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A Framework for Teaching Epistemic Insight in Schools

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Abstract
This paper gives the rationale and a draft outline for a framework for education to teach epistemic insight into schools in England. The motivation to research and propose a strategy to teach and assess epistemic insight followed research that investigated how students and teachers in primary and secondary schools respond to *big questions* about the nature of reality and human personhood. The research revealed that there are pressures in schools that dampen students' expressed curiosity in these types of questions and limit their developing epistemic insight into how science, religion and the wider humanities relate. These findings prompted the construction of a *framework for education* for students aged 5–16 designed to encourage students' expressed interest in *big questions* and develop their understanding of the ways that science interacts with other ways of knowing. The centrepiece of the framework is a sequence of learning objectives for epistemic insight, organised into three categories. The categories are, firstly, the nature of science in real world contexts and multidisciplinary arenas; secondly, ways of knowing and how they interact; and thirdly, the relationships between science and religion. Our current version of the Framework is constructed to respond to the way that teaching is organised in England. The key principles and many of the activities could be adopted and tailored to work in many other countries.

Keywords Epistemic insight · Framework for education · Curriculum · Sequence of learning · Big Questions · Uncritical scientism

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Introduction

Our case that it is important for school education to pay more attention to developing students' interest in *big questions* and their understanding of the relationships between science, religion and the wider humanities stems from research in schools. The LASAR (Learning about Science and Religion) research team conducted surveys and interviews with students and teachers which concluded that without effective teaching, students are unlikely to develop the epistemic insight they need to explain that science and religion do not necessarily conflict, and why (Billingsley et al. 2013). The research also concluded that there are pedagogical pressures and barriers in secondary school science classrooms that negatively affect young people's expressed curiosity in big questions and their opportunities to build their understanding of the ways that science and religion relate. Some of these pressures and barriers are particular to topics that have a religious aspect. In particular, science teachers typically try to avoid and dampen questions and discussions that have a religious aspect (Billingsley et al. 2014). At the same time, many of the barriers and pressures revealed by the research were ones that we surmised do more than limit students' opportunities to learn about how science relates to religion. For example, the organisation of secondary school teaching also affects students' opportunities to consider how science interacts with other disciplines that they study in school (Billingsley et al. 2016a).

During the course of several further studies, we gathered data from students in each of three age groups, age 10, age 14 and age 15–16. One project asked students what science tells them about commonly held beliefs about human personhood, such as that people have souls and that they can choose how they behave. In parallel, we created and tested the impacts of workshops on our university campus, where students discussed big questions with scientists, engineers, theologians and philosophers. When students came onto campus for a day of workshops on *Big Questions of Life, the Universe and Everything*, we began by telling them that they were 'scholars' now and in this setting, subject boundaries no longer apply. These studies confirmed our hypotheses that pressures and barriers in education prevent explorations of Big Questions in secondary school science classrooms and that there are gaps and misperceptions in many students' understanding of the nature of science which mean that they are unlikely to appreciate that and why science and religion are not necessarily incompatible. We also found that students held misperceptions about what science tells us about human personhood and that many students underestimated the complexity of reality and supposed that science has ready access to determining how reality works (Billingsley et al. 2012; Billingsley 2013a; Billingsley and Hardman 2017).

We concluded that although every student's experience of education is different, there are pressures and barriers in schools which systematically dampen students' expressed interest in Big Questions and that limit opportunities for them to learn about the strengths and limitations of science in real-world contexts and multidisciplinary arenas. These pressures and barriers are largely the unintended consequences over time of practices like entrenched subject compartmentalisation and the prioritisation of content knowledge in science lessons over epistemological understanding (Billingsley et al. 2012; Billingsley 2013a; Billingsley and Hardman 2017; Chappell 2017; Taber et al. 2011).

The recommendations arising from the research resonate with calls in England and internationally for education to put more emphasis on developing students' understanding and appreciation of epistemology within and across subject boundaries. Duschl and Osborne (2002, p.39) explain that teaching "needs to accomplish much more than simply detailing 'what we know'" and that science teaching should emphasise "the construction and evaluation of scientific knowledge". The curriculum for science in England and internationally stipulates that students should be taught about the nature of science. Science teaching in England and many other countries focuses on developing students' understanding of scientific concepts with less emphasis on developing students' epistemological understanding (Fensham 2016). When this is combined with subject compartmentalisation in secondary schools, opportunities to learn about cross-disciplinary epistemological issues tend to be squeezed out (Sandoval 2016). A resistance to discussing contentious questions means that there is also a blind spot in science education on the question of where, if at all, there is a border between metaphysics and science (Kötter and Hammann 2017).

As we have indicated, opportunities to develop students' epistemic insight in relation to big questions that bridge science, religion and the wider humanities are squeezed by several pressures including the controversial nature of the questions and by the prioritisation of teaching scientific content knowledge and comparative neglect of students' epistemological understanding. At the same time, the importance of responding to these gaps and weaknesses in provision is increasing with time. There are calls for schools to provide teaching that prepares students for the questions raised by new technologies, such as the question of whether humanlike machines should one day be granted the status and/or legal responsibilities of personhood (Billingsley 2013b; Brown 2004; Cath et al. 2018; Jones 2015; Polkinghorne 2004; Solum 1991; Wakefield 2016).

This paper responds to those findings by proposing an educational framework for schools and teacher education with curriculum objectives and teaching strategies designed to detect and address gaps and misperceptions in students' understanding that are associated with these pressures and barriers. To construct the framework, we first defined three categories of learning objectives. These categories were prompted by the research and are designed to be overlaid onto existing school subjects in ways that challenge the entrenched barriers around existing subject compartments. Our selection of the phrase 'epistemic insight' as a broader construct than 'nature of science' is similarly to motivate teachers to examine and plan students' learning experiences about epistemology across subjects and not only within them. The categories are the nature of science in real-world contexts and multidisciplinary arenas, ways of knowing and how they interact, and the relationships between science and religion. The framework is constructed in relation to the stages and design of the education system in England but the rationale and many of the ideas apply more widely. This paper focuses on two categories which are (1) the nature of science in real-world contexts and multidisciplinary arenas and (2) ways of knowing and how they interact. Before outlining the framework, we begin by highlighting some key terms and constructs.

Big Questions and the Science-Religion Dialogue

Why does the universe exist? Is life here by anything other than an accident? Do people have free will? These are some of the so-called big questions (Billingsley et al. 2013; Shipman et al. 2002) that occupy the minds of most people at some time during their lives. In this project, we characterise big questions in three ways: *big questions* are questions about human personhood and the nature of reality. Secondly, in the context of school education, they are questions that bridge science, religion and the wider humanities—a characteristic that becomes important because of the way that school subjects are framed and organised (Billingsley et al. 2016a).

Thirdly, they are questions on which both science and religion seem to have something to say (Billingsley 2004). The existence of a science-religion dialogue connected to big questions is widely stated (Polkinghorne et al. 2014; Southgate 2011; Ward 2008). The dialogue includes a vast literature of books and papers addressing the relationships and individual topics (Guessoum 2015; Humphreys 2003; Murphy 2014; Polkinghorne 2013; Ward 2008) and books that suggest and explain key questions and topics for students in education (Billingsley et al. 2018; Poole 2007; Southgate 2011). Alongside other factors, epistemic insight in the form of understanding the natures of science and religion and how they relate is important when thinking about these topics and questions (Billingsley et al. 2013; Fulljames 1996; Reich 1991).

Science and religion are each multifaceted and there is no single ‘science’ or ‘religion’—a challenge when seeking to discuss how they relate (Brooke 1991). Harrison responds to the contention by saying that science and religion are like two “categories” (Harrison 2006, p. 81). David Hull (2010) uses the metaphor of a species to say that there is more variation between science and religion than within either category—an idea we introduce via a learning objective in our framework that says, ‘science and religion are mostly concerned with different types of questions including different types of why question’.

Pressures and Barriers Affecting Students' Learning Journeys from 5 to 16 in Relation to Big Questions and How Science and Religion Relate

We have chosen the metaphor of a learning journey because it is often used in connection with research and teaching that has a learner-centred approach (Ward and Edwards 2000) and is not limited to discussing formal learning, so we can also encompass unintended and informal learning (Beetham and Sharpe 2013). In this section, we outline some of the pressures and barriers in schools that squeeze out opportunities to discuss Big Questions and that limit students' opportunities to develop their epistemic insight into the nature of science and how science and religion relate—and these are:

- *Recipe investigations:* Research across several decades has reported that students perceive science as providing experimental proof of incontrovertible and necessary truth (Driver 1989; Lederman et al. 2014). This is despite statements expressing the uncertainty of knowledge that have peppered the national curriculum for secondary school for several decades. Teachers of science mostly endeavour to address these objectives via practical work, but even within practical work, the time to discuss epistemology is squeezed by a tendency to harness practical work to reinforce an understanding of concepts (Abrahams 2017). An illustration of this is the use of the so-called cookbook or recipe investigations that are used to help students to learn and consolidate conceptual knowledge (Tho and Yeung 2016). The apparatus and instructions are pedagogically engineered to help students to arrive at a concept or relationship described in their course (Billingsley 2017). An observation study of secondary school practical work revealed that sessions were focused on concepts with little or no work on why these are appropriate methods or whether these methods have limitations (Abrahams and Millar 2008). During practical work, both teachers and students are focused on whether experiments *work* and the question that students are asking is not “What happens if?”' but is rather “Is this right?” (Longshaw 2009).

- *Entrenched subject compartmentalisation:* When students begin secondary school, they typically enter a system in which science is taught apart from other subjects. In as much as epistemology is taught, the focus is typically on the nature of science in a silo without also teaching about its relationships with other disciplines and its power and limitations in real-world contexts (Billingsley et al. 2017; Ratcliffe 2009; Roth and Alexander 1997). Students become acclimatised to learning in science classrooms in which questions and distractions from other disciplines tend to be blocked out (Bernstein 2000; Billingsley et al. 2013). This limits students' opportunities to see how science interacts with other ways of knowing (Billingsley et al. 2018; Osborne and Collins 2001).
- *Teaching science via fragmented topics:* In England and many other countries, the content in school science is divided into self-contained topics. A typical school science handout for year 8 (age 12) lists 10 topics for the year with one being, "Motion and Pressure—covers speed, distance and velocity time graphs, the pressure in solids, liquids and gases, and turning forces" (Hawkins 2017). Topics are given equal time and look similar in the textbook, hiding epistemological distinctiveness across the fields of science. In a manner of speaking, the questions and methods associated with science are *epistemologically homogenised*.
- *A lens of simplification:* By upper secondary students have experienced many years of pedagogical engineering repeated across multiple topics—combined with simplified interpretations of scientific explanations in textbooks. So in genetics, for example, students frequently develop an "'everyday' conception of genes as small, trait-bearing, particles" (Lewis and Kattmann 2004, p. 195).
- *Exaggerated headlines:* by upper secondary school students are increasingly likely to have seen media stories that suggest that scientists are on the brink of having a complete understanding of a given aspect of everyday life. Some examples are, GCSE results "influenced by children's genes, not teaching" (Paton 2013), "new blood test targets depression" (Roberts 2016) and scientists prove chocolate "better than being in love" (Freeman 2002). This is one of many pressures that originate outside the school. The way that science courses and examinations are currently structured means that students are unlikely to spend lesson time critiquing these kinds of headlines.

While every student's experience of education is different, these pressures and barriers apply widely, affecting students' learning journeys stage by stage and across several classrooms as they progress from 5 to 16. At this point in our project, we surmise that these pressure and barriers are likely to mean that there is:

- A tendency by school leavers embarking on courses in engineering to skip the limitations of scientific models and to focus their interests onto a narrowly defined material world without also asking questions that relate to ethics and values (Billingsley 2017).
- A tendency by some students to suppose that science is a way of thinking that denies the validity of other ways of knowing. This perception may arise in part because of firm borders around the science classroom (Bernstein 2000) and also because science is described as a 'core' subject while some other subjects are not (Billingsley et al. 2016a).
- A pressure on some students to hold back questions on topics that they perceive to be religiously sensitive because they want to avoid discussions that might upset or offend students with religious beliefs (Billingsley et al. 2011).

Uncritical Scientism

The next two sections introduce two key constructs to underpin the design of the framework and guide our current studies to develop it further We have coined the term 'uncritical scientism' to denote a stance that resembles scientism in its beliefs and attitudes. By referring to scientism and uncritical scientism as stances, we draw on Bas Van Fraassen (2008, p. 62) who states that stances are a mixture of beliefs and attitudes and "a good deal more". Van Fraassen refers to materialism and empiricism as stances. Kidd (2016) adds scientism, saying it involves attitudes and beliefs and that a scientistic person is likely to be closed to the possibility of there being forms and sources of knowledge, evidence, enquiry, or reason that are not scientific in character.

Stenmark (1997) says of scientism that it includes a tendency to say that in the future, science will provide a full explanation of how nature behaves using a simple 'scientific' language. In our model of pedagogical pressures, a student might form this conclusion while influenced by simplified versions and interpretations of scientific ideas (Billingsley 2013b; Jamieson and Radick 2013). Students' perceptions of the power and limitations of science to model reality are also influenced by their experiences of pedagogically engineered practical work—whereby questions asked of reality are investigated using a one-off experiment that is designed to teach an established scientific concept (Billingsley 2017). Stenmark (1997) also says of scientism that it promotes a narrow view of *what is science* focused on the natural sciences or in some cases even more narrowly on the material-physical sciences and the view that questions explored by other disciplines should be dismissed. As we noted earlier, once they are in secondary school, the subject boundary in curriculum science filters the topics and questions about reality that students explore in science lessons for reasons and in ways that may not be apparent to students (Billingsley 2017). These simplifications of what science says about reality, pedagogically engineered investigations and subject boundary filters have the potential to prompt some students to underappreciate the complexity of reality and to overestimate the extent to which science has ready access to determining how reality works.

An important criterion for uncritical scientism is that the student holds this stance uncritically—without an appreciation that there is a spectrum of views on the power and limitations of science and that scientism is a controversial stance to take. In an interview study that asked students aged 10 on how they perceived the nature of science, there were several who made comments that conceivably reflect an uncritically scientistic stance (Billingsley and Hardman 2017, p. 61):

> Well, if it wasn't for science we wouldn't know much about the world or anything, really.
> I only believe science and logical answers and theories.
> I think the universe was up to science and science did everything.

In addition, our research to discover teenagers' perceptions of what science says about common beliefs about human personhood found that there are some teenagers who believe that science has revealed a necessarily materialistic and deterministic picture of human personhood, yet were uncomfortable about accepting these ideas for themselves (Billingsley et al. 2016b). The comments that follow were written by two upper secondary school students in their responses to a survey which sought to discover students' positions on the power of science to explain behaviour and personality (Billingsley and Hardman 2017, p. 62):

> I suppose everything you do is a result of the brain, but I feel uneasy saying that I'm not a person – I'm just a brain in a shell.
> I'd still believe it's free will instead of just a mass of atoms, but I think it's because I like to believe that. I like to believe it's free will because then it shows that [. . .] there's more of a purpose to life.

The science curriculum in England states that students should understand and appreciate the powers and limitations of science (DfE 2014). In our view, teaching that is designed to develop students' understanding of the power and limitations of science needs to begin earlier. The possibility that school education is influencing students' developing perceptions of the nature of reality and of the power of science in ways that dampen their curiosity and sustain misperceptions is a matter that deserves attention. One way that teachers and researchers can discover the extent to which students' stances on the power of science are held critically or uncritically is to ask a class to evaluate and report their own learning at the end of a workshop that identifies and discusses some of the stances that people take.

Epistemic Insight

We define epistemic insight as knowledge about knowledge with a focus on knowledge about disciplines and how they interact (see www.epistemicinsight.com). By including the term *insight* and by referring to *knowledge about knowledge*, we seek to signpost that a strategy to promote epistemic insight is not the same as a course to teach epistemology. A strategy to teach epistemic insight in secondary school recognises the risk that subject boundaries become entrenched. Adding a focus on discovering and advancing students' epistemic insight in schools encourages teachers to find pragmatic approaches to helping students make better sense of the messages they receive in different subjects about the nature of knowledge across the subject boundaries (Billingsley and Ramos Arias 2017).

We envisage a whole-school approach with teaching provided in many subjects and at frequent points in a student's journey through the years of education. Becoming more epistemically insightful includes becoming wiser about the ways that each of the disciplines is distinctive, and their strengths and limitations (Sosu and Gray 2012). Teachers who teach epistemic insight are wise to the ways that over the years, pedagogical barriers and pressures can block students' interest in big questions that bridge science, religion and the wider humanities. There is recognition too that students typically have few if any opportunities to work with epistemological, cross-discipline and religiously sensitive questions in school. Teachers of science and other subjects collaborate to help students to make sense of what they are learning about knowledge in their different subjects.

In the next section, the construct of epistemic insight will be developed further in the context of a framework for education for use in England. The centrepiece of the framework is a sequence of learning objectives organised into each of the three age ranges in school. These are primary (age 5–10), lower secondary (age 11–12/13) and upper secondary (age 13/14–16). The sequence of objectives for epistemic insight builds towards some key ideas that research shows are commonly neglected in teaching and assessment. Some of the objectives are similar to the ones in the curriculum in England currently but here, they are placed in a sequence designed to teach epistemic insight while recognising opportunities, pressures and barriers in schools today. The objectives are organised into three categories designed to recognise existing school subjects while challenging barriers like entrenched subject compartmentalisation. As identified, the categories are firstly, the nature of science in real-world contexts and multidisciplinary arenas; secondly, ways of knowing and how they interact and thirdly, the relationships between science and religion. Organisationally in schools, this would bring teaching about the power and limitations of science into the science curriculum at an earlier stage. One activity, “do knots form by themselves?” (described shortly) is a practical session that questions whether a report of a scientific advance sufficiently conveys the complex nature of reality. The objectives indicated for the category, “Ways of knowing and how they interact,” which is the broadest, would be included and/or referenced in science and other curriculum subjects to create bridges between them. Students are encouraged to ask and address questions within and across subject boundaries such as: “What do we mean by evidence?” and “What are the limitations that apply for any given enquiry?” In some countries, including England, religious education (RE) is taught in schools, and in our current draft framework, we propose that RE would (continue to) be the subject that oversees teaching about big questions and the relationships between science and religion.

Some of the objectives are placed ahead of a known barrier, to futureproof students’ developing understanding about the natures of science and other ways of knowing studied in school. For example, students in primary school work with their class teacher to consider the distinctive ways that science and another discipline inform our thinking about a shared topic. They also develop their understanding of the preferred questions, methods and norms of thought of a few key disciplines—and discuss their similarities and differences. The aim is to establish some key epistemological ideas in primary school before students move to a secondary school where typically the teaching is organised by separate subject teachers. The resonance between our proposed sequence of learning objectives and those in existing curricula, together with research in schools gives us a level of confidence that the objectives are appropriate for students’ intellectual abilities. It would be important to test this further by conducting more research in schools.

The terminology for discussing interactions between science, religion and the wider humanities is complex. Without defending our choices here, we characterise science and history as examples of disciplines that students study in school. Some other sources refer to ‘the sciences’ but we generally use science (in the singular) which matches the language typically used in primary and middle schools in England. When we are discussing questions that bridge science and religion, we characterise science and religion as examples of different ways of knowing.

Expanding on the Framework and Sequence of Objectives—From Age 5–16

In this paper, we focus on explaining the objectives and activities in two of the three categories of the framework. One is the category to develop students’ appreciation of the nature, power and limitations of science in real-world contexts and multidisciplinary arenas. The second category is ways of knowing and how they interact. In our framework for education, a primary school teacher would be responsible for both categories. A secondary school teacher of science would have responsibility for the first category and shared responsibility for the second.

In a publication for science educators called *Principles and big ideas of science education*, Harlen (2010, p. 33) proposes a sequence of learning that extends from primary through to upper secondary school. In Table 1 below, we have paraphrased it and extended it in italics to include the additional insights we are recommending.

The first age group in our sequence is primary (students aged 5–10). Three objectives in our framework for this age group are for students to appreciate that:

- Science begins with observations of the natural world and constructing ways to explain our observations. [The nature of science in real-world contexts and multidisciplinary arenas]
- Science has some similarities and some differences with other ways of knowing that we learn about in school. [Ways of knowing and how they interact]
- Science and religion are mostly concerned with different types of questions, including different types of why questions. [Relationships between science and religion]

In the primary context, teachers tend to be responsible for students' academic development across several curriculum subjects. Our proposal for teaching epistemic insight is that the teaching begins in the lower primary school by establishing some of the key characteristics of disciplines like science, history and the arts. When students move into upper primary school, they compare and contrast science with a small selection of other disciplines.

In a typical science session for students aged 8, students might be finding out about the properties of air by observing how objects like parachutes, pinwheels and kites interact with air, and by testing out ideas by constructing and observing their own examples of these objects. To link these activities to a statement about the nature of science, we propose a learning objective which brings to the fore the centrality of ideas and observations. In our current draft, this is: 'Science begins with observations of the natural world and constructing ways to explain our observations'. This is likely to resonate with the learning experiences that students have in their science sessions and to be a claim that is accessible and appropriate for students to discuss with their teachers.

Table 1 Additional insights into the sequence of learning proposed by Harlen (2010)

Harlen 2010	Additional insights
In *primary school*, students begin with small and contextualised scientific ideas which they can grasp through appropriate activities and with support.	*Students talk about the nature of science and what makes science distinctive compared with other ways of knowing that they learn about in school.*
In *lower secondary school*, students have an increasing capacity for abstract thinking that enables them to see connections between ideas and events or observations (for instance, that certain changes can be explained in terms of energy transfer or that properties of materials can be explained by considering matter to be made of particles).	*Students work with cross-discipline topics to build their understanding of the relationships between science and other disciplines studied at school. Students can explain that some questions are more amenable to science than others and that some methods are more characteristically scientific than others.*
As exploration of the natural world extends in *later secondary education*, continuation of this creation of patterns and links enables students to understand relationships and models that can be used in making sense of a wide range of new and previous experiences.	*Students continue to consider the extent to which science has ready access to determining how reality works. They draw on resources including media reports of scientific advances to critically examine a range of stances on the power and limitations of science and what if any are the ultimate limitations of science. Students appreciate that and why scientism is not a necessary presupposition of science.*

The National Curriculum for primary science in England has 52 references collectively to observations, observe, observing and observable (DfE 2013b). This also concords with advice to teachers, such as that by Ward and Remnant (2016, p. 104) who describe primary science as, "focused on learners using their senses to discover the world". Harlen (2005, p.98) explains that in science "observation means using all the senses to gather information, but it is more than merely 'taking everything in'":

> Science begins with observation of our surroundings – a stone, the Moon, a plant – and proceeds through progressive generalisation of experience to more abstracts categories or ideas – force, gravitation, atom. […] Teachers need to be aware of the successive steps of abstraction and ensure that students are able to take these steps recognising that the more abstract ideas deepen understanding of everyday observations (Harlen 2010, p. 53)

Science educators' attitudes toward introducing young students to the big ideas of science have been influenced by a changing picture from research about this age group's intellectual abilities. A review of research many years ago by Metz (1995) highlighted that the notion of young students as concrete thinkers acts as a constraint in science curricula, whereby observation is only being taught as a skill. In contrast, in the current curriculum, in line with contemporary advice for primary teachers from Harlen (2005), Ward and Remnant (2016) and Loxley et al. (2017), observation is taught in the context of enquiry. Earlier we argued that a tendency towards recipe-like investigations in science lessons can suggest to some students that reality is more accessible to the methods and explanatory power of science than it currently is. This is unfortunate because these activities are often useful ways to deepen the students' understanding of scientific concepts. There is, for example, an activity described by Ward and Remnant (2016) in which students learn about a scientific idea while making and analysing observations—in the context of a historical narrative:

> Whether they are discussing what happens when they drop different objects, taking measurements about the time thing take to fall or deciding whether Aristotle or Galileo had the right idea about how objects behave when falling on the earth, science is about a way of working as well as a body of knowledge (p. 104).

Rather than discontinue the use of recipe investigations, we suggest that teachers talk about their design and purpose and supplement them with investigations designed to draw attention to the complexity of reality. This reflects the advice by other commentators that students will need explicit teaching about the nature of science (Hodson 2014; McComas 2017), and guidance by other authors that teachers should focus students' attention on different aspects of epistemology in each activity to give each one time for discussion (Harlen and Qualter 2014; Ward and Remnant 2016; Abrahams 2017).

The second objective for this age group in our draft framework is: 'Science has some similarities and some differences with other ways of knowing that we learn about in school'. For upper primary school students, we recommend teachers include a cross-curricular lesson that draws students' attention to the distinctive nature of science in comparison with another discipline such as history. The question, "Why did the Great Fire of London spread so quickly?" is an example. Teachers introducing this question as part of an epistemological discussion could explain that it is stimulated by historical curiosity and that we can produce a richer, more interesting answer by including scientific ideas and findings, such as the fire triangle. There are some educators such as Barnes (2015) who propose students work with a *fusion* of disciplinary perspectives on a given topic. Here, we propose that students should be encouraged to analyse and discuss how each discipline contributes to our overall understanding of a given cross-curricular topic. Comparing curriculum documents for science and history in England, the two subjects share many scholarly aims and for example, both refer to curiosity. History lessons are expected to inspire curiosity about the past while science lessons are expected to develop students' curiosity about natural phenomena. Comparing the curriculum guides also indicates what students should appreciate about the ways that each discipline justifies its ideas. In history lessons, students should be "choosing and using parts of stories and other sources" in order to "understand how our knowledge of the past is constructed from a range of sources" (DfE 2013a). Where the history curriculum stipulates that students have access to stories and a range of sources, the science curriculum emphases that students should have opportunities to link ideas and observations.

We have explored this idea as a way to develop pre-service primary teachers' understanding of the nature of science. Pre-service teachers were asked to produce an epistemological analysis to illustrate what kinds of things would be discussed in a scientific answer compared with one in history. Figure 1 (below) is an example of the answers they provided. The framework has a learning objective that says that students should appreciate that, 'a school is a multidisciplinary arena'.

Turning now to lower secondary school, in our framework for education, our proposal is to retain subject boundaries but to make them more explicit and permeable so that they can become part of the teaching and discussion. We recommend that teachers create conduits such as a question box to carry questions and insights between classrooms. We also propose that the timetable include some cross-curricular sessions in which students consider the contentious

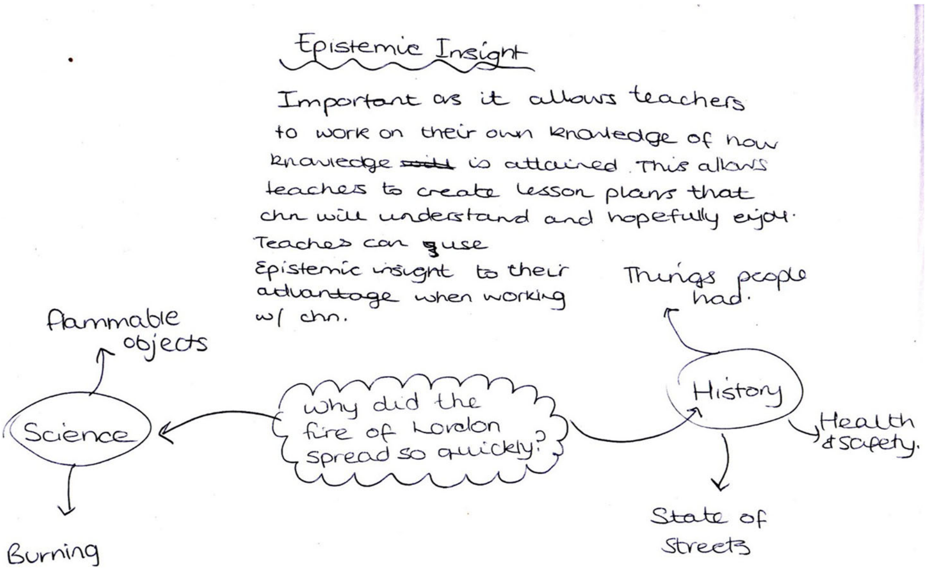

Fig. 1 Epistemological analysis by a pre-service primary teacher

borders between science and some of the other disciplines they study in school. The three objectives are that students should appreciate that and why:

- Some questions are more amenable to science than others [science in real-world contexts and multidisciplinary arenas]
- Different disciplines have different preferred questions, methods and norms of thought [ways of knowing and how they interact]
- Some people say that science and religion are compatible and some people say they are not [relationships between science and religion]

One activity, “do knots form by themselves?”, is a practical session that questions whether a report of a scientific advance sufficiently conveys the complex nature of reality. Figure 2 is a slide from the session. Students are shown the reported findings of an investigation by physicists who wanted to investigate the propensity of a piece of string to become knotted. Raymer and Smith (2007, p. 16432) explain that:

> It is well known that a jostled string tends to become knotted; yet the factors governing the “spontaneous” formation of various knots are unclear. We performed experiments in which a string was tumbled inside a box and found that complex knots often form within seconds.

In the activity, students put a shoelace into a shoebox and attempt to duplicate the physicists’ method. It has transpired that our groups of students only rarely see a knot and most times, the shoelace is unknotted after shaking the box. This prompts a discussion about the extent to which the original investigation was fine-tuned to produce knots more frequently.

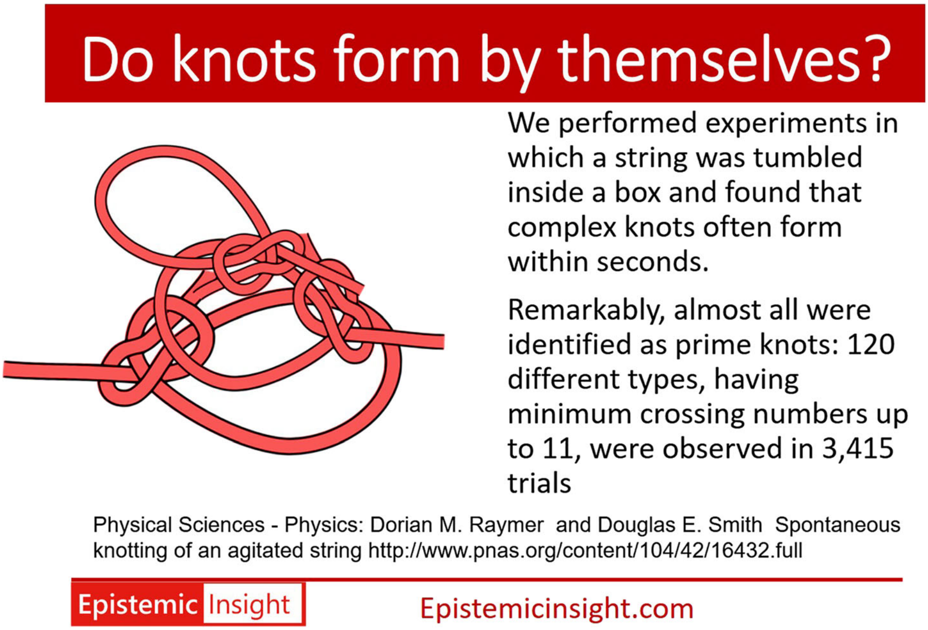

Fig. 2 Slide from teaching session: ‘do knots form by themselves?’

Some of the activities we outline in the framework bridge subjects and could be planned or taught by two teachers working collaboratively. For example, one cross-curricular workshop explores a question that bridges science and the arts. The context for the question is that the Smithsonian museum asked scientists to find a way to showcase Renoir's paintings with the colours restored—because the red paint that Renoir used has faded (Schultz 2014). Scientists identified the type of paint using chemical spectroscopy on paint in a corner of the painting—a question about the material world that was amenable to science. To revitalise the colour, one solution would have been to paint over the red paint with a fresh coat; a suggestion that was rejected as it would mask Renoir's original brushstrokes. The value in the art of Renoir's authentic brushstrokes meant that this scientific challenge required consideration of both scientific and artistic values or norms of thought.

We move now to the last stage of education in our proposed framework for education which is upper secondary (age 13/14–16). The objectives in our framework for this age group are that students should appreciate that and why:

- Scientism is not a necessary presupposition of science [the nature of science in real-world contexts and multidisciplinary arenas]
- Some questions are more metaphysically sensitive than others [ways of knowing and how they interact]
- Science and religion are not necessarily incompatible [relationships between science and religion]

One of the cross-curricular workshops we describe for this level begins with a small robot on wheels that starts or stops moving when someone claps. Students are asked if the robot can hear and how they know. Students are then asked whether their evidence is sufficient to tell us whether the robot can 'hear' or whether we only know that the robot can 'respond to sound'. This opens the way for further examples of questions that are more or less amenable to science and also to a discussion on what makes some questions more metaphysically sensitive than others.

The notion is that students are on a journey of progression towards an ever-deeper understanding of the nature, power and limitations of science. One proposed focus question for discussion in a science lesson is whether all ideas in the natural sciences (biology, chemistry and physics) can be reduced to ideas about the material or even the physical world. Students could express their views on statements such as that: 'The only questions worth asking about reality are questions we can ask in science' and 'One day, science will be able to answer every question we have'. Students indicate their levels of agreement by moving around the room—so that those strongly agreeing go to the back and those strongly agreeing come to the front and all spaces in between are also available. It would be interesting to research whether students' responses to these statements vary depending on whether they are working with teachers of two subjects or one science teacher.

It will also be important to ensure that teachers have the pedagogies they need to address questions that extend beyond their own discipline boundary. Picking up on some points made by Kötter and Hammann (2017), most of the teaching that takes place in science lessons considers canonical and established scientific ideas and teachers and students are accustomed to working with questions that conclude with a consensus on the best answer. Questions about the power and limitations of science, however, are questions *about* science rather than questions *for* science.

Conclusion

The pressures and barriers that we have described in this paper affect young people's developing understanding of the nature of knowledge in ways that may be hidden from teachers to varying extents. The framework we propose would mean that epistemic insight is taught and assessed across the curriculum subjects and at each of the key stages of a student's journey through their years of schooling. We suggest that science teaching takes a more strategic approach to the development of such a capacity, beginning earlier in primary school by developing students' perceptions of power and limitations of science. We also suggest that selected subject curricula (science, history and the arts to name a few) put more emphasis on developing students' appreciation of the ways that science and other ways of knowing interact. We advocate that secondary school teachers from across a range of subjects be provided with opportunities to collaborate and be equipped with ways to encourage students' curiosity in Big Questions about the nature of reality and human personhood.

This paper is intended to stimulate discussion and new lines of research in schools and teacher education. It is also intended to draw attention to the impacts of the current and traditional practices in schools that are entrenched, and that in England and in many other countries, have spanned more than one generation of students. The framework for education that we propose will benefit from such critical discussion, as well as the subsequent trialling in primary and secondary classrooms of the objectives that we have developed.

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