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Exploring science teachers' perceptions of experimentation: implications for restructuring school practical work

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ABSTRACT

It is commonly recognised that practical work has a distinctive and central role in science teaching and learning. Although a large number of studies have addressed the definitions, typologies, and purposes of practical work, few have consulted practicing science teachers. This study explored science teachers' perceptions of experimentation for the purpose of restructuring school practical work in view of science practice. Qualitative interviews were conducted with 87 science teachers at the secondary school level. In the interviews, science teachers were asked to make a comparison between students' experiments and scientific experiments. Eight dimensions of experimentation were generated from the qualitative data analysis, and the distributions of these eight dimensions between the two types of experiments were compared and analysed. An ideal model of practical work was suggested for restructuring practical work at the secondary school level, and some issues related to the effective enactment of practical work were discussed.

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Introduction

The term 'practical work' is not limited to its literal meaning; it can also refer to various experiences in school settings whereby students interact with equipment and materials or secondary sources of data to observe and understand the natural world (Hofstein, Kipnis, & Abrahams, 2013). Practical work is commonly recognised by science teachers, science educators, and science curriculum developers as having a distinctive and central role in science curricula as a means of making sense of the natural world. The close association of practical work with school science is manifested in the metaphor that the science laboratory belongs in science learning as naturally as gardening belongs in the garden and cooking in the kitchen (Solomon, 1980, cited in Hofstein et al., 2013). Historically, school science has featured practical work since it first appeared in the late nineteenth century. After the introduction of laboratory teaching in universities in the early nineteenth century in Europe (Liebig was an early pioneer in chemistry), it was gradually developed over the next 50 years, when in 1899 it became considered necessary that school pupils be allowed to carry out experiments for themselves (Reid & Shah, 2007).

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In tracing the histories of school subjects, Goodson and Marsh (1996) advanced the view that science had to be taught in laboratories to achieve high status in the early days of school science. Recently, while attempting to make a distinction between the experimental and historical sciences, Gray (2014) indicated that experimental methodologies have dominated the teaching practice of inquiry in school science because of their disciplinary nature, for example, chemistry, physics, and molecular biology. Obviously, practical work at the school level is closely related to experiments in scientific research in terms of its meaning and origin. Practical work is often seen as identical to experimentation (for instance, in Chinese, *shiyan*, experimenting is used to refer to practical work), and even scholars use the terms practical work, laboratory work, and experimentation interchangeably in their papers and articles.

As a special teaching approach and learning environment, practical work has been used with a variety of expectations, usually goals or purposes that are easily retrieved in curriculum documents and in the literature. In their comprehensive review, Hofstein and Lunetta (2004) summarised these purposes into five categories: (1) understanding of scientific concepts; (2) interest and motivation; (3) scientific practical skills and problem-solving abilities; (4) scientific habits of mind (more recent); and (5) understanding of the nature of science (more recent). These goals and purposes have drawn persistent attention from researchers seeking to explore science teachers' understanding of the goals of practical work in the past decades (e.g. Abrahams & Saglam, 2010; Kerr, 1964; Nivalainen, Asikainen, & Hirvonen, 2013; Pekmez, Johnson, & Gott, 2005; Wilkinson & Ward, 1997). Moreover, some researchers have investigated the consistency between the expected outcomes and the teaching practice of practical work (e.g. Abrahams & Millar, 2008) but found that the practice of science teachers did not appear to be consistent with their stated philosophy; that is, what they believed in their minds was not implemented in practice. A commonly observed phenomenon in laboratories is that students are mainly involved in 'recipe'-style activities in which they strictly follow instructions and that teacher–student interactions, if any, are focused mainly on low-level manipulative and cognitive skills. Abrahams and Millar (2008) concluded that teachers' focus on practical work was predominantly on making students manipulate physical objects and equipment but rarely on the cognitive challenge of linking observations and experiences to conceptual ideas or on developing students' understanding of scientific inquiry procedures. In their review of the current situation of practical work in school science, Hofstein et al. (2013) found that 'science education has moved forward in the last decades and improved teachers' professional knowledge and classroom practice, but this improvement has not sufficiently caught up with the challenges of using laboratory work in an efficient and appropriate way' (p. 160).

It can be assumed that the goals and objectives and the degree to which they are achieved in the laboratory are dependent on a wide range of factors, such as teachers' expectations, subject knowledge, pedagogical content knowledge, students' abilities and interests, the teaching methods of practical work (confirmatory/investigatory), and many logistical and economical elements related with the availability of equipment and facilities. Some of these factors have been examined in the literature; others have not yet. We argue that among these factors, science teachers' perceptions about practical work are a key factor that affects which kinds of goals will be attained and to what degree. Moreover, as we argued earlier, the notion of practical work has an inherent link with scientific experimentation in its historical and semantic meanings, therefore science teachers' understandings of practical work are naturally associated with their perceptions of scientific experimentation. As such, research is needed to explore the perceptions of science teachers about experimentation in the school settings with the purpose of restructuring school practical work. Specifically, this study aimed to provide empirical answers to this question: what are science teachers' perceptions on experimentation in the school settings?

Literature review

To conduct this study, it is necessary to extend our visions of practical work/experimentation from the pedagogical to the epistemological, social, and institutional perspectives. In this section, three related issues, the epistemic aspect of practical work, scientific practice, and scientific experiments, are reviewed to provide a theoretical background for the present study.

The epistemic aspect of practical work

Practical work has always been associated with science curriculum initiatives at different stages in history; however, its epistemological basis has become a target of criticism. In his review of science curriculum development, Hodson (1996) traced the changing nature of practical work from discovery learning to process-led science to the constructivist approach from the 1960s to the 1990s and argued that each of these of styles had seriously misrepresented and distorted the nature of scientific inquiry. Similarly, Osborne (2011) challenged the epistemological basis of the scientific method, which can be traced to Baconism. In a more recent article, Osborne (2015) contended that the defining feature of science is a set of ideas about the material and living world, not experimentation. Although experimentation is an important feature of science, such ideas do not readily emerge from observations and experiments. Osborne (2015) further argued that experimental exploration is one of the six major forms of reasoning that science has contributed to our culture (the other five are mathematical deduction, hypothetical modelling, categorisation, probabilistic thinking, and history-based evolutionary thinking). The epistemological underpinnings involved in practical work and especially in science teachers' perceptions and behaviour concerning practical work have been demonstrated in empirical research. For example, in a qualitative study, Kang and Wallace (2005) explored how science teachers' epistemological beliefs and teaching goals were related to their use of lab activities, which resulted from an amalgamation of their epistemological beliefs, teaching contexts, and instructional goals.

Science practice

The term science practice has drawn a great deal of attention in the current science education literature. It represents the contemporary understanding of the nature of science (e.g. Abd-El-Khalick & Lederman, 2000; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003), which has emerged from the work of science historians, philosophers, cognitive scientists, and sociologists since Kuhn (1962). Underlying this understanding is the notion that science cannot be viewed merely as a body of knowledge but must rather be viewed as a particular epistemic, social, and cultural practice (Erduran & Dagher, 2014). In this sense, the term scientific practice expresses a global meaning of the practice of science, like the practice of teaching and the practice of architecture, whereby scientists share common values, norms, criteria, and discourses. Moreover, we concur with Erduran and Dagher (2014) that the notion of scientific practice is articulated to emphasise the social and cultural processes that constitute and underpin the generation, evaluation, and revision of scientific knowledge.

In a perceptible sense, however, science practice can be described as a collection of concrete practices (plurality is used here). A typical example is suggested in *Science Framework for K-12 Science Education* (National Research Council [NRC], 2012) which consists of a number of components namely: (1) asking questions and defining problems; (2) developing and using models; (3) planning and carrying out investigations; (4) analysing and interpreting data; (5) using mathematics and computational thinking; (6) constructing explanations and designing solutions; (7) engaging in argument from evidence; and (8) obtaining, evaluating, and communicating information. According to Osborne (2011), these eight practices constitute three intersecting spheres of science as a social practice which include: (1) investigating: scientists work in the investigational space, designing experiments and collecting, analysing, and interpreting data; (2) developing explanations and solutions: scientists theorise about the world, developing hypotheses and constructing explanations; and (3) evaluation: scientists engage in arguments and critiques, evaluating the validity and reliability of their data, contrasting their data with their theoretical predictions, and identifying flaws in both their own and others' ideas.

While this set of science practices has been advocated by high-profile curriculum policy documents such as NRC (2012) and are gradually becoming familiar to science teacher educators, science teachers, and science curriculum developers, the notion of science practice has not been well defined in the literature of science education. However, some scholars have attempted to clarify it from a number of perspectives. Inspired by the work of Lehrer and Schauble (2006) and Duschl (2008), Stroupe (2015) suggested four dimensions of scientific practice: (1) conceptual dimension: how theories, principles, laws, and ideas are used by actors to reason with and about; (2) social dimension: how actors agree on norms and routines for handling, developing, critiquing, and using ideas; (3) epistemic dimension: the philosophical basis upon which actors decide what they know and why they are convinced they know it; and (4) material dimension: how actors create, adapt, and use tools, technologies, inscriptions, and other resources to support the intellectual work of the practice. Stroupe (2015) further argued that science practice emerges from a larger network of activity that includes specialised discourse and historical norms for participation and that it is influenced by the social, political, and cultural aspects of a context. Erduran and Dagher (2014) have made a deliberate differentiation between 'science practices,' 'scientific processes,' and 'scientific activities.' According to Erduran and Dagher, the term scientific processes typically refers to how scientific research is done with positivism as its root to emphasise particular skills such as the manipulation of variables and interpretation of graphs. Scientific practices on the other hand aim to situate these aspects of science into broader epistemic and discursive practices such as 'making sense in patterns of data' and the 'coordination of theory and evidence' (Sandoval & Millwood, 2005, cited in Erduran & Dagher, 2014, p. 69). Erduran and Dagher further differentiated scientific practices from 'scientific activities' (such as observing and experimenting). Citing the work of Irzik and Nola (2011) they argue that scientific practices involve not only epistemic but also the social-institutional and cultural components that underlie the choices made within the enactment of activities. For example, while scientists engage in experimentation, some particular results are derived through controlled trials that are negotiated and discussed within teams of researchers relative to particular evaluative criteria and then reviewed by peers for wider communication. These scholars' ideas have enlightened us in setting experimentation in the broader epistemic, cognitive, and social-institutional contexts rather than viewing it as an isolated activity.

Scientific experiment

It is commonly recognised that a scientific experiment is about procedures that are carried out to support, refute, or validate a hypothesis (Mayo, 1996). Among the varied forms of sciences, those that directly rely on experimentation with natural phenomena are usually called experimental sciences, in which 'knowledge is most often constructed through controlled experiments in which natural phenomena are manipulated, often to test a single hypothesis' (Gray, 2014, p. 330). In this sense, scientific experimentation is usually defined as having three essential elements: (a) an independent variable; (2) a dependent variable; and (3) a hypothesis (Bell, 2008). The substantial body of research on the history, philosophy, and sociology of experimentation provides insights into what experimentation actually is and how it works in science (e.g. Latour & Woolgar, 1979; Mayo, 1996; Shapin & Schaffer, 1985). Based on this line of scholarship, conclusions can be drawn regarding the nature of experimentation (Gooding, Pinch, & Schaffer, 1993; Radder, 2003, 2009): (1) intervention and reproducibility are two primary features of experimentation; (2) instruments, equipment, and technological innovations play critical roles in experimental practice; and (3) the relationship between experiment and theory is interactive in the formulation of scientific knowledge. Lehrer and Schauble (2006) argued that scientific experimentation is an epistemic form that is characteristic of and central to science practice. They identified three images of science and their corresponding stances towards the nature of scientific experimentation: (1) science-as-logic regards experimentation as a form of reasoning dominated by a singular rationale: the control of variables; (2) science-as-theory regards experimentation as a critical test of a theory; and (3) science-as-practice regards experimentation as the resolution of an apparent paradox (Lehrer & Schauble, 2006). In particular, these researchers emphasised that from the science-as-practice perspective, experiments are 'complex and textured' (p. 159), implying that scientific experimentation is not just about a predominant set of procedures; it involves multiple aspects and dimensions. Thus, for educational purposes, Erduran and Dagher (2014) suggested that experimentation should be positioned as scientific practice rather than the conventional activity whereby students are instructed to follow prescribed procedures – usually described as the 'cookbook' approach which is predominant in school science.

Methodology

The present study investigates the meaning of experimentation for science teachers on the basis of their lived experiences of both teaching and learning relevant to this phenomena. Given the phenomenological nature of the study, qualitative interviews were used to collect the data. Moreover, this study is not based on preconceived theories; it emphasises how science teachers describe the phenomena of experimenting from their own viewpoints. Therefore, the grounded theory approach was used to analyse the data collected from the interviews.

Data collection

This study was conducted in Guangdong province, southern China. A total of 87 science teachers with teaching experience ranging from 1 to 22 years were invited to participate in this study on a voluntary basis. Most of them had received pre-service teacher training in the science departments of normal universities or institutes; they each had a bachelor degree of science, and some had a master's degree in education. There were 35 males and 52 females, with subject backgrounds of biology (28), chemistry (21), and physics (38), coming from 12 secondary schools located in three cities of Guangdong province, southern China: Zhuhai, Guangzhou, and Zhanjiang. The demographic backgrounds of participants are listed in Table 1. It should be noted that none of these participants had been career scientists before they became school science teachers. A liaison in each school was responsible for contacting these teachers and informing them of the intent of this study.

All of the interviewees had studied in science departments at universities and had performed scientific experiments to some degree in university laboratories. Moreover, participants had been exposed to the notion of scientific experimentation through a variety of occasions and opportunities during their learning and teaching periods, such as science courses, paper reading, thesis writing, laboratory assistance, and even the media. As mentioned earlier, school practical work has a close connection with scientific experiments. Given these considerations, the interviewees were asked to compare school practical work and scientific experiments with a focus on the nature of the former. The interviews were guided by a general open-ended question: 'What are the similarities and differences between school practical work and scientific experiments?' However, in the pilot study, we found that science teachers seemed to like to talk about teachers' demonstrations, which is a type of practical work that has little connection with scientific experiments. Thus, the guiding question was revised to 'What are the similarities and differences between students' experiments at the school level and scientists' (scientific) experiments in research?' One-on-one interviews were conducted, usually beginning with the topic of experimentation, which was familiar to science teachers and then focusing on the comparison between the two types of experiments. During the interview process, when the

Table 1. Demographic backgrounds of participants.

Gender	Male	35	87
	Female	52	
Subject specialism	Biology	28	87
	Chemistry	21	
	Physics	38	
Years of teaching	1	20	87
	2–5	36	
	6–10	27	
	More than 10	4	

interviewee's account was vague or unclear, probing was used to clarify the real meaning. For example, when a teacher stated students' experiments were 'simpler' than scientists' experiments, he was asked to clarify what he meant by 'simpler.'

Interviews were conducted in Mandarin (Putonghua). In most cases, the interviews lasted about 10 minutes. The interviews were transcribed verbatim into Chinese after interviewing and the transcriptions were sent to the participants for confirmation. For instances, when they just mentioned *shiyan* (experiment/experimenting) and we could not make any sense of it, we asked them to clarify what they actually referred to, students' experiments, scientists' experiments, or practical work. In the data management process, each teacher was assigned an identifier that included one sequential number and one letter indicating his/her teaching area: B for biology, C for chemistry, and P for physics.

Data analysis

In contrast to a theory-driven approach, grounded theory provides an approach for investigating previously unreported areas. In this study, a Multi-Grounded Theory (MGT) approach that involves both empirical grounding and theoretical grounding was used to analyse the data. According to Ezzy (2002), MGT is a sophisticated model of grounded theory that deepens inductive and deductive methods of theory generation. Maxwell (2013) suggested that coding categories in a qualitative study may be drawn from existing theory, developed inductively by the researcher during the analysis, and taken from the conceptual structure of the people studied (often called *emic* categories). Given that this is a qualitative study, theories were generated from empirical data; however, the existing literature concerning the dimensions and theories of science practice and scientific experiments, such as Stroupe (2015) and Irzik and Nola (2011), were also taken into account when the data analysis was conducted.

Three phases of the grounded theory were used as a guideline to analyse the data, namely open coding, axial coding, and focused coding (Charmaz, 2006; Strauss & Corbin, 1990). First, the transcripts of the interviews were read line by line several times, and the statements concerning students' experiments, scientific experiments, and the commonalities of these two types of experiments were highlighted. By the end of this phase, a large number of highlighted statements had been generated. We then analysed all of the interview texts again and grouped those highlighted statements into temporary categories. We went back to the texts, analysed these temporary categories in a critical manner, and further edited, combined, or divided them. This resulted in the creation of 16 sub-categories, which were finally combined into 8 dimensions (categories) based on the guidelines from the literature. During each of these phases, we coded and grouped the data independently, and differing opinions were discussed to achieve a consensus. The eight dimensions (categories) together with their sub-categories and examples of teachers' statements are presented in Table 2.

Results

The results are reported in two parts in this section. First, the eight dimensions of the experiments that emerged from the interviews are presented: conceptual, epistemological,

Table 2. The eight dimensions/categories, 16 sub-categories, and examples of statements.

Dimensions (Categories)	Sub-categories	Examples of statements
Conceptual	Scientific knowledge (concepts, theories) owned by the actors	Owing to limited knowledge preparation, they [students] can only explore some simple problems. (1B)
		Scientific researchers have owned advanced and professional knowledge. (69C)
	Scientific knowledge (concepts, theories) needed by experimentation	They [students' and scientists' experiments] are different in the depth of theory; comparatively, students' experiments are simple in terms of their theoretical foundations. (23P)
		Some advanced and sophisticated theories are involved in scientist' experiments. (35P)
Epistemic	The role played by experimentation in formulating scientific knowledge	When scientists are conducting an experiment, they have a goal in their minds, which is investigating or testing an idea, a hypothesis, or a theory. (6P)
		Students are clear about what the results [of experiments] will be and therefore this is a confirmatory process rather than a creative exploration. (53P)
	The results of experimentation, predictability/unpredictability and certainty/uncertainty	The results of a students' experiment is certain, and they [students] know the results before doing it. (22C)
		As for real scientific experiments, not all of problems can be predicted and they [scientists] have to face them in reality. (65P)
	The nature of science related to experiment	Scientists' experiments aim to discover new theories, find evidence to support existing theories, or create new substances. (8C)
		The focus of scientists' experiments is to discover something that have not been known before or to make some innovations. (55P)
Procedural	'Principles' of experimentation	They [students' and scientists' experiments] have the same principles, such as controlling variables, single variable. (17B)
		When conducting experiments, some principles should be upheld, such as feasibility, single variable, repeatability (84B)
	Scientific processes	In the early stage, both of them [students' and scientists' experiments] are to find some information, and then to design the experiment. (14C)
		Students have experienced similar procedures with scientists, such as, formulating a hypothesis, designing experiments, and analyzing the data, etc. (54P)
Material	Apparatus	The equipment is not sufficient. (16B)
		The apparatus used by scientists is usually the most advanced and complex with good precision. (60P)
	Facilities	Scientists have better facilities in their laboratory. (6P)
		In a school laboratory, facilities are not so complete and formal and sometimes with kind of casual substitutes. (78B)
	Substances	Chemical experiments often involve corrosive and poisonous agents. (27C)
		The raw materials are needed to be specially ordered, sifted, or cultivated. (72B)
Social	The interpersonal	The scope of a scientific experiment maybe be very large involving many individual scientists in a research team. (4P)
		Scientists' experiments are not conducted by one person but by a team with collaborations among team members. (48P)

(*Continued*)

Table 2. Continued.

Dimensions (Categories)	Sub-categories	Examples of statements
	Social contexts	Scientific experiments are usually supported by a large amount of money. (55P) Scientists' experiments are conducted for the well-being of man. (68B)
Temporal	Length of time of experimentation	Scientists' experiments are time consuming and labor intensive. (1B) Students' experiments are usually conducted in a short time period. (11C)
	Availability of time for actors to conduct experiments	For students' experiments, there is no sufficient time. (56P) Scientists have sufficient time to prepare for their experiments and therefore their experiment design is elaborate. (58P)
Safety	Safety (safe, dangerous, poisonous)	Comparatively, they [scientific experiments] are kind of dangerous (5P) Scientific experiments often involve some substances that lead to cancer. (40B)
Pedagogical	Pedagogical (goals, purposes, expectations)	Students' experiments focus on both manipulative and investigative processes (26B) The experiments conducted in physics classrooms are to show the processes of scientific exploration to students and let them experience these processes with the aims of cultivating the spirit of investigating the natural world. (57P)

procedural, material, social, temporal, safety, and pedagogical. Second, the statistical data are analysed to identify the patterns which emerged from the 87 participants.

Dimensions of experimentation

Conceptual dimension

The conceptual dimension was addressed by some participants who recognised that an experiment inextricably included scientific knowledge or theories. This dimension includes two sub-categories. The first was the relevant scientific knowledge needed by experiments. For instance, a physics teacher commented that both students' and scientific experiments 'needed the same theoretical system' (32P), while another stated that 'theoretical theories are different in terms of the depth involved in the two types of experiments' (23P). The second sub-category referred to the scientific knowledge possessed by the actors. For students' experiments, some teachers mentioned that students' knowledge was limited or not at a professional level. In contrast, they believed that scientists had profound and wide scientific knowledge with which to conduct scientific experiments. Below is a comment from a biology teacher who was asked to compare the commonalities and differences between students' and scientists' experiments: 'Due to their limited knowledge competency, they [students] can only engage in exploring some simple problems … but the personnel in scientific experiments usually has abundant theoretical knowledge to use experiments to discover the inherent patterns' (1B). Moreover, when participants mentioned that students' experiments were 'simple' and that scientists' experiments were 'new' or 'complicated,' we noted that they usually referred to the conceptual dimension of the experiments.

According to the participants, it was this conceptual dimension that made students' experiments 'simple' and scientists' experiments 'complicated.'

Epistemological dimension

The epistemological dimension includes three sub-categories: the role played by experiments in formulating scientific knowledge, the predictability/unpredictability and certainty/uncertainty of the results of the experiments, and the features of the nature of science that relate to experiments. As some participants indicated, a common feature of both types of experiments was the role they played in the process of producing new knowledge. According to respondents, 'experimentation was a way of knowing by verifying some kind of knowledge' (76B) and 'experiments are used to investigate the essence of concepts and theories in science' (35C). Moreover, as participants noted, students' experiments were in essence confirmatory. For instance, when talking about students' experiments, some stated that 'they were used to confirm knowledge in the textbooks' (7C), the 'results existed there beforehand' (44P), and 'their results are determined without uncertainty or creativity' (22C). The investigative feature of scientific experiments was articulated by some participants. According to them, scientific experiments were purported to 'explore or test whether some ideas are true or false' (11C), 'explore what they [scientists] do not know' (48P), and 'when doing experiments, they [scientists] do not know at all what the results might be' (53P) because 'their [scientific experiments'] fundamental purpose is to explore a new kind of knowledge that was unknown before' (76B). The uncertainty was frequently mentioned, with the following points prevalent in the participants' responses when talking about scientific experiments: 'the final result is unknown' (25P), 'the conclusion has not been determined and no certainty exists' (35C), and 'the results of experiments are unknown and their successes cannot be predicted' (77B). For the third category, some respondents addressed the creativity of experiments. For instance, 'they both were creative activities' (39P), 'creativity is the main feature of scientific experiments, and scientists apply experiments to test their hypotheses' (30C), 'scientists want to create something that does not exist' (69C), and 'scientists always try to investigate new concepts and ideas that have not existed before' (87B). Some mentioned the accumulative aspect of scientific knowledge when talking about scientists' experiments. For instance, a physics teacher pointed out that 'on the basis of the experiences of predecessors, scientists design their own experiments to investigate the unknown world' (37P).

Procedural dimension

The procedural dimension refers to procedural issues associated with designing and doing experiments, including two sub-categories, the principles of designing and doing experiments and the various scientific processes of investigation. According to some of the participants, both students' and scientists' experiments should observe some principles belonging to what Osborne (2015) called 'procedural knowledge.' As a biology teacher indicated, for instance, the '"equivalent principle" and "single variable principle" apply to both students' and scientists' experiments' (2B). Moreover, another biology teacher listed 'scientific, contrasting, single variable, equivalent, operative, and repeatable principles' (20B). This teacher believed that all of these principles 'should be adhered to in the process of designing and doing any kind of experimentation' (20B).

As for the processes of the experiments, participants usually mentioned the procedural processes and skills articulated in curriculum documents, and some even gave them in a sequence. For students' experiments, for example, a physics teacher stated, '[students] make observations first, ask a question, then make a hypothesis, testing the hypothesis to see if it is correct or not, and finally draw a conclusion' (5P). According to participants, scientists 'need to define topics and design experiments by themselves' (14C) and 'need to think and design those experiments by themselves' (27C). The differences between the two types of experiments are manifested in the simplicity, difficulty, and complexity of the processes. For instance, participants indicated, 'students' experiments are relatively simple and easier to do' (12C), 'compared with scientific experiments, students' experiments are simple and this will lead to huge errors' (3B), and 'they both are different in rigor' (26B). A biology teacher provided more details: 'experiments used in science teaching are relatively unsophisticated, they are usually just a kind of qualitative description, and students do not have the awareness for precise sampling' (1B). In contrast, participants thought scientific experiments were 'strictly logical in reasoning' (2B) and had 'more rigor and were more precise in design and manipulation' (67P) and that '[scientists] are much more careful in collecting and analyzing data' (13B).

As seen by participants, another difference between the two types of experiments was subjectivity. For students' experiments, many of the participants pointed out the leading roles played by science teachers. The following are some examples: 'For students, the experiments had been designed by textbook authors or teachers, and they needed to do them step by step. If students want to make some improvements or innovations, they should discuss them with their teachers in advance' (27C). Another teacher stated, 'at my school, students' experiments are always led by teachers; in most cases, students are informed by their teachers of the goals, methods, procedures, and points needing attention' (40B). A third stated, 'actually, we lead students to do experiments, telling them the goals and steps of these experiments and how to manipulate and reduce errors' (49P). In contrast, some participants recognised scientists' initiative in the scientific experimentation process. For instance, participants observed that 'scientists determined the topics and focuses of experiments, and designed the experiments by themselves' (14C), 'when conducting experiments, [scientists] do not have anyone to rely on, they have to manipulate the experiments by themselves' (28P), and 'scientists need to prepare materials and equipment and design the experiments by themselves, but students do not' (82B). Students' initiatives in the experimentation process in recent years were also mentioned by some teachers. For instance, when comparing current students with his past experiences as a student, a physics teacher made the following comment: 'today, we tend to let students design experiments and make verifications by themselves' (66C).

Material dimension

The material dimension refers to the materials that are required in experimentation, incorporating apparatus, facilities, and substances. When talking about experimentation, some participants mentioned apparatus used in both students' and scientists' experiments. For example, 'some kinds of apparatus are used in both students' and scientific experiments to verify scientific knowledge' (21P) and 'for any kind of experiments, the rules of operating apparatus are the same' (59P). Some participants believed that these sorts of materials were different between students' experiments and scientists' experiments. The disadvantaged conditions of students' experiments were often mentioned by participants. These comments are representative: 'apparatus used in students' experiments are not complete' (1B) and 'in students' experiments, the equipment is not sufficient' (16B). One teacher stated that the 'experimental conditions' were much better for scientific experiments than for students' experiments (6P). Another teacher gave a more specific comment: 'the two types of experiments are different in terms of experimental apparatus and facilities' (43P), implying that scientists' experiments have better and more precise apparatus than students' experiments. Moreover, for chemistry teachers, this dimension also includes substances, such as chemical agents, that are used in chemical experiments. For example, a chemistry teacher stated, 'chemical experiments often involve corrosive and poisonous agents' (27C).

Social dimension

For the participants, the meaning of the social dimension was complicated, involving two sub-categories: interpersonal relationships in the research community and the political, economic, and cultural factors in a given society; these roughly correspond to the 'social dimensions of science' and the 'social and cultural embeddedness of science,' respectively (Abd-El-Khalick & Lederman, 2000; Abd-El-Khalick, Waters, & Le, 2008). For the first category, the following statements are representative: 'some scientists conduct experiments in an individual way, and some do them collectively' (27C);'the exploration was conducted in an individual way or by a group of scientists' (35C); and 'there is a research team in a scientific project with good cooperation and communication among team members' (77B). For the second category, participants gave the following comments: 'scientific experiments aim to solve the problems that concern our society' (5P);'scientific experiments have some associations with economics and especially with financial support' (13B); and 'scientific experiments are used to solve some real problems, such as producing new substances to solve resource problems and attempting to cure illnesses' (8C). It is worth noting that the social dimension was mainly discussed with regard to scientists' experiments and rarely with regard to students' experiments.

Temporal dimension

The temporal dimension incorporates two sub-categories: the length of time involved in doing experiments and the availability of time for actors to conduct experiments. This dimension emerged from the discourses on the differences between students' and scientists' experiments. As some participants pointed out for the first category, scientists' experiments took longer than students' experiments to conduct. The following comments are examples: 'scientific experiments are time consuming' (1B); 'a scientific experiment is an enduring endeavor, and it will take a longer period of time' (38P); and 'students' experiments are quick with a certain result obtained during a short period of time' (11C). For the second category, the availability of time for the actors (students and scientists) of experiments, some participants stated that scientists had more time to prepare, design, and conduct scientific experiments than students, who did not always have enough time in school. The following are examples: 'scientists have more time to prepare experiments, and therefore their design can be more elaborate' (58P); 'the timing is flexible in scientific experiments and scientists can control their time' (71C); '[for students' experiments], time is not sufficient' (56P); and 'time is indeed a problem; we do not have so much time to lead students to make scientific inquiries' (45P).

Safety dimension

This dimension refers to the issue of safety, about which several participants were concerned. At a general level, participants believed that safety had a close association with experimentation. As a participant pointed out, 'in the process [of doing experiments], the safety should be carefully taken into consideration' (12C). When comparing students' experiments with scientists' experiments, they thought that the former was safer than the latter, as the following statements show: 'students' experiments were safer [than scientific experiments]' (5P); 'students' experiments are not dangerous' (9C); 'materials used in scientific experiments may be poisonous' (11C); and 'scientific experiments may involve some substances that might lead to cancer' (40P). Even so, participants indicated that they were mindful of safety in the laboratory. For instance, a chemistry teacher provided this comment: 'if a student conducts some activities in the laboratory without permission, this may give rise to hazards because chemical experiments often involve with corrosive and poisonous agents' (27C).

Pedagogical dimension

The pedagogical dimension involves teaching issues regarding experimentation in schools. When talking about students' experiments, particularly the differences between students' and scientists' experiments, participants were willing to talk about the significance, purposes, and expected functions of experimentation in science teaching and learning, which were similar to those articulated in the literature of science education (e.g. Nivalainen et al., 2013). The following statements are examples for this dimension: 'to inspire students' interest and enthusiasm for inquiry' (5P); 'experiments provide concrete ideas for students and help them learn new knowledge' (22C); 'experiments are helpful for students to easily understand abstract concepts and theories' (57P); 'to cultivate students' ability to observe' (71C); and 'to help students experience the process of inquiry through a series of experiments' (76B). Moreover, some participants mentioned that students' experiments were actually driven by external examination. For instance, a biology teacher stated that 'students' experiments are focused on teaching and oriented for examinations' (17B). Although this dimension applies only to students' experiments, it reflects participants' views on the nature of experimentation in the situation of school science. Thus, it constitutes a special dimension of experimentation in the view of school science teachers.

Dimension distributions

As indicated in previous sections, experimentation was deconstructed into two types according to different actors: students' experiments and scientific experiments. To compare the two types of experiments in terms of the distribution of the eight dimensions, the frequency (number of statements) in each dimension was counted for students' and scientists' experiments. For a given type of experiment, the frequency in each dimension included two parts, the general and the specific type of experiments, that is, students' experiments or scientists' experiments. The statistical data are tabulated in Table 3.

Table 3. A summary of statistical data (frequency of statements).

	Conceptual	Epistemological	Procedural	Materials	Social	Temporal	Safety	Pedagogical	Total
Commonalities, N0	13	12	42	10	1	0	2	0	
Characteristics of students' experiments, N1	11	49	42	32	3	11	6	85	
Students' experiments	***24***	***61***	***84***	***42***	***4***	***11***	***8***	***85***	***319***
N0+N1	***(8%)***	***(19%)***	***(26%)***	***(13%)***	***(1%)***	***(3%)***	***(3%)***	***(27%)***	
Characteristics of scientific experiments, N2	9	64	49	26	18	13	4	0	
Scientific experiments	***22***	***76***	***91***	***36***	***20***	***13***	***6***	***0***	***264***
N0+N2	***(8%)***	***(29%)***	***(34%)***	***(14%)***	***(8%)***	***(5%)***	***(2%)***	***(0%)***	

N0: Frequency of commonalities of both experiments.
N1: Frequency of characteristics of students' experiment.
N2: Frequency of characteristics of scientific experiment.

Moreover, based on the data in Table 3, the distribution of the eight dimensions in each type of experimentation is presented in a pie chart (see Figure 1).

As shown in Figure 1, the eight dimensions of experiments were not equally distributed in either type. For students' experiments, the three largest proportions are 'pedagogical' (27%), 'procedural' (26%), and 'epistemological' (19%), and the three smallest are 'social' (1%), 'safety' (3%), and 'temporal' (3%). For scientific experiments, the three largest proportions are 'procedural' (34%), 'epistemological' (29%), and 'materials' (14%), and the four smallest ones are 'safety' (2%), 'temporal' (5%), 'conceptual' (8%), and 'social' (8%). Some points can be drawn from a comparison of the distributions of the two types of experiments. First, the pedagogical dimension is the largest dimension of students' experiments, reflecting the concerns of participants with the purposes, goals, features, and actual enactment of students' experiments in school settings. Secondly, the procedural dimension accounts for large proportions in both types of experiments, which indicates that procedures are important elements of any kind of experiment in the view of participants. Third, the epistemic dimension accounts for large proportions in both students' experiments (19%) and scientific experiments (29%). Fourth, the proportions of the 'material' dimension are similar for the students' and scientific experiments (13% and 14%, respectively). Fifth, for both of the two types of experiments, the 'conceptual,' 'temporal,' 'social,' and 'safety' dimensions account only for small proportions.

Discussion and implications

Both qualitative and quantitative strategies were adopted to examine the data collected from the interviews with the science teachers. The qualitative analysis has shown that participants' views of experimentation are generally composed of eight dimensions: conceptual, epistemological, procedural, material, social, safety, temporal, and pedagogical. Compared with the model of science practice proposed by Stroupe (2015), the procedural, safety, temporal, and pedagogical dimensions were added to increase scholarly understanding of the notion of science practice. Moreover, while the four dimensions in Stroupe's model were established on an a priori basis, the eight dimensions of this study were based on empirical data. In addition, as Stroupe (2015) observed, if one wants to elaborate the meaning of science practice, the question of whose science practice it is cannot be ignored. As we argued earlier, experimentation is a kind of science practice, but its meanings differ according to who is doing the experimenting. This is why we deliberately made a distinction between students' experiments and scientists' experiments in this study. As the data analysis indicated, these two types of experiments have subtle differences in terms of the composition of their dimensions, although the pedagogical dimension is exclusive to students' experiments.

The quantitative data analysis in Figure 1 showed that the dimensions have unbalanced distributions within each type of experiment. The three largest dimensions are pedagogical, procedural, and epistemic for students' experiments and procedural, epistemic, and material for scientific experiments. It is interesting that for both types of experiments, the conceptual and social dimensions, which are discussed extensively in the literature, were rarely mentioned by participants. Given that ideas are 'the crown of science' (Harré, 1984), the set of ideas about the material and living world constitute the defining feature of science. In fact, the dichotomy between process and content has recurred in the

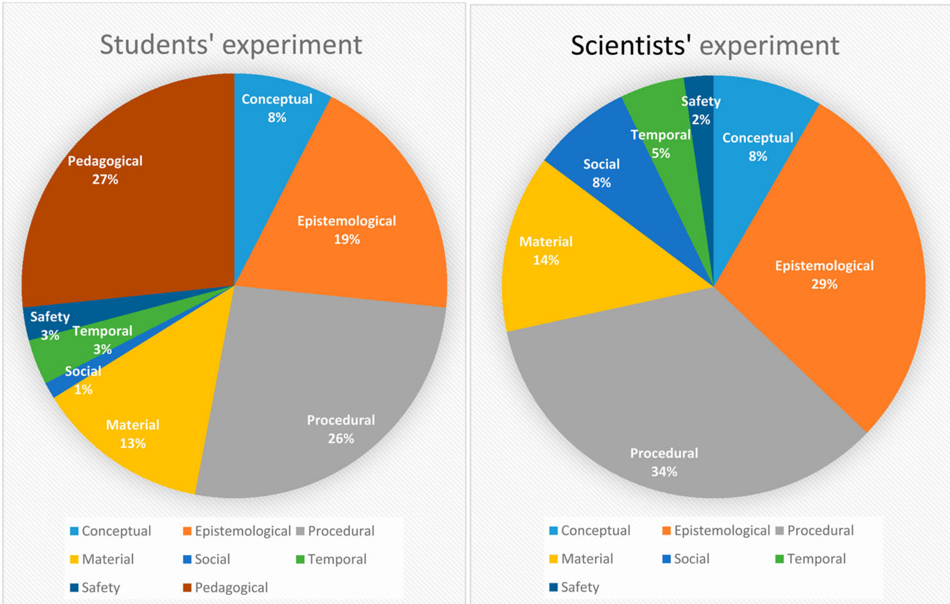

Figure 1. Dimension distributions in students' and scientists' experiments.

history of science curriculum development (Wellington & Ireson, 2012). It is now being increasingly recognised that science processes cannot be separated from scientific ideas, and the dialectic relationship between process and content has been accepted by most researchers. However, in the present study, only 8% of participants addressed the conceptual dimension. Similarly, the social aspect of science practice has been recognised by science educators in the literature (Erduran & Dagher, 2014; Osborne, 2011, 2015; Stroupe, 2015), which means that scientific knowledge is socially negotiated in the scientific community. In this study, it is interesting that although the proportions of this dimension were very low (8% of participants for scientists' experiments and 1% for students' experiments) it indeed includes not only the 'interpersonal' but also the 'social contexts' which has the same meaning with the 'social and cultural embeddedness of science' (Abd-El-Khalick & Lederman, 2000; Abd-El-Khalick et al., 2008), involving social, political, and economic aspects in a given society. The larger proportions of other dimensions do not mean that the relevant dimensions were without problems. Although many participants addressed the epistemic dimension (19% for students' experiments and 29% for scientists' experiments), their responses were mainly limited to the results of experiments, as they believed that students' experiments were 'already known' and that scientists' experiments were 'unknown.' The procedural processes were mentioned by many participants (26% for students' experiments and 34% for scientists' experiments), but only a small proportion addressed 'principles,' that is, 'procedural knowledge,' which is less common in school laboratories (Osborne, 2015). It should be acknowledged that in the present study the numerical data were only used to analyse the distributions of the dimensions of students' and scientists' experiments in the view of science teachers. A future study can be conducted to quantitatively examine whether there is correlation between science teachers' perceptions of students'/scientists' experiments and their demographic characteristics such as gender, subject specialism, and teaching experience.

Another interesting finding is that a contradiction always seemed to exist between students' and scientists' experiments in the conceptual, epistemic, safety, temporal, and procedural dimensions. In the conceptual dimension, participants tended to think that conceptual knowledge in students' experiments was subordinate to that in scientific experiments. They used negative words such as 'superficial,' 'limited,' and 'not professional' to describe the conceptual dimension of students' experiments and positive words such as 'substantial,' 'advanced,' and 'professional' to describe the conceptual dimension of scientific experiments. For the epistemological dimension, most participants tended to see students' experiments as confirmatory and believed the results were already known beforehand, while they thought scientific experiments were investigatory and that their results were unknown. For the safety dimension, participants believed that students' experiments were safer and should be safer than scientific experiments. For the temporal dimension, they believed that students' experiments took less time and would be completed more quickly than scientific experiments and that scientists had more time to do experiments than students. In the procedural dimension, participants tended to believe that students' experiments were simple, unsophisticated, and easy to carry out while they thought that scientific experiments were complicated, rigorous, and not easy to handle. These contradictory viewpoints reflected participants' personal experiences with these two types of experiments and their concerns regarding real situations of students' experiments in teaching practice.

As we argued earlier, practical work is essentially a special kind of science practice that provides a special situation and an educative environment in which newcomers can learn science. The findings of this study concerning science teachers' perceptions of students' and scientists' experiments have shed light on the notion of practical work in the view of science practice. To make the work of reconstructing this notion more reasonable and practicable, it should be based on the nature of scientific experiments and the real situations of students' experiments, which are often constrained by the current structure of schooling (Donnelly, 1998). Several considerations are given for this enterprise. First, practical work should embrace the eight dimensions that constitute this special science practice. Second, the pedagogical dimension should be seriously considered and given central status because it embodies the significance and ultimate ends of practical work in school and it distinguishes practical work from scientists' experiments. Third, the remaining seven dimensions should be given equal weight in this special science practice even though they were appreciated differently by the science teachers, implying that all of them are equally important. Fourth, all eight of these dimensions are interconnected, and the enactment of practical work cannot be determined by one or two dimensions but must simultaneously involve various issues and problems. These considerations are presented visually in Figure 2.

The implication of this model is that the notion of practical work should not be understood in isolation as a pedagogy or curriculum content; rather, it should be viewed as a multifaceted science practice that includes various interconnected dimensions. Moreover, the eight dimensions are equally important, and ignoring any dimension will lead to a failed implementation of practical work. This multifaceted and balanced view will be helpful for examining the problems, difficulties, and dilemmas encountered by school

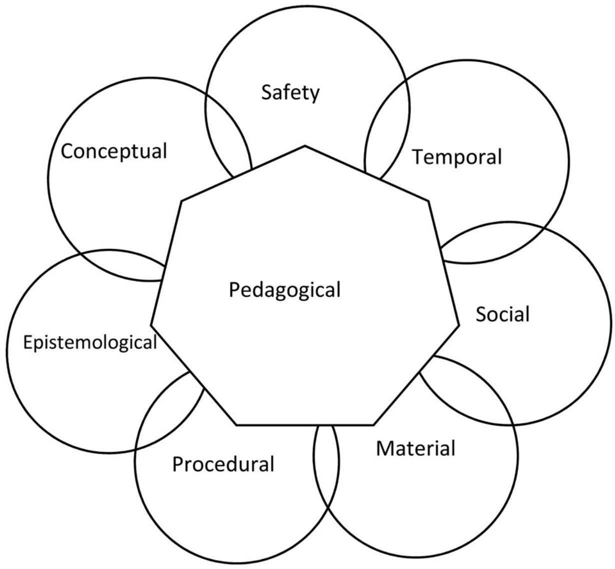

Figure 2. An ideal model of practical work.

science teachers. For example, as shown in this model, the safety, material, and temporal issues are practical issues in implementing practical work, and many of the science teachers interviewed in this study were concerned about them. Because most of these issues stem from external factors that often constrain the effective implementation of practical work, a systematic reform should be undertaken to deal with economic, political, and structural issues in a given society to enact practical work effectively and efficiently. As evidenced in this study, science teachers' views of these dimensions are not equally distributed, with less concern for the conceptual and social dimensions and problems with the epistemological and procedural dimensions. Achieving an equal distribution entails transforming science teacher education by exposing both pre-service and in-service science teachers to science studies to improve their understanding of the nature of science (Abd-El-Khalick & Lederman, 2000). As described in the methodology section of this paper, almost all of the participants were graduates from normal universities and none of them had been practicing scientists before they became school science teachers. We thus can assume that their views on scientific experiments mainly came from their perception of the experimental work undertaken by career scientists. Therefore, we suggest that the courses, modules, and programmes of science teacher education should focus on what real scientific experiments look like, what scientists do when they conduct experiments, and how scientific experiments are actually completed in social contexts. More importantly, science teachers should be provided with opportunities to learn how to transform traditional practical work towards scientific experiments with a reasonably conceptual, epistemological, and procedural foundation.

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