the victims of theoretical and/or reform views (e.g., Rutherford, 1964; Welch et al., 1981; Anderson, 2002) which often do not translate well into classroom practice, as noted by teacher 3:

We haven't got time to spend five hours on one topic. I think it can be beneficial to their [students] learning but I still have to get them through the syllabus. If the whole process....designing and doing their own research, analysing findings and reporting and questioning...all that inquiry stuff, if that could be somehow shortened and fit in to one lesson then that would be great! (teacher 3).

We view this issue as, what Gess-Newsome, et al (2003) call 'contextual dissatisfaction'. Contextual dissatisfaction is concerned with teacher's assessment of contextual characteristics of their work (e.g., I have too many students; I do not have enough equipment). This contrasts, with pedagogical dissatisfaction which is concerned with the teacher's view of the extent to which their practice is able to achieve their teaching goals (Southerland, et al, 2013). Unfortunately it seems that, due to curriculum and examination demands, the participating teachers are experiencing some level of contextual dissatisfaction which, in turn, impacts their pedagogical dissatisfaction in that they are unable to practice inquiry even though they report that they value inquiry approaches.

Environment

The teachers' understanding of an inquiry classroom environment identifies the importance of planning the classroom environment to ensure an effective inquiry approach and that effective inquiry often relies on careful grouping of students in an atmosphere which is constructive, busy and driven through the exploration and questions of students:

Sometimes I can do an inquiry lesson and it's a complete flop because I've not grouped them properly, they've not understood the brief or I've not explained the theme or problem properly. That's when it's a slog. So, I go back to the beginning and make sure that everything is explained correctly and that understanding is there, then you get a creative environment (teacher 1).

Teacher 1 indicates the importance of facilitating a creative environment for students through effective grouping and explaining the problem soundly. The other participating teachers agree but suggest this in the context of a balance of classroom approaches rather than specifically focused on an inquiry approach. They see a balance of appropriate methods as important to enable coverage of subject content while encouraging independent learning. This is potentially to the detriment of open inquiry which they believe can often be flawed due to its unstructured nature, and therefore, fails to facilitate coverage of subject content:

Well, inquiry means it takes their own independence and their own questions forward. But sometimes they need to know the answers to the right questions cause those are the ones that are going to be on the exam…if you get what I mean. So, sparking their interest on every little bit is unrealistic....I mean not everything is going to be awe inspiring. So, you need some structure and teacher-led elements to make sure they get coverage of content they need (teacher 5).

This resonates with Kirshner, *et al.* (2010) who suggest that even students with strong knowledge and understanding of science benefit from teacher instruction while learning and that a teacher-led approach is often found to be equally effective as more 'open' inquiry approaches. The authors also suggest that there is evidence that open inquiry or minimally-guided approaches may have negative results when students hold misconceptions or partial knowledge.

Confidence

The large majority of the participating teachers feel that they do not have suitable experience in deploying inquiry approaches which, in turn, negatively impacts their confidence to use this type of approach. Teacher 7 openly states that she perceives her current methods of teaching to be more deductive and much less inquiry-based and that her lack of experience and confidence in using inquiry approaches is the main barrier to her identifying appropriate assessment techniques and classroom management during inquiry. The assumption here is that inquiry has its own assessment and management techniques which differ from more traditional assessment methods. She did not explain why she believes this to be the case but we suspect that her comfort zone lies with a more traditional test and mark sheet.

Taking a back seat and not coming to a lesson with lots of resources and a lesson plan is so different and scary (teacher 7).

Teacher 9 further emphasises this point:

I might feel like, that I'm not in control cause they're running with ideas, discussing and arguing with each other but I know that supports inquiry based learning and perhaps what the ideal classroom looks like. Erm.... but that would require me developing inquiry techniques as a teacher but at the moment I'm not there yet, I haven't got the necessary experience or confidence (teacher 9).

It is worth noting the use of the term 'control'. Teacher 9 is clearly uncomfortable with ceding a certain amount of control to her students in order to facilitate student autonomy. She does not use the term to denote classroom management issues but demonstrates some anxiety towards allowing the students to lead the inquiry.

This raises a question regarding the extent to which science teacher preparation programmes include inquiry as a method for teaching and learning. Interestingly, Crawford (2006), during her study in the US of five prospective teachers' perceptions of inquiry, found that *some simply could not articulate understandings of teaching science as inquiry* (p. 635). She went on to state that despite the university having a focus on inquiry during teacher training there seemed to be a lack of understanding from prospective teachers of how to support inquiry in the science classroom. **In their study of science teachers using practical investigations Dudu and Vhurumuku (2012) found that encouraging teachers to engage learners in investigative approaches does not guarantee high levels of practice regarding the deployment of inquiry. The authors suggest that although teachers should have an awareness of curriculum aims and desired outcomes they might not have the required knowledge to translate those aims in to effective classroom practice.**

In the current study participating teachers suggest that, for some English schools, inquiry is a central part of the school philosophy and policy but that, in general, science teachers are not normally encouraged to practice through inquiry and therefore, if inquiry was to be used effectively within the majority of schools in England, a cultural change is needed. They identified cultural change as a change in the way teachers plan, structure and deliver pedagogy, a change in the content of Initial Teacher Training (ITT) and a change to the National Curriculum:

It would be a cultural change for us and for the department. I mean, we would have to look at how we deliver the curriculum in a whole new light....the timing and everything. I don't think it could be done. Then there is teacher training. That would have to change to include more content and emphasis on inquiry. It would be a whole new culture in teaching really, a lot different than the way we teach now and of course, the national curriculum would need to change dramatically (teacher 9).

The new science curriculum, which has been in place since 2017, includes a much reduced element of practical work which, while not necessarily synonymous with inquiry approaches, has the potential to limit teachers' implementing an inquiry approach. Subject content remains heavy and geared to examinations and there is little change to suggest that teachers will be able to generate more time to engage in inquiry approaches.

Student Ability

A key issue which emerged during all of the conversations was that of student ability. The teachers believe that inquiry approaches are appropriate for higher ability students but that lower ability students can often struggle with the autonomy offered to them through an inquiry approach—even 'structured' inquiry:

I think lower ability kids do find it more difficult. Like researching...if they don't know what to research they struggle. My higher achieving kids have gone with it [inquiry] and are flying, going down the expected route. My lower ability kids have just dropped off, they've lost all interest. They're not engaged at all because it's too much effort for them (teacher 4).

However, the above quote conflicts with findings from a US study of five lower track students engaged in open inquiry. Yerrick (2000) found that typical features of open inquiry (e.g. discussion, questioning, debate and researching) encouraged lower ability students to engage more effectively with the teachers about scientific problems and issues which they were previously unable or unwilling to tackle.

All of the participating teachers identify the contrast between facilitating learning and teachers leading learning by suggesting that they understand that students driving an inquiry is at the core of the approach. So, even though they may not use inquiry often due to curriculum demands and confidence, they place high value on inquiry that supports engagement with students through discussion and accept that more deductive modes of teaching tend not to do this. Teacher 5 particularly valued the opportunity to develop discussion and debate with the students about such things as how evidence is used to develop explanations and understanding and how certain criteria can be used to evaluate evidence in science:

I think that's what inquiry is all about. The kids really got into arguments about the nature of science and what evidence is. They wouldn't normally get a chance to do that so it's nice even if its not often.....cause you get time to spend with the kids as opposed to you standing at the front giving instructions (teacher 5).

The above quote and endorsement of inquiry from teacher five reinforces what some authors suggest is a critical aim of science education–that it should emphasise processes of critical reasoning and debate which encourage students to develop an understanding of science as a way of knowing (Authors; Driver, Newton, & Osborne, 2000; Millar & Osborne, 1998). However, for the other, less experienced, teachers engaging in a complex, and often messy process, of discussion and debate can be daunting and particularly so for lower ability students in the eyes of these teachers.

The above categories illustrate the participating teachers' constructs of inquiry in English science classrooms. The emerging issues are, generally, reflected within current literature about inquiry globally and contribute to the ongoing debate. We will now discuss our findings within the context of inquiry implementation in secondary school science departments.

Discussion

It is clear that the ten teachers interviewed for this study value inquiry in terms of a pedagogy which can motivate students and promote independent learning, student autonomy as well as scientific skills and knowledge development through exploration. However, while they value inquiry, they state that there are a number of issues which prevent them from using an inquiry approach regularly and effectively within their practice.

The most cited of these issues is lack of time. As all of the participating teachers practice within a heavily content-laden curriculum they show concern for complete coverage of the necessary curriculum content required for potential examination success. Unfortunately, traditional science education policy and general school science culture in England places emphasis on high stakes assessment which means teachers are caught within a highly constricted assessment model—students are trained to engage in pre-designed investigations to ensure they fit into the requirements of the mark scheme. This, in turn, leads to the teachers' perceived need for a change in culture and/or education policy in order to make space for an inquiry approach to be appopriate. Teachers practice within fixed boundaries, which are established through education policy and Initial Teacher Education (ITE), and thus develop ritualised patterns which they negotiate with relative ease (Nuthall, 2005). As using an inquiry approach is viewed by many of the teachers as different to their usual practice it is understandable that they would suggest a need for change if they are to use an inquiry approach more regularly. Effectively this would give them 'permission' to change their teaching strategy. It is clear that these science teachers do engage their students in certain features of inquiry, such as some independent learning activities, but these are mostly highly structured and subordinate to the demands of the content tested by public examinations.

However, it is perhaps a policy change that is required more than a cultural change. Unfortunately, criticisms of inquiry often come from governments, not curriculum developers or educational researchers, who argue for greater depth and rigour in science education, by which they mean more factual content and more demanding examinations to target an increased knowledge component (Authors). With already heavily burdened curricula teachers' ability to organise time to use inquiry approaches seems even less likely.

Both the literature-based worries about inquiry mentioned in this paper and the political agenda of some campaigners have driven inquiry into a restricted role in some English schools where it has become synonymous with practical work. Assessment of inquiry skills has degenerated into the following of carefully constructed inquiry skills assessments to generate appropriate marks for GCSE qualifications. To an extent the government's criticism has become self-fulfilling. High-stakes assessments, published externally, have increased the pressure on teachers to 'deliver' high grades for their students which has reduced the desire and/or ability to engage students through inquiry. It is interesting to note that Finland, whom score extremely highly in PISA rankings, have minimal testing and interference from government (Berliner, 2011).

The participating teachers also spoke of their lack of experience and understanding of inquiry which echoes the findings of other researchers (Anderson, 2007; Windschitl, 2004; Crawford, 2000) and suggests a failure within ITE frameworks and CPD programmes to promote inquiry effectively as an approach to teaching science. While the authors accept that it is likely, and advisable, that teachers use a blend of approaches and related activities through their teaching it does seem that inquiry is the poor relation to more deductive or traditional approaches.

Conclusion and implications

Based on the evidence presented in this current paper a dichotomy has emerged between some educational researchers and science teachers and government gatekeepers. While the science teachers reported in this study clearly value inquiry they do not feel confident to routinely deploy it in their classrooms. So, the indication is that without political will and policy change which would, in turn, influence cultural and developmental change (through modified ITE and CPD content for example) science teachers **in similar schools to the ones reported here** will not gain the appropriate experience and knowledge to effectively use inquiry in the science classroom. Nevertheless, the evidence presented from this study offers a slightly less negative picture. As already stated, there is strong support for inquiry within current science education literature and some existing studies have reported positive impacts on teachers and students. What remains to be seen is how far reaching these impacts will be and to what extent they will progress an argument for greater use of inquiry in school science classrooms particularly with the introduction of a new curriculum in England.

Further research that explores the reality of practicing inquiry in the science classroom in the day to day milieu of classroom teaching in relation to schools and government policy would be valuable, particularly with larger samples of teachers than reported in the present study—t**he study was limited to ten teachers from a region in England and hence more studies are needed to explore the applicability to a wider region**. Listening to teachers may help to identify strategies which will support them to engage with inquiry approaches where appropriate. Comparative studies that take account of differing contexts, cultures and needs in science education from a range of countries would be most valuable in teasing out similarities and differences across a range of science classrooms.

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