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Student perceptions of the knowledge generated in some scientific fields

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Brief description

Students recognise science as a quest for understanding, as well as the technological value of scientific findings, but show some alternative conceptions of the nature of scientific knowledge.

Abstract

Secondary age students were asked about some science-related careers, using an interviews-about-scenarios technique. This article reflects on students' comments relating to the nature of scientific knowledge. Some comments reflected the aim of science as a means to better understand the world and our place in it. Other comments reflected perceptions of the possibility of applying scientific knowledge to engineer change - something that had great benefits, but also risks. There was also evidence that some students may hold misleadingly positivistic notions about scientific knowledge that may distort perceptions of some areas of scientific work.

Introduction

This article discusses comments made by students about the value and nature of the knowledge produced in some scientific careers. A perennial issue in science education is the need to balance what might be termed 'science for all' - education to support all of those who live and work in our society, most of whom will not be undertaking scientific work - and the need for a supply of suitable candidates to enter scientific work as researchers and teachers; or other professional work which requires a strong understanding of scientific concepts and processes, areas such as medical work and engineering (Millar & Osborne, 1998). The need to service the 'STEM (science-technology-engineering-mathematics) pipeline' has been seen as an economic imperative given the importance of science and technology to the modern economy. Increasingly, however, this is also being seen as an existential imperative: given global concern about such issues as climate change, pollution, food supply, power sources, and the rate of exploiting non-renewable resources.

Another well-established tension in relation to science curriculum concerns the appropriate balance between learning about outcomes of science - some of the typologies, principles, theories, models and laws generated in scientific work - and engaging in, and learning about, the processes of science itself. Understanding the nature of science has been widely recognised as an important aim of education (Hodson, 2014).

Part of the rationale here has been offering a relevant science education for the majority who will not become scientists or engineers, but who should be able to critically engage with claims they meet about medical treatments, consumer choices, environmental issues, and so forth. Yet a strong appreciation of the nature of scientific work is clearly important for those who will go into such work themselves.

A challenge here is that scholarly accounts of the nature of science (prepared by philosophers or historians, or perhaps sociologists or psychologists) are largely inaccessible to most school students, and these experts frame their work through diverse specialist terminologies and may not present entirely consistent accounts. This challenge reflects that of representing in curriculum accounts of scientific models and theories that may be nuanced, subtle and technical (for example, sometimes being formulated in advanced mathematics). In developing accounts of science for inclusion in the curriculum, whether of the outcomes of scientific work, or of science's own nature, it is necessary to make selections (what is important, what can be considered canonical?) and to build curricular models of scholarly accounts - authentic simplifications suitable for presenting to students at a particular grade level (Taber, 2008).

The nature of scientific knowledge

Science is at its core an enterprise concerned with generating knowledge, so learning about the nature of science encompasses an appreciation of the nature of scientific knowledge and something of the processes and practices by which it is generated. This theme is *epistemological*, given that epistemology is the study of the nature and sources of knowledge.

Although scholars differ in their accounts of the epistemology of science, there are some commonalities where there is broad enough consensus to inform a curricular model of the nature of scientific knowledge. So scientific knowledge is about the natural world, and is objective in the sense that different qualified observers should, in principle, be able to come to agreement. We can expect that any inconsistent findings will ultimately be explained (in terms of choices of theoretical perspective, or methodological approach, limitations of apparatus or analytical techniques used, etc.), allowing a rational choice about which findings are sound and which should be discounted.

However, a modern understanding of the nature of science admits the limitations of process that may prevent a commitment to objectivity in undertaking careful, competent scientific work being *sufficient* to come to true knowledge of the natural world. The human cognitive system is inherently biased by the specifics of physiology, and each individual human becomes biased to understand the world in certain ways by their past experiences (Taber, 2014). Experiments can only test those possibilities scientists can imagine. Major shifts in scientific thinking have often been delayed because scientists were primed by their scientific training to think in certain ways and 'see' certain things.

All experimental results underdetermine nature - there are always alternative ways to interpret the same data (even if some alternatives may seen highly convoluted and so unlikely). Moreover, all observations are theory-laden: the way research is set up necessarily privileges some observations over others. Modern science often relies on highly complex apparatus (designed according to particular theories and models) and analytical methods - so an experimental test is strictly of the conjunction of the explicit hypothesis and the theories of instrumentation that are taken for granted in the study design.

There are some quite sophisticated treatments of these ideas, and much historical research offering case studies to demonstrate the challenging nature of scientific epistemology. How much of this material can (or should) be included in school science is an important matter for curriculum developers. Yet it is critical that students are supported in developing epistemological insight. For example, climate change is perhaps the most important issue facing the world, yet the science may seem uncertain: some powerful politicians simply deny the science, and scientists themselves talk of trend lines, and probabilities, and so seem unable to agree on definite predictions, or to commit to explaining specific floods or bush fire events in terms of climatic change.

Representing epistemology in the science curriculum

So it is critical to persuade young people that science produces robust and reliable evidence-based knowledge that often offers a sound basis for acting in the world; yet, *also,* that scientific knowledge always remains open to challenge. That is, science does not produce some kind of ultimate truth about the world. In particular, there are two features of scientific knowledge that it is important young people should learn about.

One is that *science produces theoretical knowledge*. The products of science are often laws, principles, theories, or models. Laws may seem to be absolute: they always apply. But they have only been tested in a limited range of contexts, and with measurements to a limited level of precision - so their universality remains a theoretical premise. Indeed, some 'laws' may only strictly apply to theoretical situations (the ideal gas law), or may have acknowledged exceptions (deviations from Raoult's law). Like models and theories, then, this type of knowledge is an abstraction, and simplification, of the complexity of nature. Scientific concepts can themselves be understood as inherently models (Taber, 2019). For example, students may be forgiven for assuming that the concept 'acid' is a description of a clear category of substances that exist in the world - but shifts in the meaning of acid have been motivated to produce the most *useful* definition to support chemical research, rather than to better characterise some inherent pattern in nature.

Whilst scientific knowledge is, in that sense, theoretical, it derives from empirical enquiry. Traditionally philosophers of knowledge were classed as rationalists or empiricists depending on whether they thought the primary source of knowledge was reasoning or experience. Science, once called *natural* philosophy, however, develops theoretical knowledge from the iterative interplay between logical reasoning and experience.

Secondly, *science produces provisional knowledge*. All scientific conclusions remain open to challenge - so, in principle at least, any scientific idea is subject to potentially being modified (or rejected) in the light of new evidence, or even in the light of a new theoretical framework that makes better sense of existing evidence. Being shown to be wrong and changing your way of thinking is not a sign of weakness and failure in science - but a sign of committing to core scientific values.

Student perceptions of science-based careers

There has been a good deal of work considering factors that influence young people's perceptions of careers in science and related fields - including, for example, why there might be gender differences and how home background can influence aspirations (DeWitt et al., 2013). The study drawn upon in this article presented school age students with short vignettes describing a number of science-related careers and asked them if they would be comfortable in undertaking these different types of work. The students' responses offered insights into their perceptions of these areas of work, including the scientific knowledge generated. It is that data we discuss here.

The context of the interviews

The data was collected during interviews undertaken as part of the Learning about Science and Religion (LASAR) project. Part of the rationale for that project was a concern that young people's attitudes to science may be influenced by common perceptions that science and religion were inherently contrary, something that might be of concern when students with religious faith are considering choices for courses and careers. This stance has been misleadingly presented as 'the' view of science and scientists - and thus had potential to suggest that a young person could not readily become a scientist and also hold religious commitments. The project has explored the extent to which school age students have the 'epistemic insight' to appreciate why scientists may take a range of stances on how science and religion may be related (Billingsley, Taber, Riga, & Newdick, 2013).

Interviews were carried out in a range of diverse schools in England to explore students' ideas about how science and religion might be understood in relation to each other. In one round of interviews it was decided to incorporate a set of short vignettes describing some scientific careers, chosen because they were thought to have potential to link with extra-scientific values that may be important for young people (a report on this work is being prepared for publication).

Students were read vignettes about the work of doctors, cosmologists, medical researchers, palaeontologists, conservationists, anthropologists and genetic engineers (see Table1). This was a variation of a technique known as 'interviews-about-scenarios' and offering the vignettes avoided a situation where a student might be asked about an area of scientific work they were not familiar with, or where they might have inaccurate associations of job titles. All research is shaped by the methodology used: here, the vignettes offered a particular short account of the area of work, and this needs to be kept in mind in drawing conclusions.

Students were interviewed in their schools, after they had offered voluntary informed consent to participate in the study. Fifteen students were asked about at least some of the vignettes (due to time pressures within a longer interview schedule, only seven were asked about the full set; five students were asked about five, and three about six vignettes). Eight of the students were in Y10 of the English system (that is, 14-15 years of age) and seven were in Y12 (16-17 years of age) - they are referred to below by assumed names.

Findings: Student comments relating to scientific knowledge

For the present article, students' responses have been examined to identify comments relating to the epistemic character of scientific knowledge. We found 37 instances of comments made by students that were considered to reflect perceptions of the nature of scientific knowledge. These were characterised into three classes, exemplified below. Twenty comments related to the potential for scientific knowledge to allow us act in the world to bring about change. Nine instances related to the value of scientific knowledge in helping us understand the world. Eight comments were considered to reflect alternative conceptions of the nature of scientific knowledge.

Powerful knowledge - applying scientific knowledge to engineer the world

Our vignettes elicited student comments about the utility of scientific knowledge. Denis (Y12) acknowledged how the training experiences medical doctors undertook "are necessary for improving medical care" as applicable medical knowledge relied on experience, as "it's much harder to learn about the human body…from a book or…a model than it is from the real thing and I don't think anything can really prepare you for treating a very ill patient other than treating a very ill patient".

Similarly, it was recognised by a number of participants that medical research could have real benefits that made a difference to people. Darshan (Y10) suggested that it was "for the greater good of mankind, if you did discover a cure for a disease". Donald (Y12) noted that "without that experimentation…We wouldn't get all these cures that we have today…helping other humans". Faye (Y12) referred to how "a really widespread disease or illness…could be solved" with "a really important cure" and Ivy (Y10) noted that "a few rats dying can save so many people". Henrietta (Y10) commented that "it is a really important thing that we try and find new treatments for things which kill humans…that's a really good profession to be in".

Hentrietta also noted that the work of conservationists could protect "endangered species", although she saw this as correcting "the effect we've already had". Similarly, Ianthe (Y10) suggested this was "a very, very, very important bit of science. I think that we owe it every single animal out there to maintain their habitat because we've destroyed it so far."

The vignette about genetic engineering, perhaps unsurprisingly, elicited a range of comments about how science could engineer "beneficial" (Danny, Y10) changes to the world, Denis saw this as offering "a huge benefit for the problems we have with world hunger…I think I would quite like that, you know, to try and help out as many people as possible". Similarly, Darshan thought this could be "enhancing…mankind. If you had crops…that could sustain and feed more people…I think that would be a very beneficial profession". Henrietta noted how "it's a positive thing, that like crops are influenced to make them more effective because it just means less wastage, and for people in poorer countries who it is their livelihood to farm, then it's a really good thing for them, because it just secures their income really, and it means they're not going to be on the breadline".

Donald thought such research offered insurance in case "we might have a disaster in this world and then therefore the food supply might get cut off…even if like the world changes so that the crops we currently have don't grow, we might then be able to make these new ones…so that if anything, God forbid, did happen, we have a way still of carrying on and still living".

Appreciation of the potential for good was sometimes moderated by an awareness that scientific work can have unforeseen and unintended outcomes. Denzil (Y12) acknowledged "the benefits of it" but noted "you do experiments and it can go wrong and could cause quite major problems…it seems very risky". Similarly, Ella (Y12) told us "I could do that because…it will help a lot of people but we can't see what's going to happen…like a lot down the line…it could eventually create something like that's poisonous". Ivy thought "it's great you can get better crops" but "they have to be careful, because if you make the [plants] resistant, the pests become stronger". Horace (Y10) warned that "bad things can happen if you mess with DNA…so I wouldn't like some sort of super bug or something to come out".

Fifi (Y12)'s response reflected this conditional approval of work that was

> improving food sources…and also, kind of like, saving the environment and stuff because they're on about how you can make petrol and things like that from plants. And if you can get crops that grow faster…then it will be more effective and then like about pest resistance and disease resistance, but then…if they were resistant to one thing but then they were not resistant to this other thing then they'll all get killed out…but, I think that would be quite an interesting job because…again it's, kind of, helping the world and the environment.

Ianthe also recognised the potential of genetic engineering to offer benefits, whilst also noting how she thought the work would be fascinating:

> I think it'd be very, very, very interesting. I think it'd be fascinating. I think I can see a lot of like benefits of genetically engineered plants and things like that. For example…this woman in…South Africa, she was developing genetically modified maize that had many vitamins in…and that people in poorer, hot, like dry, countries could grow.

Fascination: scientific knowledge helps us understand the big questions

Ianthe also thought that cosmology "would be really, really interesting…fascinating questions". In our interviews a number of the participants noted that some of the scientific careers mooted offered the opportunity to better understand what might be characterised as the 'big questions' of our origins. Denis noted "the sort of fascination of [cosmology], you can see images through a telescope…of stars, for example, that aren't actually there anymore…because the light has taken so long to reach it that the star has burnt down by now." Declan (Y12) thought "that's a very interesting field because it is linking what we see now and trying to find the origin of it", something echoed in Dashan's comment :"man has tried to explore and find out about his origins so…human curiosity would lead several people into that field of science, which I wouldn't mind doing".

Joy noted, in regard of palaeontology, that "fossils are quite interesting because obviously they do share a lot of, like, history and everything", and Denis thought it was "quite interesting seeing how different fields of science, for example, can fit together in that relationship. We have the geologists discovering things that explain things, biologists explaining things as well". Denis thought "studying anthropology is quite important when seeing where we've come from" and Ivy also thought this was "really interesting, how humans evolved".

Alternative conceptions of the nature of scientific knowledge

Some comments suggested that the scientific fields that some participants found most fascinating were seen by other students as offering knowledge of less inherent interest. So, where Denis was excited by the idea of collecting light from extinct stars, Denzil told us he "wouldn't be interested…I would class it as, sort of, very old science". Similarly with palaeontology, two students saw *knowledge of the past* as *passé knowledge*. Ianthe thought "you're not finding new things, you're not understanding bigger questions. It's not something that I would probably do", and Henrietta thought she would "find it a bit too boring" as "it's not quite revolutionary enough for my liking. I'm interested in discovering things that are really new, not just kind of confirming things that we already know".

There was also a suggestion from a couple of our participants that some types of scientific work could not be objective. Ella thought anthropology was "a bit subjective", by which see seemed to mean that if one already approached the work with a preformed view it would not be possible to allow for such bias:

> it makes sense that we've developed, because it explained why there's so many different kinds of creatures and it just makes sense. But, the fact is I wouldn't be able to fully do it because I already have that sort of belief that we have developed and that's going to get in the way so I might make links between like animals that are completely irrelevant.

Donald thought that scientific work could find evidence to choose between different perspectives, but seemed to see this as comparing a scientific view with a religious view (rather than seeing *any* framework constructed to make sense of, and explain, the data collected as potentially scientific):

> would I like to be like an anthropologist?…I think so yes because you're just finding like evidence to support either one claim or the other. If the evidence you find doesn't support maybe the scientific claim, then it's quite very likely that it will support the religion claim instead. So, either way you're finding like evidence that will support one side or the other…I feel comfortable doing that because…the outcome might not be what I think's right but I'm still supporting one side or the other…and it's therefore just allowing each side to go and like categorically say well this has to then be the right way…it will give like proper detailed answers onto like how the world was formed and like how our ancestors have evolved.

Donald's comments here also seem to reflect a positivistic stance, that the work can lead to a definitive, absolute knowledge of our origins. Fifi also seemed to think scientific work should be positivistic, and for this reason had doubts about fields such as cosmology ("I'd like to do something like that. The only thing is, that with trying to work out the origins of the universe you can never actually really know because you weren't ever there"), anthropology ("again, there's always like a, kind of, an element of uncertainty") and palaeontology,

> I like fossils though, I think they're interesting but…I don't think I'd really like it… yet again, I don't think you could ever really know unless you were there…There'll always be an element of uncertainty because…no matter how much evidence you supply…there will always be, like, doubt because of the fact that…you were… never there…there'll always be uncertainty.

Discussion

We cannot assume the comments of a small sample of students responding to a selective set of vignettes about scientific careers reflect students' thinking more widely. However, we do consider this study suggests a promising avenue for further research exploring students' perceptions of, and attitudes to, actual STEM careers. Moreover, we hope the reported comments will intrigue science teachers, and encourage them to engage students in discussions about the character of different science-based careers. The impression given in our interviews was that students are very open to learning about, and discussing, what is involved in different areas of scientific work.

It is reassuring to find students telling us that they see some areas of scientific work as inherently interesting and, in particular, that the areas of work sometimes seen as most fascinating related to work that offers insights into the big questions about our origins and place in the cosmos (anthropologist, cosmologist, palaeontologist). There is clearly a hook here for engaging many adolescents - science can help us understand how we come to be here, how we have reached our current state, how we relate to the rest of nature. Unlike many areas of scientific research, one does not need a high level of background knowledge in a specialist topic to appreciate what motivates the 'big questions', as they are questions about (all) our nature, our identity, our place in the world, our very humanity.

Our interviews also revealed some concerning aspects of students' metaknowledge, their insight into the nature of scientific knowledge. Being aware of potential bias is important for a scientist, *but* such bias cannot be avoided as science is *always* informed by some kind of existing theoretical perspective. Teachers can help students see that objectivity requires an open mind, not an empty mind.

Seeing knowledge of the past as 'old' knowledge surprised us, and it may be useful for teachers to recognise this possibility and be sure to emphasise the ongoing relevance of such knowledge. The elements of positivism found in students' comments reflect previous research (Driver, Leach, Millar, & Scott, 1996) including earlier findings from our project showing how students struggle to appreciate how scientific theories can be conjectural, yet often offer robust understandings that can be treated as reliable knowledge (Taber, Billingsley, Riga, & Newdick, 2015). This reminds us that it remains a challenge to help learners understand how scientific knowledge is, necessarily, (in principle) provisional, yet can often become robust enough to inform important decisions. As the example of climate change reminds us, when inaction is itself a risky option, science can offer us the best basis for moving forward even though scientific knowledge cannot be considered definitive truth.

(3991 words)

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References

Billingsley, B., Taber, K. S., Riga, F., & Newdick, H. (2013). Secondary school students' epistemic insight into the relationships between science and religion – a preliminary enquiry. *Research in Science Education*, 43, 1715-1732. doi:DOI 10.1007/s11165-012-9317-y

DeWitt, J., Osborne, J., Archer, L., Dillon, J., Willis, B., & Wong, B. (2013). Young Children's Aspirations in Science: The unequivocal, the uncertain and the unthinkable. *International Journal of Science Education, 35*(6), 1037-1063. doi:10.1080/09500693.2011.608197

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young People's Images of Science*. Buckingham: Open University Press.

Hodson, D. (2014). Nature of Science in the Science Curriculum: Origin, Development, Implications and Shifting Emphases. In M. R. Matthews (Ed.), *International Handbook of Research in History, Philosophy and Science Teaching* (pp. 911-970): Springer Netherlands.

Millar, R., & Osborne, J. (1998). *Beyond 2000: Science education for the future*. London: King's College.

Taber, K. S. (2008). Towards a curricular model of the nature of science. *Science & Education*, 17(2-3), 179-218. doi:10.1007/s11191-006-9056-4

Taber, K. S., Billingsley, B., Riga, F., & Newdick, H. (2015). English secondary students' thinking about the status of scientific theories: consistent, comprehensive, coherent and extensively evidenced explanations of aspects of the natural world – or just 'an idea someone has'. *The Curriculum Journal*, 26(3), 370-403. doi:10.1080/09585176.2015.1043926

Taber, K. S. (2014). *Student Thinking and Learning in Science: Perspectives on the nature and development of learners' ideas*. New York: Routledge.

Taber, K. S. (2019). *The Nature of the Chemical Concept: Constructing chemical knowledge in teaching and learning*. Cambridge: Royal Society of Chemistry.

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Table 1:

Career option	Scenario
Medical doctor	Doctors have to be able to deal with very ill people, and sometimes with people in great pain or even dying. In their training they have to dissect human corpses to learn about anatomy. In their work they have to examine people with infectious diseases and, sometimes, horrible injuries.
Cosmologist	Some scientists explore theories of cosmology that try to find out about the origins and history of the universe. The working assumptions in this area are that the universe is thousands of millions of years old, and has slowly developed to have the structure astronomers see today.
Medical researchers	Medical researchers explore the nature of disease and the potential of different treatments to help cure disease of relieve pain and other symptoms. Sometimes medicines and treatments are tested out on non-human animals to see if they are effective. This involves giving animals diseases or injuries, and then comparing different treatments with the untreated animals. Sometimes these animals have to be killed and dissected so that the scientists can examine their internal organs.
Paleontologist	Palaeontologists study the development of life on earth by examining fossils of living organisms that died a long time ago. These scientists work with the geologist's models for how different rock formations were formed at various times in the last four thousand millions years or so, and with the biologist's model of how all the living forms of earth today evolved from the same very simple life forms which lived on earth over three thousand millions years ago.
Conservationists	Conservationists try to preserve the different ecosystems on earth where different animals and plants are found. It is believed that many of the species on earth are in danger of extinction, and some times conservationists recommend killing some animals in certain places because there are too many for the food supply, or because one species (perhaps one not native to an area) threatens the existence of another.
Anthropologists	Some anthropologists study how modern humans have evolved from other species over the last few million years. These scientists assume that modern human beings have been round for between a quarter and half a million years, and that their ancestors were physically different from people today, for example in the size and shape of their heads.
Genetic engineers	Some scientists use genetic engineering to produce new types of animals and plants. They take some of the genetic material from one type of living thing, and add it to a completely different type. This can, for example, produce crops which can better deal with pests or cold weather or lack of water.

Table 1: Scientific careers introduced through an 'interview-about-scenario' technique, offering brief vignettes of the areas of scientific work.