Pre-service science teachers' Science Teaching Orientations and Beliefs about Science

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High-quality teachers are regarded as the single most important factor in driving educational achievement (Hattie, 2012). The European Commission (Education Audio-visual and Culture Executive Agency [EACEA], 2012) identify a lack of qualified teachers in mathematics, science, and language of instruction in many schools across Europe as a major contribution to variation in performance in international assessments such as PISA (Organisation for Economic Co-operation and Development, OECD, 2014). Successive reports (EACEA, 2011; 2012) imply this overrides factors such as: ranking science education improvements high on political agendas (2011); maintaining funding levels for education, including through the recent recession (2012); and providing infrastructures of initiatives including school partnerships, science centres, and teacher professional development (2011). These reports suggest education systems do not produce high-quality teachers consistently or in sufficient numbers. The current fashion for widening access to teaching via school-based, alternative certification routes over or alongside reduced-scale, university-based teacher education (e.g. Department for Education, DfE, 2010) is unlikely to improve this situation (Ball & Forzani, 2010). Darling-Hammond (2010) points out that teacher education programs vary in quality. In the UK, for example, only 20% of initial teacher education courses receive the top “outstanding” grade from the national inspectorate (Office for Standards in Education, Ofsted, 2013). Teachers must be educated effectively in order to become capable of promoting student achievement. Science teacher education research should contribute by defining issues and bringing clarity to practice and methodology.

Pedagogical content knowledge (PCK, Shulman, 1986b) offers a potential contribution to developing high-quality (science) teacher education (Coe, Aloisi, Higgins & Major, 2014). However, PCK research frequently adopts theoretical, not evidence-based positions, and so is prone to individual researchers’ interpretations. Barnett (2003) points out that “what counts as PCK is often defined by the researchers rather than emanating from the definitions of the teachers” (p. 617). Consequently, PCK lacks significant impact on teacher education practices. Settlage (2013) notes persistent “unsteadiness” surrounding PCK, contributing to its absence from the US K-12 Science Education Framework (National Research Council [NRC], 2011). Consensus on PCK’s components and development mechanisms awaits (Author, 2009) nearly thirty years since Shulman’s (1986a) proposals were made.

Friedrichsen, van Driel and Abell (2011) highlight science teaching orientations (STOs) as a PCK component that requires specific attention. Magnusson, Krajcik and Borko define a *science teaching orientation* as: “knowledge and beliefs about the purposes and goals for teaching science to specific age groups” (1999, p. 97). Magnusson et al.. note an orientation is a “general way of viewing or conceptualising science teaching” (p. 97). These and other authors consider orientations as a central component of PCK directing how teachers teach. Knowing more about orientations may improve understanding of how to develop high-quality teachers and PCK as a construct. Accordingly, Friedrichsen et al. (2011) call for “empirical studies to determine which distinctive different science teaching orientations exist in practice” (p. 372). These authors propose that STOs comprise three dimensions: beliefs about the goals and purposes of science teaching; the nature of science; and learning and teaching science. This study explores the latter two, providing empirical data to test Friedrichsen et al.’s (2011) proposal that STOs include beliefs about learning and teaching science *and* the nature of science. Outcomes help clarify this proposed PCK component, contributing to an evidence-based PCK model.

Methodologically, researchers to date have investigated beliefs about science and STOs separately. This paper presents an independent contribution, providing data on both, obtained simultaneously from one large sample of PSTs at the start of their teacher education.

Theoretical Background

Shulman (1986a; 1986b; 1987) conceptualised PCK as knowledge that distinguishes a teacher from someone with solely academic understanding about a subject. Re-workings of Shulman's original proposals have generated many PCK models (Lee & Luft, 2008; Author, 2009) including the Magnusson, Krajcik and Borko (1999) model ("the Magnusson model"), popular among science teacher educators (e.g., Friedrichsen, Abell, Pareja, Brown, Lankford & Volkmann, 2009; Schwartz & Gwekwerere, 2007; Park & Oliver, 2008; Avraamidou, 2013). The Magnusson model is a theoretical compilation drawn from research and curriculum projects. The model comprises five components: Orientation to Teaching Science; Knowledge of Assessment of Scientific Literacy; Knowledge of Instructional Strategies; Knowledge of Students' Understanding of Science; and Knowledge of Science Curricula. Orientation to Teaching Science (STO) lies at the apex, implying this component impacts teaching most. Magnusson et al.. proposed nine STOs (1999, p. 100-101; Table 1) reviewed below. Magnusson et al..'s definition proposes STOs comprise knowledge and beliefs and determine teachers' classroom actions (Borko & Puttnam, 1996). The nature of "knowledge and beliefs" in this context requires consideration. McComas, Clough and Almazroa (1998) note science teachers are responsible for providing an "accurate description of the function, processes and limits of science" (p. 6), arguing knowledge of the nature of science (NOS) helps students learn science content (p. 11). Probing teachers' beliefs about science and their science teaching orientations would seem useful to determine the extent of any intersection in determining teachers' practices. Investigation of teachers' beliefs about science *and* their science teaching orientations simultaneously was identified by Friedrichsen et al.. (2011) as an example of multi-angle research needed to categorise and define science teacher orientations clearly.

PSTs' Orientations, Beliefs and Knowledge

The terminology used in Magnusson et al.'s (1999) STO definition may contribute to researchers using orientations, knowledge, and beliefs as synonyms and/or separate terms. To clarify the nature of STOs, investigating if this is justified would seem valuable. From a theoretical perspective, Nespor (1987) uses four criteria to separate beliefs from knowledge. These are: existential presumption, alternativity, affective and evaluative loading, and episodic structure. Existential presumptions are personal truths, such as beliefs in gods or aliens, based on chance or intense experience. Alternativity means creating fantasy worlds without direct experience. Teachers may generate imaginary environments to prompt children's learning. The fantasy defines the learning goal, but is not knowledge. Affective loading describes a teacher applying personal preferences to decide how long to teach a topic. Evaluative loading describes beliefs such as "Year 9 students are always difficult to teach last lesson on a Friday," or "girls do not enjoy advanced physics." Beliefs have stronger affective and evaluative loading than knowledge. Nespor (1987) argues that affective and cognitive aspects of beliefs operate independently, but both influence learning. Episodic memory acts as a mental depository of past experiences that can impact on the present. Episodic memories may lead a teacher replicating teaching received as a child or utilising external experiences, such as working as a research scientist.

Nespor (1987) also distinguishes between belief and knowledge *systems*. Belief systems are non-consensual: variability leads to teachers with common knowledge about a science topic teaching it differently. As beliefs are non-consensual, there is no organised means of prompting change. Changing beliefs requires a shift in thinking, not "just" an accumulation of further evidence. Contrastingly, knowledge is learned and held according to established procedures, resulting in consensus about how and what adjustments to make. Thus, while knowledge accumulates and adjusts systematically, beliefs are fixed, personal, and resist alteration. Further, beliefs are "un-bounded," lacking "clear logical rules for determining the relevance of beliefs to real-world events and situations" (p. 322). Hence, people choose and apply beliefs freely (subject to societal laws and mores). Knowledge systems are bound by structures and rules governing rejection and acceptance of information, and the quality of evidence by which such judgements are made.

Are "science teaching orientations" Knowledge and /or Beliefs?

Applying Nespor's (1987) criteria to the Magnusson model STOs (Table 1) suggests initially that curriculum-centred orientations (Table 1) correspond more to knowledge than beliefs. Curriculum knowledge represents procedures establishing how science "should" be taught. Changes occur systematically. Thus, a curriculum is unlikely to be an existential presumption. Curricula generally do not promote fantasy worlds, failing to satisfy Nespor's (1987) alternativity criterion. Affective and evaluative loading affect curriculum implementation, but not contents. Episodic memory applies weakly to curriculum materials, as these reflect societal trends, independent of teachers' past experiences. Changing from one curriculum to another involves adjusting and accommodating knowledge into a new style of delivery.

The four research-derived orientations (Table 1) meet Nespor's (1987) belief system characteristics. These are underpinned by teachers' deeply held, intuitively preferred teaching styles, meeting the existential presumption criterion. For example, a teacher may believe explaining (*Didactic*) prompts learning, also applying evaluative loading when deciding how long to spend explaining a concept. Teaching with a *Conceptual Change* orientation requires change in practice for, say, *Didactic, Discovery,* or *Activity Driven* teachers as this is unlikely to be intuitive for them. Anderson and Smith (1987) note, "most teachers must themselves undergo conceptual change in order to engage in conceptual change teaching" (p. 103). Posner, Strike, Hewson and Gerzog's (1982) conceptual change criteria are cited as a mechanism for generating change.

However, Lewis (1990) suggests knowledge and beliefs *are* synonymous. Accepting this perspective allows an STO to comprise knowledge *and* belief. Nespor's (1987) criteria can be re-applied to illustrate this for curriculum/reform-centred orientations (Table 1). A teacher may develop existential presumptions about a novel curriculum long term, as engagement leads to personal belief, this represents "the" way to teach. Also, novel curriculum projects (as distinct from national curricula adopting societal aims) may use science contexts as "fantasy" worlds, meeting Nespor's (1987) alternativity criterion. Through enactment, all curricula become subject to affective and evaluative loading. Arzi and White (2007) demonstrate that over time, curricula organise teachers' knowledge and practice. Finally, teachers' episodic memories lead to prior experience as a factor contributing to beliefs about how best to teach a topic. Curriculum changes, even if systematic, may enforce major change and *gestalt* shifts in teachers' practices. Hence, the Magnusson model curriculum/reform-based orientations could equally become examples of belief as knowledge.

Thus, given the uncertainty, inclusion of both "knowledge" and "beliefs" in an STO definition may be justifiable. To ensure science teachers are effective instructors, investigating their knowledge and beliefs and prompting change if these are contrary to achieving desirable student learning outcomes would seem reasonable. However, methodologically, lack of clarity, as Friedrichsen et al. (2011) note, contributes to researchers using STOs in different or unclear ways; an unclear or absent relationship between STOs and other PCK components; research assigning teachers to one of the Magnusson model nine STO categories propose; and/or research ignoring STOs as an over-arching component.

Literature Review

The Origins of Science Teaching Orientations

Anderson and Smith (1987) used "orientation" to describe a teacher's "general patterns of thought and behaviour" (p. 99) in research designed to promote students' achievement by focusing on learning science concepts. They describe an "orientation" as a flexible stance changeable by specific circumstance, alterable by improving teachers' knowledge of science content and students' misconceptions, and developed by understanding teaching strategies. Magnusson et al. (1999) borrow "orientation" from Anderson and Smith, but define it differently. Their definition arises from Grossman (1990), who identified variations in pre-service English literature teachers' practices calling these "purposes for teaching." Grossman regarded these as deeply engrained and exerting extensive control over a teacher's classroom practice. Magnusson et al. (1999) combined both sources, creating a meaning for "orientation" as a deeply held, personalised classroom stance impacting on a teacher's daily practice, dictating organisation of activity and teacher-student interactions. Their position shifts Grossman's empirically-based "purpose" and Anderson and Smith's (1987) view that a teacher's "orientation" is flexible and alterable.

The Nine Orientations Proposed by Magnusson, Krajcik and Borko (1999)

Origins of the Magnusson model STOs (Table 1) are reviewed. This review supplements that of Friedrichsen (2002) and Friedrichsen, van Driel and Abell (2011), who distinguish between teacher-centred and STOs based on "reform efforts and associated curriculum projects" (p. 362). This paper distinguishes between STOs first identified in research projects (Research-based) and those proposed from curriculum reforms or novel curriculum innovations (Curriculum/reform-based).

[Insert Table 1 about here]

Academic Rigour emerged from Lantz and Kass's (1987) research probing secondary chemistry teachers' interpretations of the Canadian Alberta Chemistry (ALCHEM) curriculum materials. Lantz and Kass described teachers' practices using Crocker's (1983) functional paradigms of common "beliefs, values, exemplars and routines." Magnusson et al. (1999) ignored two other functional paradigms, "Pedagogical efficiency" and "motivating students" (Lantz and Kass, 1987, p. 123), as possible "orientations" without explanation. An *Academic Rigour* orientation involves giving "detailed background materials, challenging problems and activities aimed at developing students' intellectual abilities" (Lantz & Kass, 1987 p. 123). This seems a rigorous version of Anderson and Smith's *Didactic* orientation, which is observed most frequently in teachers across all phases. Adey (2001) describes *Didactic* teaching as "I give them information, they write it down, they learn it" (p. 41). Anderson and Smith (1987) claim a didactic teacher emphasizes rote learning of factual content knowledge.

Anderson and Smith (1987) also identify *Activity Driven* and *Conceptual Change* orientations. An *Activity Driven* orientation involves carrying out activities without planning students' learning outcomes, limiting progress. The authors claim this is typical of primary teachers "uncomfortable teaching science" who lack deep understanding of how experiments and questions generate students' learning (1987, p. 99). A *Conceptual Change* orientation is characterized by awareness and diagnosis of students' naïve conceptions; challenges to students' responses; correction of thinking; and application of the scientific concept to a new phenomenon. The authors claim this leads to "superior student learning."

Discovery, *Process*, and *Inquiry* orientations arise from 1950s curriculum projects. *Discovery* and *Process* projects both train science process skills for elementary (primary) children (Adey, 2001), but with different aims. *Discovery* relates to the *Science Curriculum Improvement Study* (SCIS) (Karplus, 1964). This gave pupils "first-hand" experiences of natural phenomena via open-ended activities; identified "abstract relationships;" and offered "intellectual challenges that will stimulate further cognitive development" (p. 294). SCIS was conceptually based and sequentially organised, offering learning based on themes centred on major concepts. Anderson and Smith (1987) also noted the "*Discovery*" orientation, but described this as "teachers using activity-based programs to avoid telling their students answers, encouraging them to develop their own ideas from the results of experiments" (p. 100). The *Process* orientation emerges from the American Association for the Advancement of Science (AAAS) programme *Science: A Process Approach* (SAPA). SAPA developed children's "skills in using the processes of science" (Livermore, 1964, p. 271), through engagement with curriculum materials emphasising development of observing, inferring, predicting, communicating, and interpreting as independent and important traits separate from understanding content knowledge. Contrastingly, the *Discovery* orientation utilises application of skills in open-ended settings. The discovery/process heuristic also occurred in UK science programmes such as the *Nuffield Foundation Science Teaching Project* (1961) and *Warwick Process Science* (1980).

The Biological Sciences Curriculum Study (BSCS), which began in 1958, provides an origin for the *Inquiry* orientation. BSCS devised a teaching method (BSCS, 2006; 2008; 2010) for secondary biology that combines conceptual and investigations-based information. Schwab (1963) supported this style, stating:-

> “teaching science as enquiry would …show some of the conclusions of science in the framework of the way they arise and are tested… tell the student about the problems posed and the experiments performed…indicate the data thus found and…follow the interpretation by which these data were converted into scientific knowledge.” (p. 40)

Tamir (1983) argues inquiry clarifies “what science really is” (p. 659). He shares Anderson and Smith’s (1987) scepticism of process/discovery teaching, noting the unstructured nature of SAPA and SCIS placed science “beyond the capabilities” of some students. Tamir finds teachers confuse “science as inquiry” and “teaching science by inquiry” (p. 660). Magnusson et al.’s (1999) *Inquiry* orientation definition (Table 1) mirrors this. Inquiry-based science remains a desirable quality of school science curricula (Qualifications and Curriculum Authority [QCA], 1999; Department for Education and Science [DfES], 2004; DfE, 2013; NRC, 2011).

The *Guided Inquiry* orientation emerges from combining teaching science content *and* science process skills using investigations or an inquiry-based context. Gowin’s Vee (Novak & Gowin, 1984) is an organising heuristic. *Guided Inquiry* imitates scientific practices by team-working or using authentic context-based activities. Teachers scaffold learning while students carry out a practical experiment or a theoretical exercise. For example, students experiencing the (confusingly named) *Process-Oriented Guided Inquiry Learning* (POGIL, 2013) follow a learning cycle (explore, concept formation/ invention, application), completing activities by taking roles in teams. *Great Lakes Science* (University of Michigan, 2013) provides “real-world” data sets relating to events occurring around the Great Lakes in central North America. The Salters science projects (University of York, 2008) are UK-based examples. Authors claim this approach promotes students’ active engagement in learning.

The *Project-based* orientation derives from a National Science Foundation (NSF) funded “teacher-support” project called *LabNet* (Ruopp, Gay, Drayton & Pfister, 1993) that ran from 1989 to 1992 to develop secondary school physics teaching. LabNet adopted three principles: using projects to enhance students' science learning; building a community of practice among LabNet teachers and science researchers; and (pre-world wide web) adopting “new technology,” namely “computer-to-computer communication via telephone lines.” Projects used contexts such as “Acid Rain,” “What are we eating?,” and “Too much trash.” Ruopp et al. (1993) claim LabNet demonstrated “enormous success.” No evidence shows LabNet continued beyond the original timescale.

Thus, the Magnusson model STOs comprise curriculum innovations and (limited) findings from research evidence of teachers’ classroom practices. Some curriculum innovations are outdated (*Project-based*); have been superceded (*Guided Inquiry*); or fallen from favour (*Discovery, Process*). The “pupil as scientist” (Adey, 2001; Driver, 1983) heuristic is apparent in *Discovery, Process,* and *Guided Inquiry* orientations. Content-based teaching is represented by *Didactic* and *Academic Rigour*. Constructivist philosophies (Carey, 1985; Hewson, 1981; Duit & Treagust, 2003) are represented by *Conceptual Change*. The *Project-based* orientation emphasizes research and technology. *Inquiry* represents a trend for investigative science that remains desirable. *Activity driven* describes teaching lacking focus on students’ learning.

Science Teachers' Beliefs about Science

McComas, Clough and Almazroa (1998) review a teacher's role in communicating science, noting claims that science teachers' beliefs, knowledge, and practices represent "the bulk" of students' science instructional experiences. Accepting this and that students should know about NOS means science teachers' NOS beliefs about science may influence those of their students. PSTs studied science and may have worked as scientists, but hold varied backgrounds (Context; Table 2). Schwartz and Lederman (2008) found variation in beliefs among twenty-four practising scientists from different subjects. PSTs are therefore likely to hold varied NOS beliefs. Prior research suggests these may be usefully described as *informed*, *partially informed*, or *naïve*.

Lederman, Abd-El-Khalick, Bell and Schwartz (2002) describe *Informed* beliefs about science as features of scientific knowledge students should acquire. These include: science knowledge is empirical; observations and inference differ; scientific theories are internally consistent explanatory systems that guide research and investigations; laws represent relationships, such as "V=IR"; science relies on human imagination and creativity, and is not lifeless or always rational; science is theory-laden, consequently observations are not objective; science is a human enterprise embedded in a social culture; there is no one scientific method; and scientific knowledge is tentative.

Lederman et al. (2002) also describe *naïve* beliefs about science. These include that science: comprises facts established through empirical evidence, generating a knowledge base; searches for objective truth about the world; relies on direct observation; utilises a single (tacitly agreed) scientific method; does not require creativity and/or imagination; prompts change in theories by accumulation of evidence; enables theories to become laws by repeated testing; and is independent of social and cultural factors.

Abd-El-Khalick and Akerson's findings (2009) from an intervention study designed to impact 49 primary (elementary) teachers' beliefs about science provide a source for "*partially-informed*" NOS beliefs. These combine aspects of informed and naïve beliefs. For example, a partially-informed belief recognises science as empirical subject involving observations, making and testing predictions, but implies a simplistic mechanism for collecting data, and lacks acknowledgement that knowledge acquired is tentative. An alternative, partially-informed belief is that technological developments enable scientists to accumulate knowledge and changes to understanding occur, but omits that "old" knowledge is discarded. A third example is the belief that imagination plays a limited role in science, such as enabling a scientist to devise an experiment. This improves on the naïve position that imagination has no role to play, but falls short of the informed view.

Science Teachers' Beliefs about the Nature of Science in Practice

Teachers' beliefs about science have been studied by researchers including Lederman (1999), who followed five experienced biology teachers over one year in a multi-method study. Data indicate teachers' science beliefs were *informed*, as they believed scientific knowledge to be tentative; acknowledged the role of creativity and imagination; understood differences between observation and inference and between theories and laws; and accepted science knowledge is embedded in society and culture (p. 922). However, only two of the five taught science in a manner consistent with their beliefs and did so unintentionally. These two teachers' practices aimed to develop students' enjoyment, confidence, and abilities in science. A third teacher believed that conveying a body of basic facts was important, as other features of science were too abstract for her students to learn. Two (less experienced) teachers believed that developing secure classroom management took precedence over teaching nature of science. Thus, despite holding informed views, none explicitly taught their NOS beliefs.

Waters-Adams (2006) reports dominance of practice over beliefs among four primary (elementary) teachers. In this case, participants held naïve beliefs about science centred on science as a body of knowledge and a hypothetic-deductive rationale. Waters-Adams found that teachers wrestled with dissonance between their NOS beliefs and teaching practices, over time becoming confident in teaching science when beliefs aligned with their understandings of appropriate pedagogy. Waters-Adams notes that "a teacher is also preoccupied with his or her children's position relative to the knowledge he or she has to teach" (p. 937). He positioned NOS beliefs last in the "direction of influence" on teachers' practices, following beliefs about teaching, children, and curriculum.

The extent to which professional development may alter teachers' NOS views was investigated by Faikhamta (2013). He probed NOS views of 25 Thai in-service teachers before and after an intervention promoting NOS teaching. Coding for Magnusson et al.'s (1999) orientations, he reports that initially teachers chose instructional strategies consistent with project-based, process, discovery, and guided inquiry orientations for NOS teaching. None showed activity-driven or didactic orientations. Post-intervention, the inquiry orientation dominated. Faikhamta also discerned teachers' NOS beliefs from documentary evidence, categorising these into three levels. Pre-intervention, about 60% held *partially informed* beliefs. These included viewing science as developing students' observation and hypothesising skills; and answering questions about nature. *Informed* beliefs included acknowledging the process of knowledge generation involving empirical evidence, drawing conclusions, utilising an element of subjectivity, creativity, and embracing uncertainty in knowledge. *Naïve* beliefs included science comprising a body of knowledge and an explanation for natural phenomena. Although more teachers showed informed beliefs post-intervention, a significant proportion retained partially-informed beliefs. These data suggest that developing teachers' beliefs about NOS seems separate from enhancing their instructional strategies, a pattern consistent with Waters-Adams (2006) and Lederman (1999).

Science Teachers' Initial Beliefs about Teaching

Research evidence points to initial beliefs being hard to change. PSTs' initial STOs emerge from their primary and secondary education experiences (Brown, Friedrichsen & Abell, 2013) a feature Pajares (1992) calls "insider" beliefs. These can be limited to "telling" students information, as Brown et al.'s (2013) investigation of PCK developed by four prospective biology teachers found. This matches Magnusson et al.'s (1999) *Didactic* orientation. Participants in Brown et al.'s study persisted in sequencing instruction to prioritise didactic transmission, leading to the conclusion that their beliefs (i.e., STOs) resisted change. The authors suggest that to develop practice, teacher education must prompt dissatisfaction with "telling" and be explicit about active science teaching styles.

Schwarz and Gwekwerere (2007) also show that moving PSTs' orientations from initial positions is challenging and inconsistent. Their case study data, obtained from twenty-four pre-service elementary teachers, showed initial dominance of *Activity-driven* and *Didactic* orientations. The teachers participated in a one-semester long intervention to prompt change to *Guided Inquiry*. Overall, post-intervention, fourteen categorised themselves as holding the desired *Guided-Inquiry* orientation. Of ten remaining, two each held *Didactic* and *Activity-Driven* orientations; two were categorised as *Inquiry* and four as *Conceptual Change*. The authors imply a hierarchy of orientations, regarding *Didactic* and *Activity-Driven* negatively and "reform-oriented" orientations such as *Conceptual change*, *Inquiry* and *Guided Inquiry* as positive and desirable.

Kang (2008) also found PSTs' initial beliefs persisted following instruction. She investigated connections between PSTs' ontological and epistemological beliefs. Kang found three patterns: eleven of twenty-three PSTs retained their initial epistemological beliefs and enacted these in teaching; seven developed and enacted beliefs different from their initial ones; the remainder did not enact their beliefs. As Schwarz and Gwekwerere (2007) report, PSTs' emerging teaching practices do not necessarily reflect initial personal epistemologies and espoused teaching goals. Inconsistencies between beliefs and actions occur, and PSTs vary in their tendency to change these as they progress through teacher education.

Summary and Research Questions

Literature reviewed above illuminates theoretical and methodological issues associated with science teaching orientations and beliefs about science. The Magnusson model STOs represent possible theoretical rather than secure, evidence-based orientations. Their origins vary and data supporting their existence is insecure. Hence, the first research question this paper seeks to answer is:

- What evidence for any of the nine science teaching orientations proposed by Magnusson, Krajcik & Borko (1999) is demonstrated in written PCK statements by pre-service science teachers (PSTs)?

The nature of STOs is imprecisely defined as comprising knowledge and/or beliefs. Theoretical positions (Nespor, 1987; Lewis, 1990) provide background reasoning for this, but not resolution. Establishing if any distinction is observed in STOs held by PSTs would be helpful. Friedrichsen et al. (2011) propose that studies combining beliefs about science and STOs may resolve issues relating to STOs. Research evidence suggests graduate scientist PSTs' beliefs about science are likely to vary. The second and third research questions investigate this and examine any overlap between PSTs' STOs and beliefs about science. Thus, for the same population of PSTs answering the first research question,

- What beliefs about science do PSTs hold? and:

- To what extent do PSTs' beliefs about science align with their science teaching orientations?

Context

Data were collected from a convenience sample of 237 PSTs attending a full-time initial teacher education course, the "Postgraduate Certificate in Education" (PGCE) at a university in northern England. The PGCE qualification is available at many higher education institutions in England and Wales. Obtaining a PGCE is a popular route to gaining "Qualified Teacher Status" (Training and Development Agency for Schools, 2008) leading to employment as a teacher. Full-time PGCE programs span one academic year from September to June. Time is divided between twenty-four weeks of teaching practice in two contrasting schools and twelve weeks work in a university or college. This Science PGCE program provides initial teacher education for teaching science to 11-14s, and a "specialist" science (physics, chemistry, or biology) to 14-16s.

Potential teachers meet national entry requirements (Universities and Colleges Admissions Service, 2014), which when data were collected included holding a degree graded 2:2[1] or better (see Table 2). Some PSTs did not meet this threshold due to: strict government requirements to fill all places; faculty allocating places across all three specialist sciences; more applications from biology- than physical science-related graduates; mitigating circumstances contributing to poor academic outcomes; and outcomes of interview assessments of applicants' suitability for teaching. Thus, in admitting PSTs to the program competition for biology places and vacancies in physics were considered with requirements to fill all places, treat applicants fairly and judgments of suitability. A majority of these PSTs are regarded as academically able. PSTs' backgrounds may contribute to the quality and type of beliefs about teaching and learning science.

PSTs' scientific backgrounds decide their specialist, or "in-field" science subjects. PSTs' backgrounds are diverse. Biology teachers hold degrees in biology or related subjects including biomedical science and ecology. Those specializing in chemistry hold degrees in chemistry or related subjects such as biochemistry or geology. Some physics specialists' degrees are in physics or theoretical physics, but most hold physics-related backgrounds in subjects such as astrophysics or mechanical engineering. PSTs' backgrounds may contribute to their beliefs about the nature of science.

PSTs' Backgrounds

Table 2 shows over half are biological science graduates. This is consistent with anecdotal evidence about similar programs elsewhere.

[TABLE 2 ABOUT HERE]

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[1] UK undergraduate degrees are awarded in five grades: "First" (Equivalent to secured marks 70+ / US Grade Point Average (GPA) 4.00 /German "Outstanding" /Australian "High Distinction"); "2:1" (60-69/ GPA 3.3-3.9 /Substantially above average/ Distinction); "2:2" (50 – 59 / GPA 3.0 – 3.2 / Good average / Credit); "Third" (40-49/GPA 2.3 – 2.9 / Average / Pass); and "Ordinary" (35 – 40 / 2.0 – 2.2/ Barely meets requirements/ Fail)

Most non-biologist PSTs are chemists, creating imbalance in subject group sizes. Most PSTs are graduates aged 21-25 choosing teaching as their first career. A higher proportion of chemists are mature entrants changing career. Chemical companies located near the university enable recruitment of well-qualified, experienced chemists. More chemists, with the oldest age profile, also hold higher degrees. Degree class data show biologists have higher quality bachelor's degrees than chemists or physicists. More physicists hold low-class degrees. Relevant master degrees were in science subjects. Non-relevant master qualifications were in subjects such as law and psychiatric nursing. PSTs' ethnicity comprised 95% white British or European (Spanish, Irish, Greek) with the remainder being Asian (Indian, Pakistani, Chinese) or African (Nigerian, Ghanaian).

Methodology and Data Analysis

This is a mixed methods study (Merriam, 2002) in which data were collected from 237 PSTs between 2005 and 2007 (2005 n = 43; 2006 n = 48; 2007 n = 48) and 2009-2010 (2009 n = 44; 2010 n = 54) by written questionnaire in September each year at the start of their one-year full-time teacher education programmes (see *Context*). Background contextual data about PSTs' degrees in science, possession of higher degrees, age, gender and science teaching specialism were collected (Table 2). Data collection was timed prior to science methods, teaching instruction classes and teaching practice periods. PSTs were given one hour under examination conditions to complete the written tasks, with extra time if necessary. They were encouraged to give as full and detailed responses as possible. The author stressed there was no "right" or "wrong" answer to any question. Data were collected in accordance with the university's ethical code for research involving human subjects, which aligns with British Educational Research Association (updated, 2011) guidelines. PSTs were informed that data were collected for research purposes only; that information given was completely independent of PGCE progress assessments; participation was optional; data were not kept in formats enabling identification of individuals; and individuals would remain anonymous in any publications.

Although PSTs comprise a convenience sample, this is advantageous in that all were selected using identical, consistent procedures annually by the same faculty. A faculty member (author) engaged in data collection, then taught and was involved in PST progress assessment. Independence of data-gathering procedures from PGCE program content and assessment was guaranteed by the author. No queries or issues relating to data collection or ethics procedures have ever been raised at any time either during the data collection period or since.

The Data Collection Instrument

The vignettes (Appendix 1) probed thinking about three topics taught to 11-14 year olds in English state-funded secondary schools (DfES, 2004). Producing a new substance in a chemical reaction, electricity flow in a simple circuit and plant growth via photosynthesis were selected as characteristic of chemistry, physics, and biology respectively. Care was taken to avoid potential overlap to prevent repeat responses without PSTs' clear intent. The decision to use vignettes emerged from extensive reading of methods for probing PCK (Author, 2009). Veal's (2002) content-specific vignettes offer classroom-based scenarios that invite a range of responses. The vignettes were preceded in the questionnaire by three questions, including "What is your definition for science?" This is based on question 1 in Lederman, Abd-El-Khalick, Bell and Schwartz's (2002) *Views about the Nature of Science-Form C (VNOS-Form C)* questionnaire and so seemed suitable for gathering data about PSTs' beliefs about science.

Coding PSTs' Written Statements for Evidence of Science Teaching Orientations

Content analysis procedures (Denzin & Lincoln, 2000; Ryan & Barnard, 2000) were applied to PSTs' responses. Each was assessed for evidence of any of nine STOs (Magnusson et al. 1999, p. 100-101) using definitions in Table 1. Responses were allocated a code number from 1-9 for entry into an Excel (Microsoft Office 2010) spreadsheet. For example, a PST's response coded "1" represented a "Didactic" orientation, while 4 represented "Conceptual Change." Responses coded 0 were "Content Knowledge (CK) only." These showed no evidence of any orientation but stated scientific knowledge. Table 3 shows numbers of responses in each category. Table 4 gives exemplars. No responses corresponded to descriptors for *Project-based* and *Guided Inquiry* orientations, so zero is recorded in Table 3 and these are omitted from Table 4. "No response/uncodeable" was recorded when PSTs did not respond, or responded with no evidence of either content knowledge or an orientation. Responses were not excluded for stating incorrect content knowledge or unrealistic instructional strategies. Although responses did not show more than one orientation, on initial reading some could be coded in two or occasionally three ways. Thus, to arrive at a reliable coding scheme, repeated readings and revisions were undertaken to achieve consistency. Experienced faculty in each subject (physics, chemistry, biology) were invited to confirm coding of a 25% sample, including potentially dually code-able responses. The following description and Table 4 present the outcomes of this process.

Responses coded as consistent with *Academic Rigour* (Tables 1 and 4) described a sequence of activities for students relating to the classroom situation in the vignettes. Responses coded *Conceptual Change* also showed this feature. A consistent distinguishing quality in *Conceptual Change*-coded responses was reference to students' knowledge pre- and post-teaching (see Table 4 Line 2). *Academic Rigour* responses did not mention prior knowledge or changes in students' misconceptions, but focused on student-centred activities, with the teacher assuming *tabula rasa* (see Table 4 Line 3).

Academic Rigour and *Didactic* both involve knowledge verification. The *Didactic* orientation focuses on passive development of student learning. *Academic Rigour* emphasises connecting activities to verify concepts in ways likely to lead to students' deeper understanding (compare Table 4 Lines 1 and 3). *Didactic* responses utilise "I would explain/tell/show /demonstrate…" to *inform* students about the "real" scientific or "correct" position described in a vignette. The link to the vignette is explicit. *Academic Rigour* responses draw on additional relevant information, proposing an extended sequence that builds knowledge of featured concepts. These responses include associated or higher order concepts not mentioned in a vignette, such as energy, patterns in chemical reactions and photosynthesis. *Academic Rigour* responses focus on students' learning; the word "I" is not used.

Responses coded for evidence of an *Inquiry* orientation (Tables 1 and 4) adopted a questioning stance and included reference to students carrying out their own experiment(s).

Discovery shares the *Inquiry* orientation emphasis on student experiments, but differs in the degree of structure (compare Table 4, Lines 5 and 6). A *Discovery* orientation emphasises pupils' *self*-discovery through experimentation, with the teacher standing back (for example, the biologist's response to the biology vignette). No conceptual ideas are mentioned. An *Inquiry* orientation response focuses around a central idea or concept under teacher direction. *Inquiry* responses draw on related ideas, such as heat, energy, and photosynthesis, and/ or the concepts' abstract nature.

Two responses were consistent with a *Process* orientation (Table 4, Line 7). These included statements suggesting development of new knowledge, and implied students would undertake a confirmatory practical activity. These differ from *Inquiry* responses discussed above.

Responses coded *Activity-driven* gave generalised statements (Table 4, Line 4) about possible questions and student-focused tasks. Relevant correct content knowledge was often absent. Evidence for incorrect content knowledge was present (for example, the physics vignette response, Table 4). *CK only* responses (Table 4, Line 9) are the opposite of *Activity-driven,* showing nothing about *how* information should be presented to students.

Coding PSTs' Responses to "What is your definition for science?"

PSTs' responses to "What is your definition for 'science'?" were analysed using content analysis procedures. Twelve non-pre-determined categories (Table 5, Column 2) emerged. These were grouped into *naïve, partially informed,* and *informed* categories (Table 5, Column 1) based on descriptors in NOS literature (see above). *Naïve* beliefs (Schwartz & Lederman, 2008) are consistent with science being a fixed body of knowledge; finding an absolute "truth;" science for positive social benefits; and studying the world, or how "things are." *Informed* beliefs (also Schwartz & Lederman, 2008) indicate science knowledge as tentative, involving investigation and intellectual curiosity in order to develop rules, theories and models. *Partially-informed* beliefs recognise the role of experimental practice, implying application of a specific scientific method to acquire "objective" knowledge that adds to pre-existing information and explains phenomena/experiences. Exemplar responses are shown from PSTs in each subject specialist sub-group. "None" is used where no example was available. Percentages of the total sample giving each response type are shown in Column 3 (Table 5).

Examining Alignment between PSTs' Science Teaching Orientations and Beliefs about Science

Data were examined to investigate if PSTs' beliefs about science align with their STOs. For this analysis, orientation definitions (Table 1) were cross-matched with naïve, partially-informed, and informed belief descriptors (Table 5) producing Table 6. *Didactic* and *Academic Rigour* orientations present science as a fixed body of knowledge comprising mainly facts and concepts to be learned. This is consistent with *naïve* beliefs about science, which emphasise understanding natural phenomena and searching for objective truth about the world. *Discovery* and *Guided Inquiry* are consistent with *partially-informed* beliefs. These acknowledge science is an empirical subject, involving making and testing predictions and data collection by investigation, but do not emphasise knowledge is tentative and may be discarded. *Inquiry, Process, Conceptual Change,* and *Project-based* align more closely with *informed* beliefs. These emphasise uncertainty in knowledge, the possibility of rigorous investigation by different methods, and application of intellectual curiosity to arrive at, for example, a new explanatory theory. *Conceptual Change* specifically assumes that knowledge is tentative and subject to change and allows for the possibility of changing students' NOS beliefs towards an informed view. The *Activity-Driven* orientation definition does not match any proposed NOS belief, so is excluded from this analysis.

Data were examined to establish consistency between PSTs' STO codes and NOS beliefs. This analysis included only data from 118 PSTs who responded to all three vignettes with evidence of an orientation (see Table 3) AND answered "What is your definition for science?" as shown in Table 5. This analysis excluded PSTs giving CK-only, uncodeable or no response to one or more vignettes and/or the NOS beliefs question. These counts resulted in Table 7.

Findings

PSTs' science teaching orientations

Magnusson, Krajcik and Borko's (1999) STO definitions are sufficiently detailed and discriminating to form a reliable coding scheme for PSTs' written vignette responses (Tables 3 and 4).

[TABLE 3 ABOUT HERE]

Table 3 shows *Didactic, Academic Rigour, Conceptual Change, Inquiry,* and *Activity-Driven* STOs dominate responses to all three vignettes. Three, *Didactic, Academic Rigour,* and *Conceptual Change,* represent about two-thirds of responses. Around 79% of responses to the chemistry vignette were coded *Didactic*, *Conceptual Change,* or *Academic Rigour.* Comparison figures for biology and physics were about 60% and 58% respectively. The chemistry vignette generated these STOs most frequently among PSTs in all three subject specialist sub-groups. This suggests the chemistry concept was understood by most PSTs, who were eager to disseminate their knowledge. Conversely, the physics vignette generated the lowest proportions of these three STOs, accounting for only around 50% of chemists' and 59% of biologists' responses. The biology and physics vignettes prompted higher numbers of other STOs than the chemistry vignette: around 6% of biology responses were coded *Inquiry*; while 11% of physics vignette responses were coded *Activity-Driven* and approximately 3% *Discovery*.

Didactic alone represents about 50% of all responses (Tables 3 and 4). The *Didactic* definition (Table 1) describes an intuitive "teacher" instinct to explain, tell, or show confirmed knowledge (see examples, Table 4). Responses suggesting *questioning* and *reminding* students were also coded *Didactic,* for example:-

> "*Question* the suggestion of the ash theory more. *Ask* about the reactive components of air… *Suggest* this may be a component of the reaction. *Ask* about the burning reaction of something else they may have seen…" (Chemist, chemistry vignette)

> "*I would remind* the pupils of what an ammeter does and how a bulb works. *I would then draw* the [circuit] diagram on the board with boxes all around it. *Students would then come up and fill in* what the ammeter readings would be. Being all the same, the *students would see* this." (Biologist, physics vignette)

The *Didactic* definition is satisfied in multiple ways compared to other STOs which require fulfilment of specific qualities (Table 1). Second, the vignettes may unintentionally prompt didactic-style responses. Each presents a misconceptions-based situation inviting respondents to address students' ideas. About half of respondents excluded student knowledge statements, describing the scientific position only, thus being coded *Didactic*. They may have assumed there was no need to refer back to students' understandings. However, this shows PSTs focused on teacher content knowledge transmission, not students' perspectives. Thus, although the vignettes may be a limitation, responses are likely to reliably represent PSTs' thinking about the situations. Evidence collected from experienced teachers (currently under analysis) indicates that shifting to considering students' thinking in planning and delivering lessons takes time.

[TABLE 4 ABOUT HERE]

About 15% of all responses seemed consistent with *Conceptual Change* (about 8%) and *Academic Rigour* (7%) orientations. The frequency of these responses varied across vignettes. About 7% of biology and 8% of physics vignette responses corresponded to *Conceptual Change*, compared to 10% for the chemistry vignette. This suggests more PSTs understood and could handle students' chemistry misconceptions. Similarly, the chemistry vignette drew more *Academic Rigour*-coded responses (10%) compared to about 4% and 6% for biology and physics vignettes respectively. This indicates PSTs' familiarity with relevant additional concepts, including combustion, oxidation of metals, and symbolic representations. The biology vignette, presented last in the questionnaire, may have generated lower numbers of *Academic Rigour* responses due to respondent fatigue, as PSTs devoted less time to completing this in sufficient detail to satisfy the definition. However, Table 3 shows only five fewer PSTs gave *Academic Rigour* responses to the biology vignette compared to physics, which was presented second. Thus, numbers affected by fatigue are likely to be small.

About 5% of responses were *Activity-Driven*. Table 3 shows the physics vignette prompted more *Activity-Driven* responses (11%) than biology (1%) or chemistry (1.6%). Anderson and Smith (1987) indicate this STO may arise when a teacher possesses poor quality subject-matter knowledge: in this case, *Activity-Driven* responses occurred most frequently when biologists responded to the physics vignette (Table 4). PSTs proposed children testing the electric circuit, implying this would be sufficient to ensure understanding of constant current.

Twenty-four responses (3.4%) showed evidence of the *Inquiry* orientation, split between fourteen for biology and five each for physics and chemistry vignettes. This low overall figure is surprising, given that investigations have featured in UK school science education since the 1990s (DfES, 1989). Biology vignette *Inquiry*-coded responses cited experiments to provide firm evidence for plant growth conditions. These share a characteristic with the *Activity-Driven* responses given to the physics vignette discussed above, as PSTs propose activities to prompt children "seeing" and therefore understanding a phenomenon without a teacher-based explanation. Across the three sciences, *Inquiry*-coded responses proposed investigations of varying degrees of openness (Table 4). The biology response proposes students *raising their own* *questions*; the physics response proposes a *controlled experiment*; and chemistry response suggests *inviting the class to hypothesise*.

Two responses to the biology vignette were consistent with *Process*. No responses in over 700 were consistent with definitions for *Guided Inquiry* and *Project-Based*. Evidence supporting a *Guided Inquiry* orientation requires adaptation of contexts for investigation, and scaffolding students' learning. Teaching this way requires managing student-led investigations in contextual settings. The *Project-Based* orientation requires use of an authentic, organising question to mimic scientific practice. These orientations derive from specific curricula (Table 1).

About 18% of responses showed no orientation but described science, so were coded *Content Knowledge only*.

PSTs' Beliefs about Science

Table 5 shows exemplar responses and percentages coded as *Informed* (14.3%), *Partially Informed* (38.4%) and *Naïve* (43.5%). Data suggest that these classifications are sufficiently discriminating to code PSTs' responses reliably. The style and content of responses varied across subject-specialist sub-groups. For example, biologists tended to draw on medical or biological examples (see Table 5, "to gain positive social benefit", Biologist). Chemists and physicists focused on application of experimental method, objectivity, systematic processes, and logical thinking.

[TABLE 5 ABOUT HERE]

The most common belief, held by about one-quarter of respondents, is the *Naïve* response that science is studying or understanding "how the world works." This was expressed in slightly different ways depending on PSTs' science background. Subject-specialist PST sub-group data (not reported in Table 5) show 45% of physicists favoured this (although numbers are small), compared to around 20% of biologists and chemists. Less frequent responses include fourteen coded "body of knowledge" (Table 5, line 11) and the idealistic response that science generates positive benefits (Table 5, line 12). Around 5% in total stated science is studying "how things are." This response was given by 9% of biologists but few chemists and physicists.

About 45% of chemists compared to 40% of biologists and 23% of physicists stated a *Partially Informed* belief. The higher figures for biologists and chemists may correspond to greater involvement in open-ended experimental work compared to physicists. For example, responses coded "investigations" comprised twenty-one (16%) biologists, seven (10%) chemists and only two physicists. Similarly, a higher proportion of physicists (13%) stated "application of scientific method", compared to only 9% of chemists and 4% of biologists.

Informed responses were given by about one in seven of all PSTs, and small proportions of specialist science sub-groups. No background factors, such as possession of higher degree or age, corresponded with possession of informed beliefs.

Alignment between PSTs' Beliefs about Science and their Science Teaching Orientations

Table 6 shows theoretical alignments of PSTs' beliefs about science with STOs. Table 7 shows corresponding data.

[TABLES 6 and 7 ABOUT HERE]

Alignment patterns in Table 7 do not match those predicted in Table 6 consistently. Only five responses were coded *Inquiry*, *Process* or *Conceptual Change* from twenty PSTs stating informed beliefs. Only three vignette responses were coded *Discovery*, although 47 PSTs indicated they held partially informed beliefs. However, alignment is observed between naïve beliefs, *Didactic* and *Academic Rigour* STOs. For example, this biologist illustrates alignment between belief that "science is study of the world" and the *Didactic* STO:-

> "Science is the study of everything around us, involving biology, chemistry or physics" (Naïve, Study of the world)

> "Speak to them about the chemical reaction involved and what were the products… this would be done in a discussion with the whole class…" (Chemistry vignette, Didactic)

> "I would talk to them about the theory behind electricity and that electricity is not used up…" (Physics vignette, Didactic)

> "Talk to them about how the plant makes energy with photosynthesis and how it takes up nutrients and water from the soil…" (Biology vignette, Didactic)

Alignment also occurred between all belief categories and *Academic Rigour* / *Didactic* STOs.

Inspection of responses revealed alignments additional to those proposed in Table 6. For example, this physicist stated that science is:-

> "…the development of models that describe the Universe based on observation. They allow us to use and understand the properties of the world and make informed choices." (Informed; Rules, theories, models)

His vignette responses all proposed use of models or analogies, but met the *Didactic* definition:

> "I would use Duplo® bricks of different colours to represent the different atoms and allow the children to use them to work through the reaction on the desk with these bricks…" (Chemistry vignette, Didactic)

> "Use ping pong [table tennis] balls. A basket of ping pong balls would be the battery. Another would be the bulb. Children would be electrons and file round the room…" (Physics vignette, Didactic)

> "I would compare the plant to humans breathing and eating." (Biology vignette, Didactic)

This suggests alignment between STO and "beliefs about science" by descriptors alone is imperfect.

Discussion

The Nature of PSTs' Science Teaching Orientations

Based on this dataset, PSTs' STOs classify consistently as *Didactic*, *Academic Rigour*, *Conceptual Change*, *Inquiry,* or *Activity-Driven.* This finding is consistent with Anderson and Smith (1987) and Lantz and Kass (1987). The dominance of these STOs suggests they are representative, intuitive teacher attributes in well-qualified science graduates. Four STOs (*Process*, *Discovery*, *Guided Inquiry,* and *Project-based*) are based on curriculum projects, some out-dated. Low/zero response levels arose partly because these PSTs lacked exposure to these projects. Hence, these are not intuitive STOs for these PSTs and do not represent their proposed teaching practices. Although procedural and other reasons may contribute to this response pattern (see *Limitations*, below), all respondents had complete freedom to respond as they wished. Consistent response patterns were found in a large population of PSTs over a five-year period.

Data corroborate Anderson and Smith (1987) in finding the *Didactic* orientation dominates. The *Didactic* orientation encompasses teacher actions such as "explaining," "telling," and "showing" knowledge. As data were collected prior to engagement in a teacher education program, PSTs' statements represent cultural transmission favouring *Didactic* teaching as PSTs drew on past "insider" experiences as students and employees (Nespor, 1987; Pajares, 1992).

PSTs' Beliefs About Science

Data provide evidence that these science graduates hold mainly naïve and partially informed beliefs about science. Few hold informed beliefs. This confirms Lederman et al.'s (2002) and Abd-El-Khalick and Akerson's (2009) categorisations and, as far as the author is aware, represents a novel finding for a relatively large population of PSTs. The low level of informed beliefs is unexpected as all PSTs are qualified scientists, some with significant scientific experience. One factor may be that asking one "beliefs" question gives an incomplete picture, representing only PSTs' most instinctive thoughts. A larger proportion of the cohort may have shown beliefs characteristic of an informed view on responding to additional questions. Nevertheless, that consistent response patterns showing naïve and partially informed notions rather than sophisticated informed beliefs were obtained over five years is significant.

Alignment between PSTs' Beliefs about Science and their Orientations

Connections between STOs and epistemological beliefs were mixed. The dominant *Didactic* and *Academic Rigour* STOs seemed to override all three belief categories. Thus, where the predicted combination between naïve and these STOs occurred, connections were strong. Elsewhere, connections were limited or non-existent.

Tentatively, these data suggest PSTs' instinctive ideas about teaching and learning science more strongly influenced their responses than their beliefs about science. These PSTs' STOs are personal, intuitive proposals, separate from partially informed and informed beliefs about science. Revisiting Friedrichsen et al. (2011), these data suggest that STOs comprise notions about learning and teaching science, but are inconclusive about "beliefs about science" as a component. Further, these data imply support for Nespor's (1987) arguments, but contradict

Lewis (1990) in showing that knowledge and beliefs relating to orientations appear to be separate, not synonymous.

Implications

Defining PSTs' Science Teaching Orientations: Clarification

The study aimed to clarify the nature of STOs as a PCK component, testing aspects of Friedrichsen et al.'s (2011) proposals from PSTs' perspectives. An implication emerging is that PSTs' STOs more strongly emphasise notions about teaching and learning science than their beliefs about science. Hence, PSTs' STOs could be defined as "ideas and knowledge about learning and teaching science." STOs may vary according to teachers' experiences and expertise so will not necessarily remain constant throughout a career. However, research reviewed above suggests that changing teachers' intuitive STOs is challenging. The dominance of *Didactic* practices linked to naïve beliefs about science, may, if left unaltered, mean that achieving high-quality science teaching and learning may be problematic. Including beliefs about science in an STO definition should be withheld until confirmatory evidence justifies this. For the moment, these may be more usefully classified as aspects of a teacher's subject-matter knowledge.

A Developmental Science Teaching Orientations Continuum

A second implication is that the Magnusson model STOs are simplified to five: *Academic Rigour*, *Didactic*, *Conceptual Change*, *Inquiry,* and *Activity Driven*. The remaining four STOs, *Discovery*, *Process*, *Guided Inquiry,* and *Project-based*, should be reclassified as curriculum knowledge. These five STOs (Table 4) can be represented on a continuum (Figure 1).

[INSERT FIGURE 1 ABOUT HERE]

Activity-Driven responses are the lowest quality. An *Activity-Driven* instructional strategy does not generate student learning. One step up is the *Didactic* orientation, which promotes student learning often via teacher-centred instructional strategies. A precursor for the *Didactic* STO is possession of relevant content knowledge. The *Academic Rigour* orientation features sequenced activities and links to additional concepts. This develops the *Didactic* STO, requiring a teacher to possess deep content knowledge allied to conceptual understanding. The *Conceptual Change* and *Inquiry* orientations represent higher quality teaching. These involve taking students' prior knowledge into account and /or promoting learning via investigative techniques. Instructional strategies consistent with these STOs require teachers to adopt student-centred perspectives on their practice. The continuum may be useful to teacher educators in supporting PSTs as they progress in their practice, contributing to developing and retaining a strong student learning focus. To achieve this, teacher education programs may characterise STOs usefully in terms of teaching and learning, explicitly relating these to science concepts, scientific knowledge and aspects of the nature of science as appropriate.

Limitations

The study is exploratory and limited by the fact that PSTs attended one institution. However, data were collected over five years. Response patterns were consistent, suggesting reliability. Only one data source is utilised. Vignettes were limited, as they featured one science concept each. The open structure permitted freedom of response. Few null or uncodeable responses were obtained, implying most PSTs understood the vignettes, recognised the concepts presented, and could respond adequately in the permitted time. Only one “beliefs about science” question was posed. Corroborative data using a full “beliefs about NOS” questionnaire would be useful. Additional data from additional vignettes, observation, and/or interviews would help confirm these findings.

References

Abell, S.K. (2007). Research on Science Teacher Knowledge. In S.K. Abell, and N.G. Lederman, (Eds.), *Handbook of Research on Science Education* (1104 – 1149). New Jersey: Lawrence Erlbaum Associates Inc.

Abd-El-Khalick, F., & Akerson, V. L. (2009). The influence of metacognitive training on preservice elementary teachers' conceptions of nature of science. *International Journal of Science Education*, 31, 2161–2184.

Adey, P. (2001). 160 years of science education: an uncertain link between theory and practice. *School Science Review,* 82, 41-48.

Akerson, V. L., & Donnelly, L. A. (2008). Relationships among learner characteristics and preservice elementary teachers' views of nature of science. *Journal of Elementary Science Education,* 20(1), 45–58.

American Association for the Advancement of Science (AAAS) *Commission on Science Education (1963 – 1983). Science a Process Approach.* Retrieved from http://archives.aaas.org/aids/SAPA.php

American Association for the Advancement of Science (1990). *Science for All Americans*. New York, Oxford: Oxford University Press.

Anderson, C.W. & Smith, E.L. (1987). Teaching Science. In V. Richardson-Koehler, (Editor), *Educators' Handbook A Research Perspective* (84 – 111). London: Longman

Arzi, H., & White, R. (2007). Change in teachers' knowledge of subject matter: A 17-year longitudinal study. *Science Education,* 92(2), 221–251.

Author (2009)

Avraamidou, L. (2013). Prospective elementary teachers' science teaching orientations and experiences that impacted their development. *International Journal of Science Education,* 35 (10), 1698 – 1724.

Ball, D.L. and Forzani, F.M. (2010). What does it take to make a teacher? *The Phi Delta Kappan,* 92 (2), 8 – 12.

Barnett, J. (2003). Review of Examining Pedagogical Content Knowledge: The Construct and its Implications for Science Education, by Julie Gess-Newsome and Norman G. Lederman, 1999. Kluwer Academic: Dordrecht, Netherlands. *Science Education,* 87, 615 – 618.

Biological Sciences Curriculum Study (2006). *BSCS Science: An Inquiry Approach Level 1.*

Dubuque, Iowa: Kendall-Hunt Publishing Company.

Biological Sciences Curriculum Study (2008). *BSCS Science: An Inquiry Approach Level 2.* Dubuque, Iowa: Kendall-Hunt Publishing Company.

Biological Sciences Curriculum Study (2010). *BSCS Science: An Inquiry Approach Level 3.* Dubuque, Iowa: Kendall-Hunt Publishing Company.

Biological Sciences Curriculum Study (2013). Retrieved from http://www.bscs.org/history .

Borko, H. & Puttnam, R.T. (1996). Learning to Teach. In D.C. Berliner & R.C. Calfee, (Eds.), *Handbook of Educational Psychology* (673 – 708). New York: Simon & Schuster Macmillan

British Educational Research Association (2011). *Ethical guidelines for Educational Research.* Retrieved from http://www.bera.ac.uk/wp-content/uploads/2014/02/BERA-Ethical-Guidelines-2011.pdf

Brown, P., Friedrichsen, P. & Abell, S.K. (2013). The development of prospective secondary biology teachers' pedagogical content knowledge. *Journal of Science Teacher Education,* 24, 133 – 155.

Carey, S. (1985). *Conceptual change in childhood.* Cambridge, MA: MIT Press

Coe, R., Aloisi, C., Higgins, S.E. & Major, L.E. (2014). *What makes great teaching?* Retrieved from http://www.suttontrust.com/wp-content/uploads/2014/10/What-makes-great-teaching-FINAL-4.11.14.pdf London: The Sutton Trust

Crocker, R.K. (1983). The functional paradigms of teachers. *Canadian Journal of Education*, 8 (4), 350 – 361.

Crocker, R.K. (1984). Determinants of implementation of an elementary science program. *Journal of Research in Science Teaching,* 21 (2), 211 – 220.

Darling-Hammond, L. (2010). Teacher Education and the American Future. *Journal of Teacher Education,* 61, 35 – 47.

Denzin, N.K. & Lincoln, Y.S. (2000). *Handbook of Qualitative Research, 2nd Edition*. Thousand Oaks: Sage Publications, Inc.

Department for Education (DfE, 2010). *The importance of teaching.* London: The Stationery Office

Department for Education (DfE, 2013). *Teachers' Standards.* Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/208682/Teachers__Standards_2013.pdf

Department for Education (DfE, 2013). *Science programmes of study Key Stage 3 The National Curriculum in England.* London: The Stationery Office.

Department for Education and Science (DfES, 1989). *Science in the National Curriculum.* London: Her Majesty's Stationery Office.

Department for Education and Skills (DfES, 2004). *The National Curriculum Science*. London: The Qualifications and Curriculum Authority and Her Majesty's Stationery Office.

Driver, R. (1983). *The pupil as scientist?* Milton Keynes: Open University Press

Duit, R. & Treagust, D. F. (2003). Conceptual change: a powerful framework for improving science teaching and learning. *International Journal of Science Education*, 25 (6), 671 – 688.

Education Audio-visual Culture Executive Agency, EACEA (2011). *Science Education in Europe: National Policies, Practices and Research.* Brussels: EACEA P9 Eurydice. Retrieved from http://eacea.ec.europa.eu/education/eurydice/documents/thematic_reports/133EN.pdf

Education Audio-visual Culture Executive Agency, EACEA (2012).*Developing Key Competencies at School in Europe: Challenges and Opportunities for Policy.* Brussels: EACEA P9 Eurydice. Retrieved from http://eacea.ec.europa.eu/education/eurydice/documents/thematic_reports/145EN.pdf

Faikhamta, C. (2013). The Development of In-Service Science Teachers' Understandings of and Orientations to Teaching the Nature of Science within a PCK-Based NOS Course. *Research in Science Education,* 43, 847–869.

Friedrichsen, P. (2002). A substantive-level theory of highly-regarded secondary biology teachers' science teaching orientations. *Dissertation Abstracts International*, 63(07), 2496A (UMI No. 3060018).

Friedrichsen, P., Abell, S., Pareja, E., Brown, P., Lankford, D., & Volkmann, M. (2009). Does teaching experience matter? Examining biology teachers' prior knowledge for teaching in an alternative certification program. *Journal of Research in Science Teaching*, 46, 357 – 383.

Friedrichsen, P., van Driel, J.H. & Abell, S.K. (2011). Taking a closer look at science teaching orientations. *Science Education,* 95 (2), 358 – 376.

Grossman, P.L. (1990). *The Making of a Teacher. Teacher Knowledge and Teacher Education.* New York: Teachers College Press.

Hattie, J. (2012). *Visible Learning for teachers Maximising impact on learning*. London: Routledge.

Hewson, P. W. (1981). A conceptual change approach to learning science. *European Journal of Science Education,* 3(4), 383-96.

Kang, N.-H. (2008). Learning to teach science: personal epistemologies, teaching goals and practices of teaching. *Teaching and Teacher Education,* 24, 478 – 498.

Karplus, R. (1964). The Science Curriculum Improvement Study. *Journal of Research in Science Teaching,* 2, 293 – 303.

Lantz, O. & Kass, H. (1987). Chemistry Teachers' Functional Paradigms. *Science Education,* 71 (1), 117 – 134.

Lederman, N. G. (1992). Students' and teachers conception of the nature of science: A review of the research. *Journal of Research in Science Teaching,* 29, 331–359.

Lederman, N.G. (1999). Teachers' Understanding of the Nature of Science and Classroom Practice: Factors That Facilitate or Impede the Relationship. *Journal of Research in Science Teaching,* 36(8), 916 – 929

Lederman, N.G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R.S. (2002). Views of Nature of Science Questionnaire: Toward Valid and Meaningful Assessment of Learners' Conceptions of Nature of Science. *Journal of Research in Science Teaching,* 39 (6), 497 – 521.

Lee, E. & Luft, J.A. (2008). Experienced Secondary Science Teachers' Representation of Pedagogical Content Knowledge. *International Journal of Science Education,* 30 (10), 1343 – 1363.

Lewis, H. (1990). *A question of values.* San Francisco: Harper & Row.

Livermore, A.H. (1964). The Process Approach of the AAAS Commission on Science Education. *Journal of Research in Science Teaching,* 2, 271 – 282.

McComas, W. F., Clough, M. P., & Almazroa, H. (1998). The role and character of the nature of science in science education. In W. F. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (3–39). The Netherlands: Kluwer Academic Publishers.

Magnusson, S., Krajcik, J. & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In Gess-Newsome, J. and Lederman, N.G. (Eds.), *Examining Pedagogical Content Knowledge* (95 – 132). Dordrecht: Kluwer.

Magnusson, S. & Palincsar, A.S. (1995). Learning environments as a site of science education reform: An illustration using interdisciplinary guided inquiry. *Theory into Practice, 34,* (1) 43-50.

Marx, R. W., Blumenfeld, P. C., Krajcik, J. S., Blunk, M., Crawford, B. A., Kelly, B., et al.. (1994). Enacting project-based science: Experiences of four middle grade teachers. *Elementary School Journal, 94*(5), 517-538.

Merriam, S.B. (2002). *Qualitative Research in Practice Examples for Discussion and Analysis.* San Francisco: Jossey-Bass

National Board for Professional Teaching Standards (NBPTS, 2002). *What teachers should know and be able to do*. Retrieved from http://www.nbpts.org/sites/default/files/what_teachers_should_know.pdf

National Research Council (2011). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Washington, D.C.: National Academies Press

Nespor, J. (1987). The role of beliefs in the practice of teaching. *Journal of Curriculum Studies,* 19 (4), 317 – 328.

Novak, J.D. & Gowin, D.B. (1984). *Learning how to learn.* Cambridge: Cambridge University Press

Nuffield Foundation Science Teaching Project (1961) retrieved from http://www.nationalarchives.gov.uk/a2a/records.aspx?cat=100 - kclcacnunuffcddcnu_2&cid=0#0

Office for Standards in Education (Ofsted, 2013). *Official statistics release: Initial Teacher Education inspections and outcomes.* London: Ofsted

Organisation for Economic Co-operation and Development (OECD, 2014). *PISA 2012 Results in Focus: What students know and can do with what they know.* Paris: OECD Publishing Retrieved from http://www.oecd.org/pisa/keyfindings/pisa-2012-results-overview.pdf

Pajares, M.F. (1992). Teachers' beliefs and educational research: clearing up a messy construct. *Review of Educational Research,* 62 (3), 307 – 332.

Park, S.Y. & Oliver, J. S. (2008). Revisiting the conceptualization of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education*, 38, 261 –284.

Posner, G.J., Strike, K.A., Hewson, P.W., & Gerzog, W.A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66,* 211 – 227.

Process-Oriented Guided Inquiry Learning (POGIL, 2012-2014) retrieved June 10, 2015 from https://pogil.org/about

Qualifications and Curriculum Authority, QCA (1999). *The National Curriculum.* London: Her Majesty's Stationery Office

Ruopp, R., Gal, S., Drayton, B. & Pfister, M. (1993). *LabNet Toward a Community of Practice.* New Jersey: Lawrence Erlbaum Associates, Inc.

Ryan, G.W. & Bernard, H.R. (2000). Data management and analysis methods. In Denzin, N.K. & Lincoln, Y.S. (Eds.), *Handbook of Qualitative Research 2nd Edition* (769 – 802). Thousand Oaks: Sage Publications, Inc.

Schwab, J.J. (1963). *Biology Teachers' Handbook.* New York: Wiley

Schwarz, C.V. & Gwekwerere, V.N. (2007). Using a grounded inquiry and modeling instructional framework to support pre-service K-8 science teaching. *Science Education,* 91, 158 – 186.

Schwartz, R.S. & Lederman, N.G. (2008). What scientists say. Scientists' views of nature of science and relation to science context. *International Journal of Science Education*, 30, 727 – 771.

Settlage, J. (2013). On acknowledging PCK's shortcomings. *Journal of Science Teacher Education,* 24, 1 – 12.

Shulman, L.S. (1986a). Paradigms and research programs in the study of teaching: A contemporary perspective. In M.C. Wittrock (Ed.), *Handbook of Research on Teaching*, 3rd Edition (3 – 36). New York, Macmillan.

Shulman, L.S. (1986b). Those who understand: a conception of teacher knowledge. *American Educator,* Spring 1986, 9 – 15 and p 43.

Shulman, L.S. (1987). Knowledge and Teaching: Foundations of the new reform. *Harvard Educational Review,* 57(1), 1 – 22.

Tamir, P. (1983). Inquiry and the Science Teacher. *Science Education*, 67 (5), 657 – 672.

Training and Development Agency for Schools (2008). *Professional Standards for QualifiedTeacher Status and Requirements for Initial Teacher Training (Revised 2008).* Retrieved from http://www.rbkc.gov.uk/pdf/qts-professional-standards-2008.pdf

Universities and Colleges Admissions Service (UCAS, 2014). *Teacher training entry requirements*. Retrieved from http://www.ucas.com/how-it-all-works/teacher-training/entry-requirements

University of Michigan (2013). *Great Lakes Science*. Retrieved from http://www.miseagrant.umich.edu/lessons/teacher-tools/guided-inquiry-process/

University of York (2008). *Salters Advanced Chemistry Chemical Ideas. 3rd Edition.* Harlow: Heinemann

Veal, W.R. (2002). Content specific vignettes as tools for research and teaching. Retrieved from http://wolfweb.unr.edu/homepage/crowther/ejse/veal.pdf

Warwick Process Science (1980). Retrieved from http://www.nationalstemcentre.org.uk/elibrary/collection/1653/warwick-process-science

Waters-Adams, S. (2006). The Relationship between Understanding of the Nature of Science and Practice: The influence of teachers' beliefs about education, teaching and learning. *International Journal of Science Education*, 28 (8), 919-944.

Orientation	Definition	Curriculum reform / materials	Curriculum /reform- (C) /Research- (R) based	References	Possible teacher action: Acids and bases
Academic rigour	Provides a range of activities to verify concepts, showing links; represents science as a body of knowledge	Alberta Chemistry (ALCHEM)	R	Lantz and Kass (1987)	Shows a wide range of examples, including non-typical; links topic to other areas, e.g. ions, solutions.
Didactic	Tells, shows, explains, questions students to verify knowledge; teacher presents content knowledge and focuses on students' recall	None	R	Anderson and Smith (1987)	Describes / defines "acid" and "base"; shows examples of acids and bases; demonstrates reactions;
Activity-driven	Offers hands-on activities, may lack conceptual coherence	None	R	Anderson and Smith (1987)	Provides a range of acids and bases to test, e.g. pH, but little information. Focuses on "fun" tasks.
Conceptual change	Asks for children's views and helps establish valid claims; prompts dissatisfaction with initial thinking and/or intuitive ideas	None	R	Hewson (1981) Anderson and Smith (1987) Duit and Treagust (2003)	Probes prior understanding of acids and bases; uses this to plan activities that develop students' understanding about the topic.
Discovery	Allows children to experiment following their interests and discover scientific concepts for themselves	Science Curriculum Improvement Study Nuffield Curriculum Projects	C	Karplus (1964) Anderson and Smith (1987)	Poses conceptually-based questions such as "What makes a substance acidic?" allowing students to investigate for themselves.
Process	Science is a process creating new knowledge; help students develop scientific skills	Science: A Process Approach	C	American Association for the Advancement of Science, (1963 – 1983) Gagné (1965)	Focuses on developing skills, e.g. measuring pH using different indicators; making indicators from plants; how to carry out a titration.
Inquiry	Represents science as inquiry; instruction requires students to	Biological Sciences	C	BSCS (1958, 2006, 2008, 2010)	Offers opportunities to investigate questions such as "What kinds of

	investigate problems & assess knowledge	Curriculum Study (BSCS): An Inquiry approach		Tamir (1983)	chemicals are acids and bases?”
Guided Inquiry	Participates in investigating, scaffolds learning to achieve students’ independence; adapts genuine scientific contexts for investigation environments	Gowin’s Vee Guided Inquiry Process Process Oriented Guided Inquiry Learning (POGIL)	C	Novak and Gowin (1984) Magnusson and Palinscar (1995) University of Michigan (2013) POGIL (2012 – 2014)	Presents contexts such as “How can we make glue from an acid and a base?” Students work in groups to solve the problem with teacher support.
Project-based	Uses a driving question to organise concepts and activities; students investigate authentic problems working “as a scientist”	LabNet: Toward a Community of Practice	C	Ruopp, Gal, Drayton & Pfister (1993) Marx, Blumenfeld, Krajcik, Blunk, Crawford, et al. (1994)	Asks “How do we use acids and bases?” Promotes experiments using real-life examples

Table 1: Magnusson, Krajcik & Borko’s (1999) science teaching orientations

Background characteristic	**All PSTs N = 237**	**Biologists N = 128**	**Chemists N = 69**	**Physicists N = 40**
Male	**104 (43.9)**	45 (35.2)	31 (44.9)	27 (67.5)
Female	**133 (56.1)**	83 (64.8)	38 (55.1)	13 (32.5)
Totals (percentages of whole sample)	**237 (100.0)**	**128 (54.5)**	**69 (29.1)**	**40 (16.9)**
Age				
21 – 25	**140 (59.0)**	86 (67.2)	26 (37.7)	28 (70.0)
26 – 30	**49 (20.7)**	25 (19.5)	18 (26.0)	6 (15.0)
31 or over	**48 (20.3)**	17 (13.3)	25 (36.3)	6 (15.0)
Degree class				
1st	**26 (11.0)**	9 (7.0)	9 (13.0)	8 (20.0)
2:1	**93 (39.3)**	60 (46.9)	24 (34.8)	9 (22.5)
2:2	**84 (35.4)**	45 (35.2)	23 (33.4)	16 (40.0)
3rd or other, e.g. overseas	**34 (14.3)**	14 (10.9)	13 (18.8)	7 (17.5)
Higher degree				
None	**191 (80.6)**	105 (82.0)	49 (71.0)	37 (92.5)
PhD	**16 (6.8)**	6 (4.7)	10 (14.5)	0
Non-relevant Masters	**8 (3.4)**	5 (3.9)	2 (2.9)	1 (2.5)
Relevant Masters	**19 (8.0)**	12 (9.3)	7 (10.1)	0
Other	**3 (1.2)**	0	1 (1.4)	2 (5.0)

Figures in parentheses are percentages of n values relating to each column, except where indicated.

Table 2: PSTs' background data: gender, age, degree class, possession of higher degree

Orientation	**All responses Totals**	**Total responses to each vignette**			**Biologists' responses**			**Chemists' responses**			**Physicists' responses**		
		Biology	Physics	Chemistry	Biology	Physics	Chemistry	Biology	Physics	Chemistry	Biology	Physics	Chemistry
Academic Rigour	47 (6.6)	9 (3.8)	14 (5.9)	24 (10.1)	8 (6.3)	8 (6.3)	13 (10.2)	1	2	8 (11.6)	0	4 (10.0)	3 (7.5)
Didactic	363 (51.1)	118 (49.8)	105 (44.3)	140 (59.1)	66 (51.5)	60 (46.9)	77 (60.2)	31 (44.9)	28 (40.6)	42 (60.9)	21 (52.5)	17 (42.5)	21 (52.5)
Activity-Driven	32 (4.5)	2 (0.8)	26 (11.0)	4 (1.7)	2	18 (14.1)	3	0	4 (5.8)	0	0	4 (10.0)	1
Conceptual change	60 (8.4)	16 (6.7)	20 (8.4)	24 (10.1)	8 (6.3)	8 (6.3)	12 (9.4)	5 (7.2)	5 (7.2)	8 (11.6)	3 (7.5)	7 (17.5)	4 (10.0)
Discovery	11 (1.5)	4	7 (2.9)	0	2	2	0	1	4 (5.8)	0	1	1	0
Process	2	2	0	0	2	0	0	0	0	0	0	0	0
Inquiry	24 (3.4)	14 (5.9)	5	5	7 (5.5)	4	3	5 (7.2)	0	1	2	1	1
Guided Inquiry	0	0	0	0	0	0	0	0	0	0	0	0	0
Project-based	0	0	0	0	0	0	0	0	0	0	0	0	0
CK only	131 (18.4)	60 (25.3)	40 (16.9)	31 (13.1)	29 (22.7)	17 (13.3)	16 (12.5)	22 (31.9)	18 (26.1)	9 (13.0)	9 (22.5)	5 (12.5)	6 (15.0)
No response/ uncodeable	41 (5.8)	12 (5.1)	20 (8.4)	9 (3.8)	4	11 (9.1)	4	4 (5.8)	8 (11.6)	1	4 (10.0)	1	4 (10.0)
Totals	711	237			128			69			40		

Note: Figures in parentheses are percentages of the totals shown.

Table 3: Frequency of PSTs' science teaching orientations shown in responses to vignettes in biology, physics and chemistry

Orientation	Exemplar responses to each vignette		
	Biology	Physics	Chemistry
Academic Rigour	"Ask, 'How do plants/ trees get water/nutrients from the soil?' …draw a picture of different plants, without different nutrients, P, K, N, so that they can see that without these the plant cannot grow. Then explain photosynthesis [Equation provided]. The glucose produced is used to provide energy for plant growth. Discuss /explain suggestions – air – without soil would the plant grow? Soil- without air / CO_2 would the plant grow? Air + soil – explain nutrients + photosynthesis." (Biologist)	"Go back to the basics of electricity to remind them what electricity is and how it is a form of energy. Demonstrate that energy cannot be created or destroyed, only converted from one form to another and that light is a form of energy. Combine the ideas of energy and electricity to show that the conversion has no bearing on the ammeter reading. Further demonstration using a buzzer for sound should cause a similar result and would not limit the experiment to light only. Go over the basics of electricity and current and energy." (Biologist)	"The class needs an understanding that it is O_2 in the air that causes the reaction. Therefore … perform the experiment demo again using another gas… Use a diagram or molecular model to show the class the formation of the MgO_2 (sic)… Use a word equation to visualise the information and talk about other metals burning. Show that there is a pattern of metal reactions with O_2 to form oxides." (Chemist)
Didactic	"I would advise...that plants are different to animals…I would advise that this process is called photosynthesis… I would inform the students of the composition of the air…" (Biologist)	"Thought experiment, either with little bricks or using children, of an electric circuit… We can show that in a circuit, the flow must be constant… We can demonstrate why it would be equal on both sides." (Physicist)	"introduce an idea of particles of magnesium and oxygen in the air combining…explain the white light came from energy given off as particles combined and the ash was the mass of particles coming together" (Biologist)
Activity Driven	"As regards minerals…students could carry out a series of experiments, e.g. one lacking in phosphate… from the air, if the plants are placed in pots under airtight glass jars it would be possible to remove CO_2 from one jar to compare the effect of limiting chemicals from the air." (Chemist)	"If resources are available then get pupils to carry out a practical and record both sets of results. Set up experiments that do "use" up electricity to show different examples." (Chemist)	"Encourage the class to discuss the responses and the reasons for the responses. Remind the class of other lessons using similar concepts. Work through the equation [Not stated] with the group. Use similar experiments to illustrate the point." (Biologist)
Conceptual Change	"I would explore the answers the children gave and use the information they should know about photosynthesis. [I would do] the experiment and have the children explain the results…" (Biologist)	"1. Talk about current – ask question to determine what they already know. 2. Discuss why it would not be higher or lower than before. 3. Ask why they thought it would be the same. 4. Do experiment to show it was the same as before. 5. Use open/closed questions to determine if children understand the concept." (Chemist)	"I would find out what students know about reactions and combustion. I would get the students to think in terms of gases given off… I would also get the class to think about why it might be oxygen… and relate it to any prior knowledge… I would show the chemical equation ... so that students can

			understand and see what is reacting. I would use a clear, exploratory and knowledge building approach. I would test students’ knowledge at the end.” (Chemist)
Discovery	“Allow the children to do this experiment for themselves – using different methods, i.e. removal of carbon dioxide from around one plant. See if a plant grows without soil etc. Lots more discussion and questioning. Try to allow the class to think it through themselves, for a while.” (Biologist)	“Use a practical in which the children would see for themselves and ask each group of responses why they think that. When discussed as a class, explain it fully.” (Biologist)	None
Process	“Write the suggestions on an acetate [sheet for use on an overhead projector] – Brainstorming. Suggest the new scientific theory – your idea + discuss + explain using questions building on ‘the plant has just grown’. Use a classroom activity to reinforce this. Extend this knowledge with an activity.” (Biologist)	None	None
Inquiry	“Question pupils to find out their understanding and pre-conceptions of how plants grow then challenge them on their understanding. Ask the kids to think of ways to investigate how to test their theories. In addition explanations of the detail of photosynthesis will be required.” (Chemist)	“Electricity and charge are “invisible” concepts and so in order to explain them you must show them in action… My question to the class would be “find out how the reading on the ammeter changes between the two set ups.” Each group would do the experiment and then we would discuss the results. I would ask what they observed” (Physicist)	“They need to be taught that the heating is just a way of providing energy for the reaction to happen. The teacher could also get the class to hypothesise what will happen and use the experiment to prove or disprove this.” (Physicist)
Content knowledge (CK) only	“Plants are special and can do a process called photosynthesis which takes energy from sunlight, carbon dioxide and water to produce simple sugars. The plant uses these sugars to grow and to survive.” (Chemist)	“I would use an analogy of water flowing through pipes and coming to a water wheel (bulb) water isn’t used its conserved and pass on to complete its journey through the pipes.” (Chemist)	“What is inside the magnesium = atoms of magnesium. Therefore the white stuff can’t be inside the magnesium. When the magnesium and oxygen react, they form magnesium oxide.” (Biologist)

Note: Guided Inquiry and Project-based orientations are excluded as no examples were found.

Table 4: Exemplar PST responses coded for science teaching orientations using Magnusson, Krajcik and Borko’s (1999) definitions

Exemplar responses from

Category	Science is …	%	A biologist	A chemist	A physicist
Informed (14.3%)	**using skills to investigate tentative knowledge**	5.9	"… a subject which provides transferable skills used to analyse, investigate and problem solve…"	"…understanding and exploration of the world and materials around us using multiple disciplinary skills. It involves the use of key scientific skills, evaluation and re-evaluation."	"… a process of (a) creatively forming a hypothesis; (b) testing this hypothesis against the world; (c) building up detail."
	intellectual curiosity	4.2	"… a foundation for the development of curiosity and creativity as well as learning about everyday life."	"…study of everything in the Universe to gain a deeper knowledge of existence, etc."	"… the basis of exploration and explanation."
	to develop rules/ theories/ models	4.2	"… the study, research into, and application of the rules by which we understand how the world around and within us works."	"…an attempt to qualify and quantify our physical environment."	"…the development of models that describe the Universe based on observation. They allow us to use and understand the properties of the world and make informed choices."
Partially-informed (38.4%)	**investigation**	12.6	"…an area where we investigate + explain things happening in the world around us."	"…understanding & investigation of why and how things happen in the world, Universe and inside ourselves."	"…the investigation of how things work and why they happen. Science allows principles to be used to solve a specific problem."
	experiment / testing	11.4	"…the pursuit of knowledge and understanding through experimentation and testing."	"…an objective method of understanding the Universe around us by experimental procedure and imaginative, applicable theory."	"…the pursuit of knowledge of the environment around us by observing & experimenting. Also it is using this knowledge to make informed decisions."
	explanations for events / phenomena	7.6	"…what we know about the world and Universe in which we live. It is the explanation of how things work and evolve and of the interaction between things."	"…explanations and ideas of everything that surrounds us, with a view to encourage a child to probe these ideas about their environment and understanding why things happen the way they do."	None
	scientific method	6.8	"…a fun and exciting subject that uses experimental and	"…any systematic knowledge or practice. It is the system of	"…the broad method of using empirical evidence…to

			observational methods to quantify concepts that could be related to everyday life."	acquiring knowledge based on scientific method as well as to the organised body [of knowledge] gained through such research."	hypothesise and apply the findings of results. The scientific method...involves clear logical thinking as well as creative theorising…"
Naïve (44.3%)	**how the world works**	24.9	"…the understanding and appreciation of biological, chemical and physical properties in the world around us."	"…an understanding of how the world works relative to the parts it is made up from."	"…fundamental to understanding the world and Universe around us."
	finding the truth	6.3	"…knowledge gained from objective principles and asking of questions from observations and experiments, trying to find the reason 'why'."	"…an all encompassing subject that help[s] give answers to the why of life. If not the answers it gives you the tools needed to work out some of these answers for yourself."	"…study of natural phenomena and the world about you to obtain the truth."
	study of the world / how things are	5.9	"…the study of the world around us from particles to whole organisms and their interaction to their environment."	"…the underlying nature of how everything works/ happens."	"…the logical study of why and how things are like they are."
	a (fixed) body of knowledge	5.1	"…a body of knowledge formed from the results of observation and analysis, experimentation and discussion of phenomena in the biological, chemical and physical world and Universe."	"…the study of all things in all environments. How and why these things (living and inanimate) interact and how they have come to be."	"…about the knowledge of man and [his] environment."
	to gain positive social benefit	2.1	"Science allows us to develop medical technique (sic) so we can live longer. Physics is responsible for a much more comfortable life in respect to material things, mobile phones, aeroplanes, etc."	"…discovery & exploration of the how, what & why of everything around us to progress our understanding and to develop new & improved technologies / methodologies."	"…an understanding of things that happen to and around us and is essential to enable us to make informed choices in our lives."

N= 237 No response / uncodeable = 3.0%

Table 5: Exemplar beliefs about science: PSTs' responses to "What is science?"

Orientation	Definition	Belief about science
Academic rigour	Provides a range of activities to verify concepts, showing links; represents science as a body of knowledge	**Naïve** how the world works / a (fixed) body of knowledge / study of the world /how things are/ to gain positive social benefit / find the truth
Didactic	Tells, shows, explains, questions students to verify knowledge; teacher presents content knowledge and focuses on students' recall	
Discovery	Allows children to experiment following their interests and discover scientific concepts for themselves	**Partially informed** investigation /experimentation /testing / explanations for events / phenomena/ scientific method
Guided Inquiry	Participates in investigating, scaffolds learning to achieve students' independence; adapts genuine scientific contexts for investigation environments	
Conceptual change	Asks for children's views and helps establish valid claims; prompts dissatisfaction with initial thinking and/or intuitive ideas	**Informed** To investigate tentative knowledge/ satisfy intellectual curiosity / develop rules or models
Inquiry	Represents science as inquiry; instruction requires students to investigate problems & assess knowledge	
Project-based	Uses a driving question to organise concepts and activities; students investigate authentic problems working "as a scientist"	
Process	Science is a process creating new knowledge; help students develop scientific skills	
Activity-driven	Offers hands-on activities, may lack conceptual coherence	**No alignment**

Table 6: Science teaching orientation definitions aligned with PSTs' beliefs about science

Vignette	**Biology**	**Physics**	**Chemistry**		**Biology**	**Physics**	**Chemistry**		**Biology**	**Physics**	**Chemistry**	
Belief about science Orientation	**Informed N=20**			**Total**	**Partially informed N=47**			**Total**	**Naïve N=50**			**Total**
Academic Rigour/ Didactic	19	16	18	**53**	31	32	37	**100**	36	25	41	**102**
Discovery	0	0	0	**0**	1	2	0	**3**	1	2	0	**3**
Inquiry/ Process/ Conceptual Change	1	2	2	**5**	14	6	9	**29**	13	13	9	**35**

Note:

- N= number of PSTs with a belief coded in this category, who also gave three coded vignette responses
- Exclusions
    - *Guided Inquiry* and *Project-based* orientations because no vignette responses corresponded to these
    - Responses coded *Activity-Driven* as these do not align with any NOS belief: hence numbers do not always add up to N values
    - CK-only responses as these do not include an STO

Table 7: Comparing PSTs' beliefs about science and science teaching orientations

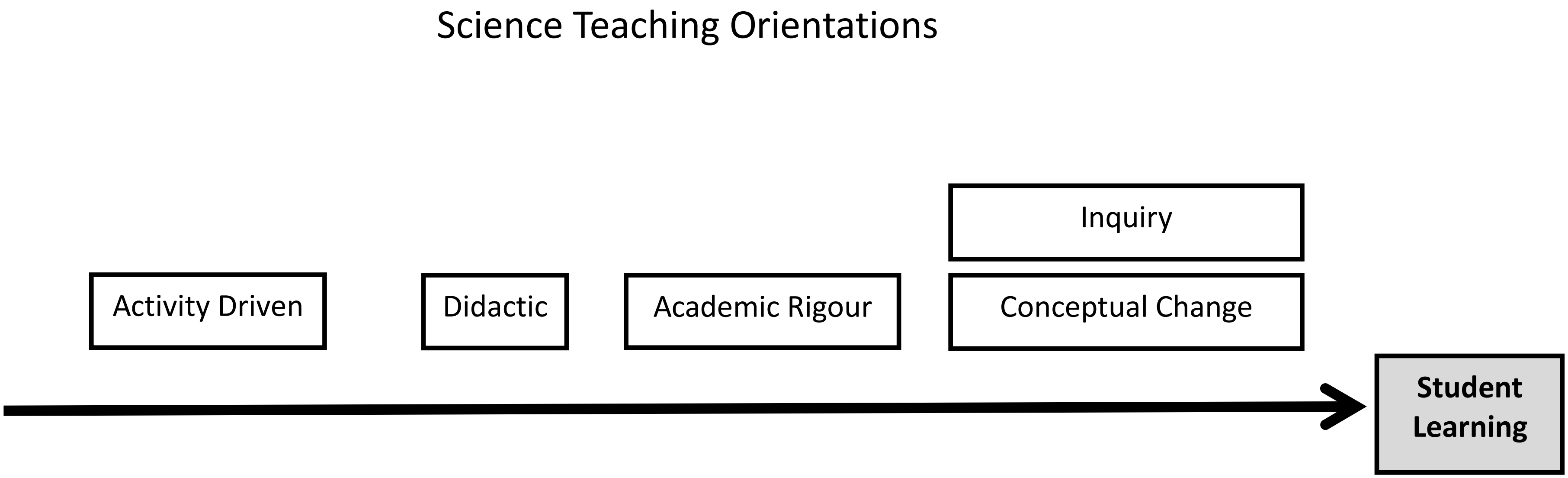

Figure 1: Proposed continuum for pre-service teachers' science teaching orientations and Nature of Science beliefs