The role of intellectual virtues in the development of the science teacher:
An initial provocation

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ABSTRACT

Initial, informal observations of work with pre-service chemistry and other science teachers suggest that a number of intellectual virtues are required, alongside a shift in identity, in order to help secondary school science students negotiate the pathway from 'science learner' to 'scientist'. This article explores these virtues, the ontological shift that accompanies them and pedagogical suggestions for how these attributes might be promoted in a programme of pre-service training, along with suggestions for further empirical research which might form the basis of further investigation into these initial observations

KEYWORDS

Science Teachers

School Science

Epistemic Humility

Teacher Development

INTRODUCTION

In this think-piece we explore the intellectual virtues required by pre-service chemistry teachers (registered on a Postgraduate Certificate in Education (PGCE)- at a UK university) who are passing from being a chemistry learner/practitioner to being a science teacher. An exploration of these virtues, we believe, also highlights those qualities required of secondary school science students who are on what we term, the 'school science pathway': the route taken by those students who will move from 'learner about science' to someone who eventually will be employed in science or engage in further science study. While we would contend that all trainees need to undergo a change in identity in order to move from being learner/practitioner to teacher, we would further extend this point by suggesting that are two types of trainee that we see on our PGCE Secondary science course, characterised by their response to the challenge of this change and their demonstration of the intellectual virtues required by it. We as teacher educators not only need to emphasise this need for a change in identity, we also have to devise a pedagogical approach which facilitates it, and suggest some ways of doing this, along with further explorations, made at the end of the paper.

INTELLECTUAL VIRTUES

For the purposes of this article, we identify three intellectual virtues which we believe to be integral to making this change in identity: epistemic curiosity, self-regulation and epistemic humility. This identification is based on some initial, informal observation of the pre-service teachers we work with, connected to some ideas from critical realist perspectives on education.

Epistemic curiosity is defined as the 'motive to seek, obtain and make use of new knowledge' (Lauriola et al. 2015). While this may seem self-evident, we would suggest that this virtue is significant for pre-service science teachers, because it is a quality required to ensure that the individual becomes autonomous in terms of their subject knowledge development. We would also note that this virtue is not perhaps as widespread as it may seem; the existence of defined syllabi and 'strong classification' (Bernstein 1971) between disciplines may limit the science teacher's epistemic curiosity to the extent that they curb the overall aim of the subject.

Self-regulation in this article is aligned with Zimmerman's interpretation of the term, which sees the ability to self-regulate as being an extended sort of metacognition. In this interpretation, self-regulation is defined as both knowledge and skills (metacognition) along with 'self-efficacy and personal agency' (Zimmerman 1995; Gascoine et al. 2017). This virtue not only allows trainees to recognise that they have the correct scientific knowledge, but also may involve them in recognising how much of this correct scientific knowledge is enough in order to teach that knowledge.

Epistemic humility is best described as the ability to recognise that the knowledge and skills that an individual possesses are neither fixed nor finite, and that subsequently that knowledge may need revision and reorganisation. This idea, borrowed from Critical Realism (Matthews 2006), is useful, we believe, for thinking about the long-term aims of science education. We suggest below that certain aspects of school science require teachers to recognise that there is a fallibility to the models that are used to teach certain concepts and that this recognition is an essential part of learning to be an effective science teacher.

Our observation, after working with a number of PGCE science trainees, is that in order to be successful teachers, such individuals need to experience an ontological shift in their identity, moving from a scientific realist perspective, in which the nature of objects is independent of human observation, to something more like (but, for good reason, not completely like) a social realist position in which what is important is the way that those objects are known by the pupils the trainee is teaching. For example, a teacher who has recently arrived from an undergraduate chemistry degree is likely to be well versed in the quantum model of the atom. However, arriving in school on their first day of placement, they are likely to be confronted with a situation in which they have to induct pupils into a much less sophisticated model of atomic structure. This in some ways seems self-evident; teachers often have to present limited models of reality in order to establish essential knowledge, and this situation is explored most eloquently by both Allan Luke (Luke & Deng 2008; Luke & Exley 2009) and Zyongi Deng (Deng 2007) who make a convincing argument that there is something distinctly different about school science as compared to the academic discipline of science. While both Luke and Deng have much to say about the nature of school science and its relationship with the academic discipline of science, they do not consider the question of the way that this relationship might be navigated in pedagogical and ontological terms by people learning to be science teachers. This paper puts forward some initial thoughts as to how and why such a navigation might occur. We suggest that the trainee teacher's ability to both retain and demonstrate the intellectual virtues highlighted above will go some way to explaining how they will respond to the need for a change in identity, and their ability to carry out this kind of induction successfully.

IDENTITY CHANGE IN SCIENCE TRAINEES

It has become apparent to us as teacher educators that this need for a change in identity is connected to the perceived differences between 'the pathway' and 'authentic science'. Teacher identity is acknowledged to be both a contested and problematic term, with a number of authors suggesting that there are actually multiple conceptions of identity at work in the way that both new and more-established teachers perceive themselves and are perceived by others. Some key literature in this area posits that there are three integral identities which 'indicate what a teacher should know and be able to do': teacher as subject matter expert, teacher as pedagogic expert and teacher as didactic expert (Beijaard et al. 2010). Other sources suggest that identity is a matter of how the teacher perceives themselves, and how other people – such as fellow professionals, parents, pupils etc – perceive them (Czerniawski 2011) . For the purposes of this article, we are most interested in this second conception of identity, which we believe relies upon the trainee teacher recognising that they have both a science practitioner identity and a science teacher identity, and that the latter needs developing in a very particular way. Some recent and relevant research in the area of science practitioner/science teacher identity (Chung-Parsons & Bailey 2019) suggests that there is a hierarchical view of these identities held by trainees who are preparing to be science teachers. While this research was conducted amongst individuals who were on an undergraduate science education degree in the USA, it points towards a need to consider the fact that there are some tensions in this area of teacher development. In this article, we are seeking to explain what we think teacher educators need to do to align these identities more effectively (moving between them more 'fluidly' to use Chung-Parsons & Bailey's term) in order to influence productive relationships between teacher and pupils in their negotiation of the school science pathway through use of the above-identified intellectual virtues.

To illustrate this change in the trainee's self-perception and pupils' perception of them, we might return to the example of atomic structure discussed above. In the majority of school chemistry curricula, pupils are required to learn electron configurations according to the Bohr model of the atom; however, once they reach a higher level of understanding (say in their first year of university) they learn that this is an inadequate model of atomic structure when confronted with a quantum model of the atom. The beginning science teacher, at this point, may end up agreeing with that breed of chemistry teacher who proclaims in the first A-level lesson of the course that 'Everything you've learnt at GCSE is a lie !' While this reaction might seem overly dramatic, it does highlight an inherent problem in school chemistry curricula, namely that doing science in school does not always necessarily involve acting like a scientist. For us, the ability of a trainee to recognise this situation through a combination of epistemic humility and self-regulation is key to making a success of their PGCE. In effect, the teacher needs to maintain and promote a kind of epistemic humility which acknowledges that the pathway of school science is not an authentic account of science, while at the same time inducting the pupil into the necessary pathway which will transport them to more authentic accounts. It would appear that the Royal Society of Chemistry agrees with this self-regulatory view; in a recent position paper on the chemistry curriculum, they suggest that

> *We would like to see the use of conceptual and mathematical models more explicitly discussed as approximations that allow us to explain and predict behaviour. In current curricula, treatment of models is often restricted to a succession of atomic models, with the implication that the older (more simple) ones are to be discarded and the most recent one is 'true'. In practice, scientists should aim always to apply the simplest model that will explain a given phenomenon, and may use different models in different situations. Bringing this thinking into the open would give students a more nuanced understanding of chemical thought and hopefully put a stop to teachers being accused of teaching things that were 'wrong' in previous years. (Gibney 2018: 35)*

This situation demands a particular kind of shift in teachers, who need to think about the way that they reconcile their own subject knowledge with the requirements of curriculum. However, trainees who make this ontological shift from being someone who sees themselves as having 'learnt enough chemistry to teach', to someone who can 'construct chemical knowledge in such a way that they facilitate the learning of chemistry' are, in our experience, more successful. Those trainee teachers who can have conversations with their pupils about the limitations of the scientific models they are using are likely to engender the kinds of intellectual virtues discussed above, which we would suggest enables those learners to be both better scientists and better at negotiating the pathway.

As teacher educators, we are interested in the question of whether or not trainees are capable of making this shift themselves; alternatively, do we need to facilitate this shift by enacting specific pedagogies with the trainee? In reality, we have noticed that both situations are present in our PGCE chemistry cohort, with trainees falling into one of two categories:

> 1) Trainees who quickly respond to 'epiphanic events' in the taught element of the PGCE course and identify that their knowledge has been mediated and that they will need to revise and reorganise what they know. Here, we define an epiphanic event as a situation or example which initially seems to involve a straightforward application of knowledge, but once unpacked proves more troublesome. Consider the following example of an epiphanic event we have used to explore trainee knowledge;

In a session with trainees, the teacher educator asks for a volunteer to stand facing a wall, about a metre away from it. (The wall must be perpendicular to the floor – no curved or sloping surfaces.) The teacher educator then places a small rectangular mirror on the wall and positions it so that the volunteer can see just the top of their head reflected in it. Then, the question is posed 'How long does the mirror have to be in order for you to see the full length of your body without moving your head?' All trainees then have the opportunity to try to answer this question.

The kind of epistemic curiosity required to deal with such examples ensures that they will tend to think much more about the need to represent this mediated knowledge to the learners in their class.

> 2) Trainees who initially resist these events by operationalising the process of teaching; this involves relying on a combination of whatever prior knowledge they have and the knowledge that is present in the school environment to teach structured lessons, which may not acknowledge the mediated nature of the science curriculum.

For the first type of trainee, self-regulation is evidenced by those individuals who recognise that, while they know certain key chemical principles, they are, initially at least, ill-equipped to teach them. This is part of a wider realisation that their knowledge gained from learning chemistry has been mediated and they need to construct mediated knowledge themselves to allow their students to access the pathway successfully. We would suggest that the realisation that knowledge is mediated results in them questioning their subject knowledge, and trainees that do so find it easier to plan learning where they can construct the kind of knowledge that students need in school science.

Trainees in the second category, who need to have this shift and the associated virtues identified with it reinforced for them, benefit from a pedagogical programme that presents a series of epiphanic events that continually ‘nudge’ them to confront the fact that their knowledge has been mediated. An example of this sort of programme, again returning to the question of atomic models, might involve the following series of questions:

1. *What is an atom?*
2. *What is an atom made of?*
3. *What is the mass of a proton?*
4. *What is a proton made from?*
5. *What is the mass of a quark?*

As chemistry students, the trainees would have committed themselves to the quantum model of an atom, as it currently provides the most sophisticated explanation of what an atom is. However, for chemists it could be argued that the proton is of less epistemic value than the electron. This is because, if we accept that chemistry, on some level, is concerned with the synthesis of new substances and this occurs through a change in the bonding between atoms, then electrons are the key protagonists in this change. A cursory glance at the index of an undergraduate chemistry textbook and the number of pages dedicated to protons and electrons respectively should demonstrate this. Question 5 in the above sequence demonstrates this further: for the chemist a quark is an interesting oddity; for a physicist it is a fundamental particle.

As a consequence, this commitment to something like the quantum model of an atom means that rather than being fully acquainted with the quantum model of the atom through their undergraduate education, lecturers would have selected the relevant information for their chemical advancement. This point is not lost on Thomas Kuhn, who, despite referring in this example to physics, makes an allied observation:

But science students accept theories on the authority of teacher and text, not because of evidence. (Kuhn 1970: 80)

He adds:

> *Until the very last stages in the education of a scientist, textbooks are systematically substituted for the creative scientific literature that made them possible. Given the confidence in their paradigms, which makes this educational technique possible, few scientists would wish to change it. Why, after all, should the student of physics, for example, read the works of Newton, Faraday, Einstein, or Schrödinger, when everything he needs to know about these works is recapitulated in a far briefer, more precise, and more systematic form in a number of up-to-date textbooks? (Kuhn 1970: 165)*

In a school environment where policy guidance (Gibb 2015b) appears to encourage a return to the wholesale use of textbooks, Kuhn’s view should make us think about both the kind of science students we want, and the kind of science teachers we want to work with them.

As David Aldridge suggests, ‘The affirmation of identity requires a turning away from certain possibilities’ (Aldridge 2014), and here we would suggest that the success of the trainee science teacher requires a turning away from their existence as chemistry practitioner transmitting chemistry knowledge (or ‘sage on the stage’) to something more like a person offering membership of an organisation (Erduran & Dagher 2014: 146) by overtly indicating that epistemic humility is required for entry. In realising that there is a mediation process that learners need to be inducted into, the successful trainee shifts their position, from one where knowledge and its structures are fixed, to one where they are more flexible; a metaphor like Alan Luke’s ‘weaving’ (Luke & Exley 2009) might help to describe the nature of the necessary pedagogy here. We must also acknowledge, however, that this is quite hard to do, particularly when the wider, pedagogical narrative is, in some respects, returning to the notion that transmission and instructional models of teaching are in some way superior (Rosenshine 2012; Sweller 2016). This challenge is, though, the one that teacher education needs to address. Rather than attempting to privilege the quantity of, or type of, subject knowledge a trainee has, as the current UK government appears to suggest (Gibb 2015a), it would appear to us that the demonstration of these intellectual virtues and the ability to make this shift in identity may be of greater significance, and a PGCE programme that gauges how trainees respond to a programme of epiphanic scientific events might be much more useful than one that reifies large amounts of subject knowledge. We intend to explore this possibility in empirical terms (outlined below) to see if this does what we think it will do.

FUTURE RESEARCH: WHAT WE WANT TO EXPLORE FURTHER

These observations are of an anecdotal nature, and this think-piece reflects our current view of how PGCE science might need to be developed to produce successful and effective trainee teachers. We would propose four pieces of empirical research which would allow for data to be gathered which tests the ideas put forward here.

1) As researchers we would be interested in following up on a distinction that is made in Lauriola et al. (2015) about the individual’s predisposition towards epistemic curiosity, and its possible connection with personality types. While identity and personality are clearly two different things, it would be interesting to explore whether or not there is a relationship between

the individual's view of their science practitioner/science teacher identities and personality type. For Lauriola et al., there are two types of personality connected with epistemic curiosity: 'I-type' individuals who associate positively with that curiosity, and 'D-type' who see it as being connected to negative outcomes such as the avoidance of risk. We would be interested to explore if there was any such correspondence between trainee and personality types, as this might help in terms of personalising the PGCE programme more effectively.

2) The pedagogic programme that confronts trainees with epiphanic events would require a robust evaluation to examine what kinds of difference it made to trainee, and subsequently learner, outcomes. This might be carried out by comparison to the outcomes achieved by previous years' cohorts, when such a programme was not in effect, or to other PGCE programmes not using such an approach outside our institution. This programme would probably also need to think about how the intellectual virtues above were promoted and explored in practical terms. For example, what kinds of activity within the PGCE programme could be devised to emphasise the importance of developing one's epistemic humility and curiosity?

3) We would also be interested in examining more closely the type of behaviours that trainees exhibit while on school placement which demonstrate (or otherwise) the identified intellectual virtues, and the extent to which these virtues might be interrelated. Such an examination would involve a mixed methods study which observed trainees in situ and coded certain types of behaviour which we might hypothesise are indicative of epistemic humility, self-regulation and epistemic curiosity.

4) Finally, if the problem with school science is its inauthentic nature, perhaps other types of inquiry might produce more authentic science inquiry. One thing that we propose is a study which looks at whether or not there is epistemological or educational value in science teachers using other non-scientific methods to promote better learning and more authentic scientific inquiry. While there is some limited literature on the use of artistic teaching methods within science (eg Boujaoude et al. 2005) we would be interested in seeing how such methods might be used not just to teach science, but to teach scientific enquiry. Again, a project which trialled some means of doing this would use mixed methods but might have particular emphasis on learning outcomes which may be of a quantifiable nature.

CONCLUSIONS

In summary, then, we see three ideas as being key to the way that PGCE science trainees might be prepared in order to best help pupils navigate the pathway of school science. Firstly, the intellectual virtues identified above can be developed, both in the trainee themselves and in the pupils they are teaching. This development is facilitated by a shift in identity (or perhaps more accurately a movement between identities of science practitioner and science teacher) that can be encouraged by the kind of epiphanic event we outline above. Secondly, programmes of Initial Teacher Education for science teachers, in our opinion, need to be designed so that they both prompt and support this shift, helping all trainees to recognise that their scientific knowledge is, to a greater or lesser extent, both mediated and mediating. Finally, we propose a number of 'lines of inquiry' which could provide empirical support for the ideas expressed in this provocation, and we welcome further discussion, exploration and challenge from teachers, teacher educators and others in the science education community who may be interested in this area of teacher development. ■

FOOTNOTE

i Generally, trainees struggle with this problem. The actual answer is that the length needs to be half the length of your body, which can be worked out using ray diagrams. The most common response is 'it depends on how far away from the mirror you are', or some trainees realise that they do not know the answer, so try to put additional conditions on the situation to contrive a 'correct' result. A possible reason for the 'wrong' answer is that trainees apply experiential knowledge from their casual interactions with mirrors and do not think about the situation in terms of the properties of light.

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