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Becoming a Science Teacher: Is It Merely a Process of Trial and Error?

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Abstract

In this paper, I explore preservice science teachers' (science PSTs') reflective practice (RP) during a 1-year Postgraduate Certificate in Education programme in England. Previous research suggests that science PSTs are not very reflective, and I hypothesised that lack of reflectivity is related to their difficulty in learning to teach. Science PSTs ($n=38$) took part in a teaching intervention designed to support development of RP, and eight volunteered as research participants. Four seminars about the *diagnostic teaching cycle* and *action learning* (AL) took place in the university during the year. Data collected included written reflective journals, analyses of critical incidents, and action plans; audio recordings of AL sets; and school-based mentors' reports of participants' progress in school placements. I investigated participants' reflectivity using Zwokdiak-Myers' *nine dimensions of reflective practice*. There was substantial variation between participants, and more evidence of reflectivity in some dimensions than in others. A relative strength was that participants adopted a range of teaching strategies (*Dimension 6*), but linking theory with practice (*Dimension 3*) was a weakness.

Keywords Science teacher education · Reflective practice · Action learning · Diagnostic teaching cycle

Introduction

Reflective practice (RP) has long been considered an essential component of teacher development, within the UK and beyond. Wilkin (1996) suggests that prominent academics (e.g. Pring) advocated RP from the mid-1970s. Twenty years later, the Modes of Initial Teacher Education study (MOTE) suggested that most teacher preparation courses in England included RP, and its use was believed to be increasing (Furlong & Maynard, 1995). Furthermore, RP is considered fundamental to science teacher preparation. Nichols et al. (1997, p. 186) state:

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Engaging prospective science teachers in reflective practice is crucial towards preparing them to identify and deal with situations in need of change in science education.

This paper is a case study of science preservice science teachers (PSTs) on a 1-year university-schools partnership Postgraduate Certificate in Education (PGCE) course in England in academic year (AY) 2016–2017, on which I was a science education tutor. These courses have been the predominant mode of PST preparation in England since a government directive in 1992 (DES, 1992). PSTs spend 12 weeks in university and 24 weeks in school placements. Core content for initial teacher education (ITE) has been specified by the DfE since 2016 (Department for Education, 2016). The course had two blocks of university teaching and two block school placements. PSTs spent approximately two-thirds of their university-based time in science education seminars, with one-third in more general professional studies sessions.

In this period, university tutors and school-based mentors assessed PSTs' teaching using guidance from the National Association of School-Based Teacher Trainers (NASBTT) and the Universities Council for the Education of Teachers (UCET; UCET & NASBTT, 2012). PSTs' teaching was graded *outstanding*, *good*, or *requiring improvement*, against the Teachers' Standards (Department for Education, 2011), following government guidance (Department for Education, 2012). Generally, I found physics PSTs' grades were lower than those for PSTs of other science specialisms, and science PSTs attained less well than those of other subjects, e.g. English or history. Table 1 and Fig. 1 show course data aggregated over 3 years prior to my research.

Additionally, data for England in 2013–2014, before starting the research (Department for Education, 2015, p. 8), suggested that a lower percentage of science PSTs (87%) are awarded qualified teacher status (QTS) at the end of their courses than across all subjects (mean 91%), with physical education the highest (98%) and physics the lowest (81%). (For further details, please see the Appendix Table 6.)

My interest was in how science PSTs can be supported to attain better outcomes. There is a shortage of science teachers, particularly physicists, in England (National Audit Office, 2016) and internationally, and understanding their development better may contribute to addressing it.

To provide appropriate support, we must understand the difficulties science PSTs face. Why might they do less well? Possibilities include:

- Since entry is less competitive, recruitment standards are lower and their subject knowledge is weaker;
- Science teacher shortages make circumstances in school science departments more challenging;

Table 1 End of course grades for different PGCE subjects over 3 years

Grade	English ($n=51$)	History ($n=46$)	Modern foreign languages ($n=51$)	Physical education ($n=49$)	Sciences ($n=86$)	Physics and physics with mathematics ($n=15$)
Outstanding	31	26	31	26	38	3
Good	17	20	20	23	40	10
Requiring improvement	3	0	0	0	8	2

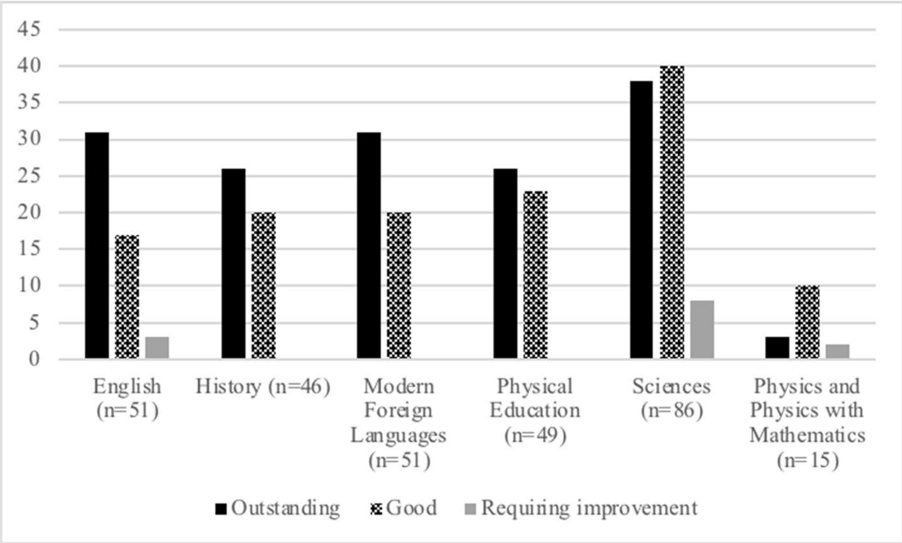


Fig. 1 Bar chart showing final grades for PSTs with different subject specialisms (note that the group labelled 'physics and physics with mathematics' is a subset of the 'sciences' group)

- Science teachers in England often teach all three sciences to GCSE (age 16) so developing pedagogical content knowledge is more challenging (Gilbert, 2010);
- Science teaching is more demanding because PSTs manage practical work alongside developing general teaching skills (Maskan, 2007);
- Some scientists (physicists) lack soft skills, 'such as team working or communications skills' (Jagger et al., 2001, p. 12), but is this negative stereotyping, since Bruun et al. (2018, p.1) note that there is a negative stereotype that physicists are 'unattractive, tech oriented, awkward, and loners'?;
- They do not reflect well enough (Malthouse & Roffey-Barentsen, 2014);
- They adopt transmission teaching, limiting pupils' progress (Loughran, 2007);
- Science mentors and tutors have higher standards;
- A combination of some or all of the above.

The line of enquiry I pursue is whether science PSTs have difficulty in being reflective, because it may explain why they do less well than their peers on teacher preparation courses that adopt a reflective practitioner model.

This project adds to the literature because it is practitioner research, in which I designed and implemented a teaching intervention with a group of science PSTs, intended to support development of reflectivity. *Action learning* (AL) was one strategy I adopted.

Reflective Practice

What Is Reflective Practice?

Approaches to RP are based in Dewey's (1933) and Schön's (1987) work. Dewey (2011) sees experience as involving both active and passive elements. When we carry out an action, and something happens as a consequence, we learn something about the world. Dewey suggests that we move beyond trial and error in our interactions with the world by thinking. Seeking causal relationships enables us to make predictions about the consequences of our actions. We are then able to take 'thoughtful action' and see what happens (Dewey, 2011, p. 81). If the outcome is not as expected, we modify our original solution and try again. Therefore, RP is a process of enquiry. So far, we have considered conscious thinking, but is this all there is to it?

Schön (1987) argues that practitioners' work involves dealing with complex problems and develops several concepts to help us understand how practitioners solve them. He refers to skills that professionals carry out without conscious thought as 'knowing-in-action' (Schön, 1987, p. 22). However, we come up against unexpected situations whilst we are working, which make us think — 'reflection in action' (Schön, 1987, p. 26). Professionals must make rapid judgment calls in the course of their work. Additionally, they work within particular social and institutional contexts, and therefore need to apply their theoretical knowledge about education to both new and familiar situations — 'knowing-in-practice' (Schön, 1987, p. 33). Thus, the process of becoming a teacher can be thought of as learning to think like a teacher. So how are novices to develop this thinking?

Schön suggests introducing a suitable practicum, which entails giving novices opportunity to work in contexts that simulate professional practice. For university-schools partnership PGCE courses, the school placements can be viewed as the practicum.

Schön suggests that professional practice develops by reflecting on what has happened after the event — 'reflection-on-action' (Schön, 1987, p. 26). In the absence of reflection-on-action, our actions become routinized. Additionally, Argyris and Schön (1974, p.6) describe the theories we might infer that someone holds based upon their behaviour as 'theories-in-use'. Reflection makes us aware of our theories-in-use, and allows us to consider alternatives, leading to change. So far, these models refer to conscious and unconscious thought, but is anything else involved?

Tripp (2011) adds to Argyris and Schön's approach by identifying an emotional element to developing teachers' practices, drawing upon Dewey's suggestion that 'reflection is… the term we should use for our processing of emotion' (Dewey, cited in Tripp, 2011, p. xii). The inclusion of an emotional element is of interest because Baird et al. (1991) suggest that science teacher development has an affective component.

What Are We Aiming to Achieve in ITE?

The Teachers' Standards in England (Department for Education, 2011, p. 11) state that teachers should 'reflect systematically on the effectiveness of lessons and approaches to teaching' — a somewhat limited interpretation. Atkinson (2004, p. 381), for example, distinguishes three levels:

- Simple RP — the individual teacher reflecting upon their teaching in order to improve
- Reflexive practice — considering the effect of systems and process within the school concerned
- The critical practitioner — considering challenges at a system-wide level, 'interrogating political, ideological and social processes that frame educational work'.

Moreover, Zwozdiak-Myers (2009) has synthesised concepts underpinning teachers' RP into *nine dimensions of reflective practice* (Table 2). This framework is included in a

Table 2 Dimensions of reflective practice

Dimension	Description	Scores were assigned according to the extent to which participants…
1 Study your own teaching for personal development	Engaging in a process of enquiry into your teaching, to evaluate your teaching, and to understand yourself better as a teacher — encompassing cognitive and emotional development	Made detailed written contributions, including consideration of teachers' and pupils' feelings
2 Systematically evaluate your own teaching through classroom research procedures	Carrying out action research in your classroom, including: • Planning and implementing classroom-based enquiry • Considering research ethics • Collecting and analysing data using educational research methods	Collected data in school as evidence of overcoming teaching issues
3 Link theory with your own practice	Being able to make reasoned judgments about teaching, based on: • Espoused theories — formal educational theories and research informed practices • Theories-in-use — practical theorising developed from classroom experiences	Referred to formal theories of education, material taught in the university, or articulated personal theories of practice
4 Question your personal theories and beliefs	You may have preconceived ideas about teaching which are tacit and resistant to change, which affect your teaching. Questioning beliefs leads to action grounded in evidence	Made their beliefs explicit, questioned their beliefs, or appeared to change their beliefs
5 Consider alternative perspectives and possibilities	Developing an attitude of open-mindedness, including realising that: • Others (including pupils) might have a different viewpoint • One might take different courses of action	Considered different perspectives and multiple possibilities
6 Try out new strategies and ideas	Taking action to develop a wider range of teaching strategies — actively engaging learners	Recounted using different teaching approaches, and put new ideas into practice
7 Maximise the learning potential of all your pupils	Developing strategies to • Support pupils' progress • Meet all pupils' needs • Formatively assess pupils' progress	Considered pupils' individual needs, and responded to pupils' learning using assessment for learning (AfL)

Table 2 (continued)

Dimension	Description	Scores were assigned according to the extent to which participants…
8 Enhance the quality of your own teaching	Developing 'pedagogic expertise from a research-informed evidence base' and 'quality teaching from an international perspective' (Zwozdiak-Myers, 2012, p. 161)	Referred to science-specific pedagogies, rather than general teaching approaches
9 Continue to improve your teaching	Continuing to develop one's teaching throughout one's teaching career	

widely used text for PSTs in England (Capel et al., 2009). (The final column describes how data were scored — relevant to the 'Analytical Framework' section.)

Are Science Teachers Not Reflective?

Malthouse and Roffey-Barentsen (2014) asked a group of 18 PSTs of different specialisms to rate the reflectivity of their reflective writing on a four-point scale, from descriptive to critical, analytical, and considering different perspectives. They noticed that three STEM PSTs rated themselves lower than PSTs of other specialisms. They argue that science PSTs' difficulty in being reflective is caused by their science backgrounds positioning them as positivists, which manifests itself as thinking there is a right way to teach. Does other literature support their suggestion?

Baird et al. (1991, p. 181) note that science is 'striving for the one correct explanation of a particular scientific phenomenon (or a method, etc.)', so perhaps science PSTs' educational backgrounds encourage them to think there is a right answer to a given problem. They suggest that science teachers need to adopt a more pluralistic and relativistic view, which might be interpreted as needing greater reflectivity, but are they positivists?

The consensus in science education literature is that there is a deficit in experienced science teachers' understanding of the nature of science (NOS; Cofré et al., 2019). Furthermore, Lederman and Lederman's (2014, p. 604) review of research suggests that science PSTs do 'not possess adequate conceptions of [the] nature of science'. Researching science PSTs' views in Turkey, Adak and Bakir (2017, p. 472) suggest they have a 'traditional understanding of science based on [a] positivist paradigm'. So, Malthouse and Roffey-Barentsen's suggestion seems reasonable.

Tsai (2007) suggests a link between teachers' epistemological views and their approaches to teaching. Positivism is associated with direct instruction, rote learning, and an emphasis on test scores, whereas constructivism is associated with science inquiry, conceptual change, and group work. I found this interesting because science education research suggests that transmission approaches contribute to problems with learning science, such as failing to overcome pupils' alternative conceptions, and failing to develop pupils' understanding of the NOS (Loughran 2007). Could it be that a lack of reflectivity is linked to positivism, which leads science PSTs to adopt transmissive approaches, limiting their pupils' progress, leading to a perception that they are less good teachers than their peers in other subjects?

That there is a link between positivism and lack of reflectivity is a conjecture I explore. There is some support for the suggestion that science PSTs are reluctant to reflect (Corrigan, 2009), and that they have difficulty writing higher-level reflections that are evaluative and interpretive, rather than descriptive (McFadden et al., 2014). There is also research interest in methods to support science PSTs in becoming more reflective (e.g. Barth-Cohen et al., 2018), suggesting that others perceive this to be a development need.

My research questions (RQ) are:

- To what extent are the research participants reflective?
- In what ways are they more reflective, and in what ways are they less reflective?

  Science education literature suggests that science teachers may teach by transmission methods, and that this might limit pupils' progress. This issue can be linked to the dimensions of reflective practice, and I explore the extent to which it was demonstrated by the research participants. A sub-question (SQ) is:

- To what extent are participants wed to transmission modes of teaching?
  Emerging from the data was the fact that participants made little reference to material they were taught in the university-based part of the programme. Another SQ is therefore:
- To what extent are participants linking theory with their practice?

Intervention

I carried out an intervention with a group of science PSTs. Table 3 gives an overview of the research participants' backgrounds:

I combined Tripp's *diagnostic teaching cycle* (DTC; Tripp, 2011) and *AL* (Bayley, 2015) to support development of PSTs' reflectivity. These approaches encouraged trainees to reflect independently and collaboratively.

The intervention took place in the university at four points — October, December, January, and April. PSTs kept reflective journals whilst on teaching placement — considered to be 'foundational' in science teacher education courses (Nichols et al., 1997, p. 178). In October, December, and January, PSTs analysed selected teaching issues from their journals in a seminar. Tripp (2011) considers these issues to become critical incidents through a process of written analysis. The aim is to describe what happened, to understand why it happened, and to develop a more general view of what the incident means. To

Table 3 Overview of the participants

Pseudonym	Science specialism	Relevant prior experience
CM	Physics with mathematics	Career changer Engineering STEM Ambassador
Connor	Biology	New graduate Educated overseas prior to ecology degree Undergraduate science communication module
Dean	Chemistry	Recent graduate Biochemistry Secondary science technician; scout leader
Emily	Biology	New graduate Zoology Voluntary projects overseas
Kathryn	Chemistry	Career changer from retail Mature student for chemistry degree Outreach in schools
Paul	Chemistry	New graduate Chemistry US summer camp counsellor
Rachael	Physics	Career changer Combined science degree; physics subject knowledge enhancement course Secondary teaching assistant
Zoe	Biology	Recent graduate Molecular biology and genetics Worked in a special school

facilitate analysis, I introduced PSTs to some of Tripp's analytical approaches, summarised in Table 4.

Where Tripp's discussions of incidents happened in action enquiry groups, I adopted AL sets of four to eight people. A protocol is shown in Fig. 2.

This was a pragmatic decision, since the course had piloted AL with PSTs during AY2015–2016, following a lecture and workshop at its conference for school-based mentors in AY2014–2015 (Bayley, 2015). However, Aubusson et al. (2009) trialled AL extensively in Australia, suggesting it has theoretical underpinning, and in science education research, Baird et al. (1987) point to collaborative reflection supporting science teacher learning.

PSTs then wrote action plans, describing how they would address their teaching issue — identifying their area for development, success criteria, actions, support arrangements, and monitoring (intended to provide feedback). I suggested a range of material to provide evidence of progress, including samples of pupils' work, lesson evaluations, field notes on lesson plans, and notes of mentor meetings.

Figure 3 summarises the process. Two full cycles took place during the research.

My data collection tools fall into two categories — observation-based research and documentary methods. The observations were audio recordings of AL sets. I also used both extant and elicited documents. Extant documents were:

- Students' application forms for the course
- Teaching reviews and reports of their progress, written by participants' mentors
  Elicited documents were:
- Reflective journals
- Critical incident analyses
- Action plans
- Reviews of action plans

Analytical Framework

I used *the nine dimensions of reflective practice* (Zwozdiak-Myers, 2009, 2012) as an analytical lens through which to judge participants' reflectivity, omitting Dimension 9 *Continue to improve your teaching* because it relates to continuing professional development, beyond ITE.

I carried out content analysis using the dimensions, assigning each trainee a score on a 3-point scale:

1 Not seen/very little evidence
2 Some evidence
3 Considerable evidence

How scores were assigned is described briefly in the final column of Table 2. (See Gourlay, 2019a for further details.)

The dimensions most relevant to the RQs addressed in this paper are *Dimensions 3 Link theory with your own practice* and *6 Try out new strategies and ideas*, and hence I elaborate on how I interpreted them. *Dimension 3* is relevant because the data suggest that participants made little reference to what they learned in university. Teacher educators

Table 4 Approaches to critical incident analysis (Tripp, 2011)

Approach	Sub-approach	Description
Thinking strategies	Positive, negative, interesting	Clarifying what we like or dislike
	Alternatives	What else might have happened? How could we have made that happen?
	Other points of view	Look at the incident from someone else's point of view, e.g. a student
	Parts and qualities	'Because teaching is a social practice, we must examine our attitudes, values and judgments and work on those too.' (Tripp, 2011:45)
	Reversal	Look at it from the opposite point of view
	Omissions	What did we leave out?
The why? challenge		Socratic questioning, e.g. 'why might the pupil have refused to do his/her work?'
Dilemma identification		'…the schooling process contains a number of major contradictions' (Tripp, 2011, p. 49) Identify dilemma and work out how best to resolve it
Personal theory analysis		On what assumptions are our professional judgments based?

Fig. 2 Exemplar protocol for an action learning set

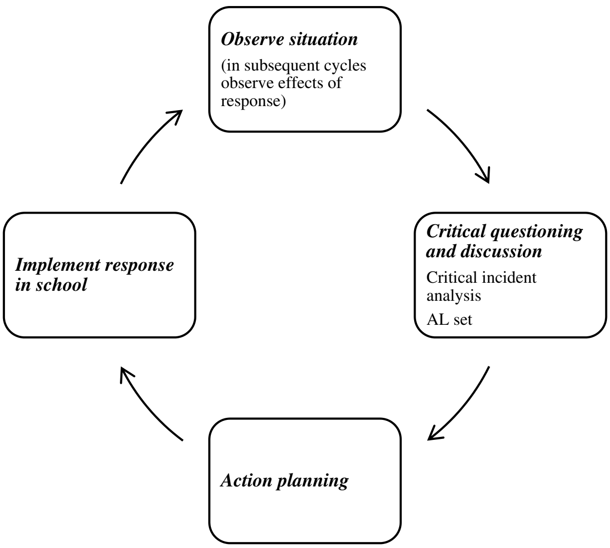
1. Think of an issue which you have faced related to teaching practice.
2. One by one outline your issue to the rest of the group. The group then chooses one person's issue that they would like to explore further. This person becomes the presenter.
3. The group then decides upon a facilitator who will control the timing and running of the process and help agree a contract between the group.
4. The process begins by the presenter presenting their issue in greater depth.
5. Next, the facilitator will allow the rest of the group to begin one by one asking open questions to encourage the presenter to explore and reflect upon their chosen issue further.
6. The facilitator ends the questioning and asks the presenter to reflect on the conclusions they have made and actions that they plan to take to move on with the issue in light of the process.
7. The whole group will then review the process. What did we do? How did we do? What did we learn?

will find this interesting as we may need to consider how to encourage PSTs to apply their knowledge. *Dimension 6* addresses the teaching strategies participants used. This is of interest to science teacher educators because it relates directly and specifically to teaching science, rather than more general aspects of pedagogy.

Dimension 3: Link Theory with Your Own Practice

Zwozdiak-Myers (2012, p. 67) distinguishes between 'espoused theories' and 'theories-in-use'. Espoused theories are those based on formal theories of education, or research

Fig. 3 Action learning combined with the diagnostic teaching cycle



informed practices. Theories in use are personal theories of practice — incorporating 'those patterns of behaviour, learned and developed in the day-to-day work of the professional'.

I began analysis by seeking examples of named theorists, or evidence of application of ideas taught in the university-based programme. It quickly became apparent that participants made little reference to these elements. Thus, I sought examples of participants developing personal theories. I coded these in terms of Korthagen and Lagerwerf's model of three levels of teachers' professional learning (Korthagen & Lagerwerf, 2001): Gestalt; schematicization, and theory.

At the gestalt level, teachers' actions are informed by internal entities (gestalts), and not necessarily by rational thought. Most PSTs went to school themselves, and may unconsciously teach by methods based on their own experiences of being taught. Influences of their role models will be one form of gestalt, along with their own needs, concerns, preferences, and values. The process of schematization is one in which the teacher gains sufficient appropriate experience to enable them to adjust their original gestalt. As a result, 'the person develops a mental framework of concepts and relations between these concepts' (Korthagen & Lagerwerf, 2001, p. 181). At the theory level, the teacher is conscious of an underpinning explanatory model, and the elements of their schema are logically self-consistent.

Dimension 6: Try Out New Strategies and Ideas

Zwozdiak-Myers (2012) envisages this dimension involving developing a wider range of teaching strategies. She gives examples of appropriate approaches for PSTs, including:

- Adopting teaching strategies that actively engage pupils
- Modelling ways of thinking about, or methods of accomplishing, tasks
- Skilful questioning, encouraging thinking
- Giving clear explanations
- Managing group work effectively

This list has some overlap with strategies suggested for developing pupils' understanding in science education (Brooks & Brooks 1999), including:

- Eliciting pupils' ideas and introducing cognitive conflict
- Being dialogic, built around classroom discussion and questioning
- Allowing guided discovery and enquiry, rather than solely illustrative practical work
- Responding to children's interests and understandings
- Fostering higher-order thinking, not recall alone

In coding, I looked for examples of participants recounting the use of different teaching approaches. These included approaches which actively engage pupils, such as demonstrating to pupils, using strategies for obtaining feedback, deploying science practical work, and applying generic uses of ICT (such as research and presentation). Where it was not clear what approaches had been deployed in participants' teaching, I gave lower scores, with higher scores where there was more evidence of using a range of named approaches.

Table 5 Scores for each participant in each dimension

Participant	Score for each dimension (Dim.)							
	Dim. 1	Dim. 2	Dim. 3	Dim. 4	Dim. 5	Dim. 6	Dim. 7	Dim. 8
CM	2	2	1	1	2	3	3	2
Connor	2	1	2	2	3	3	2	2
Dean	3	1	3	3	2	3	1	3
Emily	2	1	1	1	2	2	2	2
Kathryn	2	1	1	1	1	2	3	2
Paul	2	1	2	1	2	1	2	1
Rachael	3	1	2	1	3	3	3	2
Zoe	3	1	3	3	2	3	2	1
Mean score	2.6	1.1	1.9	1.6	2.1	2.5	2.2	1.9

Findings

Table 5 summarises scores for each participant in each dimension, and Fig. 4 shows them as a bubble plot — larger bubbles indicating greater reflectivity. This representation is somewhat impressionistic, but it indicates the degree to which different dimensions were seen.

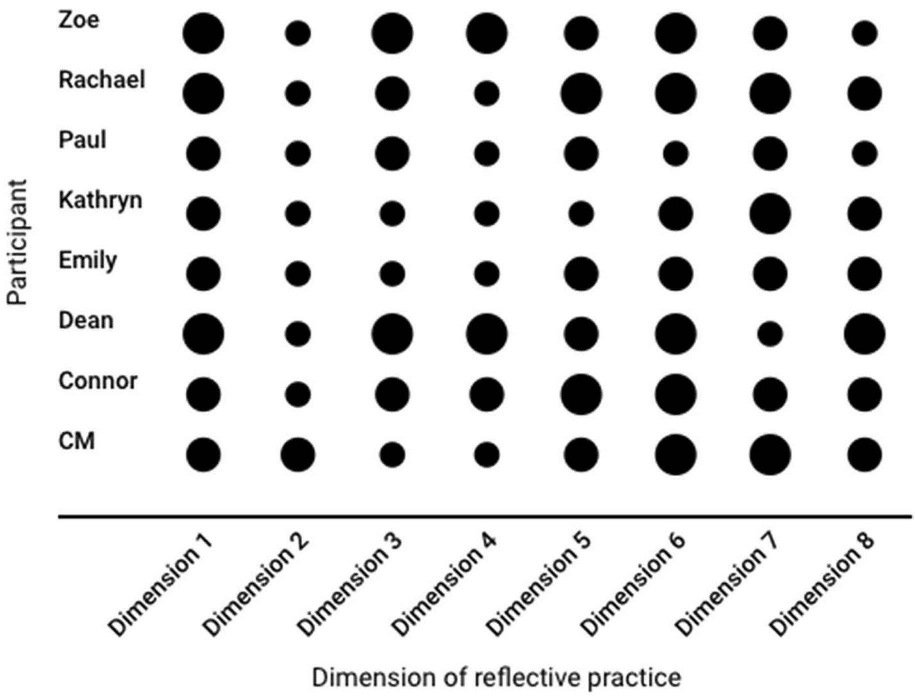


Fig. 4 Bubble plot representing participants' reflectivity

Dimensions 1 Study your own teaching for personal development and 6 Try out new strategies and ideas were a relative strength, and Dimensions 2 Systematically evaluate your own teaching through classroom research procedures, 3 Linking Theory with Practice, 4 Question your personal theories and beliefs, and 8 Enhance the quality of your own teaching were relative weaknesses. I consider Dimensions 6 and 3 to be of greatest relevance to the RQs and hence I present some of the data in greater detail. Dimension 6 data relates to the question of whether science PSTs are unreflective positivists who teach by transmission. Dimension 3 data is concerning because it suggests the course was ineffective in supporting trainees to link theory with practice.

Dimension 6 Try Out New Strategies and Ideas

There was evidence that all participants adopted active teaching approaches, but it was not always clear what this entailed. For example, Paul's mentor wrote only that 'Paul has found different strategies to engage the pupils', which explains, in part, his lower score for this dimension. Dean, who scored higher, recounted strategies in greater detail, for example when teaching bonding:

> They [the pupils] were doing dot and cross diagrams, so when you start off you can put them onto cupcakes — you can use the little silver, like, sweet ball things that you put on cupcakes. You can make a carbon atom, and oxygen atom and things like that. It's actually kind of fun with all the rings, but when it comes to ionic bonding, covalent bonding, the occasional one you can do is marshmallows-cocktail sticks.

He also tried role-play with pupils representing atoms or ions.

Most participants implemented practical work. Zoe was concerned about year 8 (age 12–13) pupils wandering during practical work, and not completing work. Dean recounted a health and safety issue during practical work on halides with a challenging year 11 group (age 15–16), and Rachael was unhappy with her set-up for year 8 investigating speed of toy cars. Connor was concerned about organising practical work in a group where students had fallen out, and another class had done dissection. Kathryn used a circus of experiments with year 7 (age 11–12), and Emily described a year 8 investigation of the effect of temperature on dough rising.

Most participants used ICT. Connor, Emily, and Kathryn carried out internet research projects. Dean, Rachael, and CM used software tools (Kahoot! or Plickers) for classroom quizzes.

Participants found some topics harder to teach, particularly where practical work was not available, or where topics were not intrinsically interesting to pupils. Examples included atomic structure (CM), electron configuration in the atom (Kathryn), and bonding (Dean). In these circumstances, CM described the topic as 'lecture-based', suggesting he taught by transmission.

Dimension 3 Linking Theory with Practice

In the first analysis, participants made almost no reference to espoused theories, whether this was named theories or researchers, or research informed practices. (See Gourlay, 2019a, Appendices H and I for examples of topics taught in the university.)

Firstly, the only reference to a named theorist came in Rachael's January AL set. Her issue was that a tutor's feedback on an observed lesson was that her 'questions weren't very good'. She responded:

> I'm trying to put more questions into my lesson plans, so I have actually got questions written down. I've found Bloom's taxonomy, sort of, sheets that have prompts to make me think a bit wider. (Gourlay, 2019b, p.18.)

Secondly, only three other examples suggested participants implicitly understood material taught in the university. In January, Dean's issue was a quiet class, where no one answered oral questions.

> There was no way of me telling where they are and if they understand during this lesson because there was no interaction at all.

This suggested he understood an aspect of AfL — that he should use assessment to inform his teaching (Black et al., 2004). Similarly, Zoe noted that she collected a lot of assessment data but was unsure how to use it to guide future lessons. The university programme included several sessions about aspects of formative assessment.

In January, Emily's issue was 'I need to always link the 'point' of the practical back to the wider scheme of things', adding:

> With year 8, an experiment into the influence of temperature on the rise of dough was carried out – but I needed to place more conscious emphasis on WHY we did this… relating back to conditions microbes need to grow.

Perhaps Emily showed awareness of Abrahams and Millar's (2008) model for judging effectiveness of practical work, which was taught in a science education seminar in the university.

However, some participants were able to articulate theories-in-use. Data from the December AL set exemplify the balance between schema and gestalts. Connor's issue was a pupil whom he sent out of class for passively refusing to work. This incident may have triggered a gestalt for Connor because he felt bad about sending the pupil out. The group's assumption appeared to be that it would be better to keep the pupil in class, although they did not articulate this explicitly, nor explain why that might be important, and hence were not at the level of schema. The discussion revealed that Connor would have felt more comfortable sending the pupil out had he been aggressive, but he was not.

Dean gave Connor some advice about resolving teacher–pupil conflict, which Connor appeared to draw upon, concluding:

> I liked your [Dean's] idea about the kind of taking him outside bit. I think that would be quite helpful because when I've spoken with him, particularly one on one, because he's quite smart and he likes to learn, it's usually gone quite well. But normally when he's like, around other kids, he sort of like wants to show off and you know, show that he's smart.

I suggest Connor was working at the level of schema here. The idea is that you might have greater success talking to a pupil about their behaviour outside the classroom because if you do it in the classroom, they might be more inclined to show off in front of their peers.

Of all the participants, Dean came closest to articulating a theory. This was observed in his advice to Connor about the pupil refusing to work:

> So you give them a chance. So you go 'Right, okay' So you get up to your C2 [second warning]. You give them a chance. You go, right, you then go, and this is where you're taking them out of the room. And then that way they're less likely to get defensive because that way you're not doing it in front of their friends. You've got a little bit of an extra step. By taking them outside you've got rid of that flight or fight moment that they're having with you because you've put them into a situation where you've gone 'You're doing something wrong' and that person's gone 'no I'm not' and then locked themselves down.

I suggest that Dean has at least a schema about how to approach teacher–pupil confrontation. Perhaps it is moving towards being a theory because he refers to the fight-or-flight response, which has a basis in psychology — an idea that could reasonably apply to a range of situations.

Conclusions

Malthouse and Roffey-Barentsen (2014, p. 179) ask 'Are science teachers immune to reflective practice?', implying that they are. In this study, I have added to the literature by researching my own practice — trying out an intervention designed to support science PSTs' reflectivity. My initial RQs were:

- To what extent are the research participants reflective?
- In what ways are they more reflective, and in what ways are they less reflective?

My findings are, to some extent, at odds with Malthouse and Roffey-Barentsen's suggestion. Some participants were more reflective than others — Dean being most reflective and Paul the least, and participants were more reflective in some ways than in others.

Additionally, it was suggested that a lack of reflectivity is related to positivistic thinking, where, for example, Loughran (2007) links positivism with teaching by transmission. The literature further suggests that science teachers may teach by transmission methods, and that this might limit pupils' progress. I hypothesised that this might account for science PSTs doing less well on their courses. A sub-question (SQ) was:

To what extent are participants wed to transmission modes of teaching?

Data for *Dimension 6 Try out new strategies and ideas* revealed that participants used a range of active teaching approaches, including practical work, ICT, and role-play. Whilst there was room for development in terms of promoting discussion and cognitive conflict (Brooks & Brooks 1999), participants did not generally conform to the stereotype of 'science teaching as telling' (Loughran 2007, p. 1043), and were therefore not necessarily locked in positivism. In this sense, participants were seen to be reasonably reflective, and hence a lack of reflectivity might not account for their less good course outcomes in comparison with their peers.

Initial analysis revealed that participants made little reference to material they were taught in the university. Another SQ was:

To what extent are participants linking theory with their practice?

Dimension 3 Linking theory with practice was a weakness. There was little evidence of participants referring directly or indirectly to espoused theories. Nor was there much evidence of developing personal theories of practice. Perhaps this lack of linking of theory with practice accounts for science PSTs' difficulty in learning to teach.

Discussion

Malthouse and Roffey-Barentsen (2014, p. 166) go as far as saying that science PSTs ‘don’t see the point of reflective practice’. However, I suggest that participants became more appreciative of reflection during the year. In December and January, participants expressed a preference for obtaining concrete advice — an attitude summed up by Paul:

> My criticism of the process [of reflecting in the AL set] is there’s not much opportunity for providing suggestions, because I think the way you solve a problem in your classroom is you try lots of different things and then when something works you stick with that, and if it stops working you try something else. It’s good asking the questions and getting them to reflect themselves on it, but I felt that it’s getting all of these ideas from people you know and then trialling them. (Gourlay, 2019b, p.19.)

Zoe appeared to agree — ‘I just want that bank of ideas’ (January AL set). Perhaps, at that stage, participants were seeking the right answer as to how to teach — which might suggest a positivistic mindset — and were learning to teach by trial and error.

Four participants took part in the April AL set. I would argue that they were all quite positive about reflection by that point, but perhaps they were a self-selecting group. Paul, for example, commented:

> I think it is quite useful, the open non-leading questions, as long as the purpose of those is to try and make you think about it deeper, or in a way you haven’t, potentially, thought about it — without trying to lead them to what your own, kind of, preconception of what the answer should be. It is a difficult thing to do, but I think when you do do it, it is quite effective.

I note that in some of the earlier AL sets, participants tended to ask closed questions, suggesting a particular course of action, such as ‘Have you given any detentions?’.

Perhaps science PSTs are not unreflective, but rather become increasingly reflective as their courses progress. Lotter and Miller (2017), for example, also suggest that PSTs develop greater criticality in their reflections as they gain greater experience.

I found the weakness in linking theory with practice, which included the lack of reference to material taught in the university, concerning. I agree with Osborne and Dillon (2010) that there is a substantive body of knowledge about science education that could usefully inform teachers’ practices. Even where Rachael mentioned Bloom’s taxonomy, it was some months after the material was taught and could have been inspired by conversations with school-based colleagues — since it is commonly used in schools. This observation has implications for teacher educators. Perhaps if we were to modify courses to better support linking of theory with practice, science PSTs would make better progress in learning to teach.

Limitations

Firstly, it was only possible to collect data until April. It would have been preferable to continue at least through participants’ first year of employment. This would help to strengthen or challenge the suggestion that science PSTs become more open to reflection as they gain experience, as well as facilitating inclusion of *Dimension 9 Continue to improve your teaching*.

The validity and reliability of my conclusions rest on the transparency of my data analysis and sharing with critical readers (supervisors). Inter-coder reliability could be enhanced by having a number of researchers repeating the data analysis to see whether they assess reflectivity in the same way.

Additionally, a more direct investigation of PSTs' epistemological and ontological beliefs would add greater weight to questions of whether positivism affects their reflectivity. Including non-scientists in the intervention would further illuminate the question of whether science PSTs are less reflective than their peers.

Given the small number of participants, it may not be appropriate to generalise.

Implications

Participants were not unreflective, but there may be a mismatch between the demand for reflectivity and their readiness. Perhaps RP is not a realistic approach for the early development of science PSTs. Instead, science teacher educators might adopt a staged approach, so how might we do this?

When participants first started teaching, they wanted more concrete guidance. It would be reasonable for tutors and mentors to provide this guidance, since much material about how to teach particular science topics already exists. This activity could incorporate simple reflection (Atkinson, 2004), with PSTs evaluating the suggested approaches.

The fact that participants made little reference to course material suggests that an up-front block is not helpful. Perhaps taught sessions could be more closely interleaved with teaching lessons, giving PSTs immediate opportunities to apply theoretical ideas.

The systematic reflection and enquiry in AL could be introduced later. To bridge the gap between theory and practice, I suggest extending action planning. PSTs could research strategies to overcome their teaching issue, including:

- Library (and online) searches for relevant research and professional publications
- Consulting their tutors, mentors, other teachers, and peers
- Referring to published (or online) materials for teaching, e.g. to research different teaching strategies to teach particular science concepts

Thus, relevant theory could be introduced when needed, potentially increasing the likelihood of application. This would meet two conditions for science teacher development noted by Bell and Gilbert (1996, p. 34) — the teacher's awareness of their developmental needs and their need for 'input of new theoretical ideas and new teaching suggestions'. This activity could be coupled with more time planning methods of assessing the impact of their action (noting that *Dimension 2 Systematically evaluate your own teaching through classroom research procedures* was also a weakness). More systematic data collection could provide higher-quality feedback to PSTs about their teaching, potentially accelerating their development compared to the trial and error approach.

Table 6 Percentage of PSTs awarded QTS nationally

Subject	All secondary subjects ($n=13{,}789$)	English ($n=2263$)	History ($n=785$)	Modern and ancient languages ($n=1596$)	Physical education ($n=1088$)	All sciences ($n=2474$)	Physics ($n=652$)
% awarded QTS	91	94	94	92	98	87	81

I have included a selection of subjects similar to Table 1. n is the total number of PSTs who started the course

Appendix

National data showing postgraduate qualified teacher status awarded 2013–2014 academic year (Department for Education, 2015, p. 8).

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Data availability A database of the written material may be inspected by readers upon request.

Declarations

Ethics Approval Obtained from School of Education and Lifelong Learning, University of East Anglia, NR4 7TJ, UK.

Consent to Participate Research participants gave informed consent as part of the ethical approval process.

Consent to Publish Research participants gave consent to publish as part of the ethical approval process.

Conflict of Interest The author declares no competing interests.

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