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Nested epistemologies: science teachers' beliefs of teaching, learning and science

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This study explores the relationships among teachers' beliefs about teaching science, learning science and the nature of science. Through interviewing 37 Taiwanese science teachers, teachers' beliefs about teaching, learning and science were respectively categorized as either 'traditional', or 'process', or 'constructivist'. It was found that most science teachers had 'traditional' beliefs. Moreover, more than a half of the teachers held views about teaching, learning and science that were closely aligned. This study, hence, called these closely aligned beliefs as 'nested epistemologies'. This study also suggested that the 'nested epistemologies' tended to be found in teachers of greater teaching experiences. It is suggested that the 'nested epistemologies' affect teachers' perceptions of the practice of science instruction.

Introduction

Over the last two decades, research on teachers' beliefs has received much attention from educators, as the educational paradigm has shifted from behaviorism to constructivism (Kang and Keys 2000). Constructivists may assert that people's subsequent actions and thoughts are mainly based on their ideas constructed earlier. Consequently, many educators agree that teachers' beliefs may, in some way, affect teachers' instructional practice (Nespor 1987, Pajares 1992). Research on teachers' beliefs has thus become one of the major concerns for studies of teaching and teacher education (e.g.Tilemma 1994, Tirri *et al*. 1999, Holt-Reynolds 2000).

In science education research, Hewson and Hewson (1987, 1988) may have first highlighted the importance of appropriate conceptions about teaching science and learning science. They also emphasized the study of science teachers' beliefs about teaching and learning.[1] Maor and Taylor (1995) also concluded that, even in computerized classroom environments, teachers' epistemologies continue to perform an essential role in meditating the quality of student science learning. In their view, teachers' epistemologies are mainly concerned with pedagogical beliefs about teaching and learning. Moreover, science educators have recently become aware of the possible impacts of teachers' beliefs about the nature of science on their instructional plans and teaching practice (Abd-El-Khalick *et al*. 1998, Lederman 1992, 1999). Teachers' beliefs about how science is developed may be potentially related to their beliefs about how to teach science and how students learn science. However, little research literature is found to explore the relationships among

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science teachers' beliefs about teaching, learning and the nature of science. Although Aguirre *et al.* (1990) and Gustafson and Rowell (1995) may have perceived some linkages among science teachers' views about learning, teaching and science, these studies did not explicitly address this research issue. Koballa *et al.*'s (2000) study may be viewed as another attempt, but they only explored the interplay between science teachers' conceptions about learning and teaching and they found that these conceptions, in many cases, were consistent. This study investigates science teachers' beliefs about teaching, learning and science and then clarifies the relationships among these three belief systems.

Method

Sample

Thirty-seven secondary school science (physics and chemistry) teachers in Taiwan were selected as the subjects of this study using cluster sampling. The population of science teachers was clustered into three demographic areas: northern, central and southern Taiwan. Six schools from northern Taiwan, three schools from central Taiwan and three schools from southern Taiwan were selected. The school number ratio selected roughly corresponded to the actual junior and high school number ratio across these three areas. For each school, one to four science teachers, depending on the size of the school, were selected for this study. All of these teachers taught physics and chemistry in the junior high school and high school levels (grade 7 to grade 12). All of them had at least a bachelor degree in physics or chemistry. Seventeen of them were female. Their teaching experiences ranged from 2 to 20 years, with an average of 7.3 years.

Data collection – interview

The research data were gathered by interviewing the sample teachers. The interview was conducted individually by two trained researchers. The interview questions consisted of three major parts, which responded to three belief systems: the first one exploring teachers' beliefs of teaching science, the second one investigating teachers' beliefs of learning science, while the final one exploring teachers' views about the nature of science. Some of the interview questions were modified from those used in Tsai's (1998a) study. The main interview questions are presented below:

1. Beliefs of teaching science: In your view, science is best taught by which ways? What makes the most successful science teaching? Could you describe what an ideal science teaching environment would look like? Why?
2. Beliefs of learning science: In your view, science is best learned by which ways? What do you think about the responsibilities of students when learning science? What is the most important determinant for the success of learning science? Why?
3. Beliefs about the nature of science: If someone asks you 'what is science?', what will you tell him or her? What are the main characteristics

of scientific knowledge? What are the differences of scientific knowledge and other knowledge?

For the interview about teachers' beliefs about the nature of science, the involved teachers were asked to reflect their views about the nature of science *in general*. The interviewer did not provide specific contexts for teachers' discussion. Recent studies revealed that people's views about the nature of science might depend on the contexts for discussion (e.g., Leach *et al*. 2000); therefore, an interesting follow-up study may be necessary to explore how teachers' views of science may differ under different contexts. Nevertheless, the teachers, although asked to express their views about science in general, displayed various perspectives about science in this study. Moreover, in order to avoid contamination of responses across these three belief systems, or to avoid the situation that teachers directly perceived some connections among these systems during interview, the interview for each teacher was conducted three times, for once each of three belief systems. The period between two consecutive interviews was about two to three weeks. Also, the involved teachers did not know the main purpose of this study. All of the interviews were tape-recorded. The interviews were conducted in Chinese and then fully transcribed for further analyses.

Data analysis

After examining teachers' interview transcripts, the researchers (one university science education professor and one research assistant) concluded more than twenty descriptors[2] (or 'coding keywords') that were shown in teachers' beliefs about teaching science, learning science and the nature of science, respectively. Similar to the study by Koballa *et al*. (2000), this study developed a framework for representing teachers' beliefs by merging and clustering these descriptors based on perceived connections. The framework included three categories that could be applied to teachers' beliefs about all these areas. The categories were 'traditional', 'process', and 'constructivist'. The 'traditional' category perceives teaching science as transferring knowledge from teacher to students, learning science as acquiring or 'reproducing' knowledge from credible sources, and scientific knowledge as correct answers or established truths. The 'process' category perceives teaching science and learning science as an activity focusing the processes of science or problem-solving procedures, and scientific knowledge is viewed as facts being discovered through 'the' scientific method or by following codified procedures. The 'constructivist' category views teaching science as helping students construct knowledge, learning science as constructing personal understanding and science as a way of knowing. Also, although constructivism is still a controversial topic in science education (Osborne 1996, Nola 1997, Jenkins 2000, Matthews 2000), the position of this paper, as proposed by Staver (1998) and Tobin (1993), is that constructivism is a sound theory to help science educators understand how students learn science as well as to explicate the practice of science and science teaching. There are, of course, various forms of constructivism (Tsai 1998b). This study was not intended to be a detailed analysis of the forms of constructivism, while the term is used in this paper to imply a broader philosophical position concerning science, science teaching and learning. A description of the three analysis categories is presented in table 1 for beliefs of teaching science,

Table 1. The framework of categorizing teachers' beliefs of teaching science.

Category	*Perspective and descriptors*
Traditional	Science is best taught by transferring knowledge from teacher to students.
	Descriptors: transferring of knowledge; giving firm answers; providing clear definition; giving accurate explanations; practicing tutorial problems; presenting the scientific truths or facts.
	Sample interview transcript: Teaching science is transferring concepts from my brain to students. Teaching science should also emphasize the certainty and accuracy of these concepts.
Process	Science is best taught by focusing the processes of science or problem-solving procedures.
	Descriptors: teaching the scientific method; following problem-solving procedures; experiencing the processes of (self) discovery; working on the processes of verification.
	Sample interview transcript: Teaching science focuses on the processes of discovering the scientific knowledge. Hence, students need to know the scientific method.
Constructivist	Science is best taught by helping students construct knowledge.
	Descriptors: helping students make interpretations; providing authentic experiences; interacting with students; encouraging discussion and cooperative learning; paying attentions to students' prior knowledge or misconceptions.
	Sample interview transcript: Teaching science needs to help students think about their ideas, and then help them construct scientific ideas. Therefore, as a science teacher, I need to explore students' prior knowledge when implementing science instruction.

table 2 for beliefs of learning science, and table 3 for the nature of science. These tables also provide sample interview transcripts for each category.

This framework of categorization corresponds to three major types of teaching strategies commonly used in school science as proposed by Hewson and Hewson (1987) and Millar and Driver (1987): the didactic approach, the process approach and the constructivist approach.[3] This framework of categorization is also similar to that proposed by Koballa *et al*. (2000). Moreover, these categories also reveal three philosophies of science (or three sets of beliefs about the nature of science). The 'traditional' category is supported by empiricism and logical positivism; the 'process' category is supported by naive realism, while 'constructivism' category is supported by a broadly constructivist philosophy (see Tsai 1996).

Two independent researchers performed the classification processes. The classification was based on the teachers' most dominant views in each category as perceived by researchers. The agreement for the classification of teachers' beliefs of teaching science, learning science and science was 0.81, 0.86, and 0.86 respectively. For the interview data that did not have researchers' agreed categorization, the researchers reviewed the interview transcripts again and discussed case by case, and then determined a final categorization.

Table 2. The framework of categorizing teachers' beliefs of learning science.

Category	*Perspective and descriptors*
Traditional	Learning science is acquiring or 'reproducing' knowledge from credible sources.
	Descriptors: transferring of knowledge; memorizing formula, definition, keywords and scientific facts; copying what teachers do; hard work on practicing tutorial problems; passive listening; finding the right answer; accurate calculation.
	Sample interview transcript: For successful learning science, students, first, need to memorize relevant formulae and definitions. Moreover, they need to practice tutorial problems extensively.
Process	Learning science is focusing the processes of science or problem-solving procedures.
	Descriptors: understanding the scientific method; following problem-solving procedures; learning through the processes of (self) discovery; working on the processes of verification.
	Sample interview transcript: Science is best learned through practicing the scientific method. If students carefully followed the processes of verification, they can gain scientific concepts.
Constructivist	Learning science is constructing personal understanding.
	Descriptors: making interpretations; exploring or coping with authentic experiences; discussing with peers and teacher; relating to prior knowledge or (personal or daily) experiences.
	Sample interview transcript: Learning science will become successful if students can effectively relate the scientific concepts to their personal experiences. They should use scientific concepts to interpret personal experiences.

Results

Table 4 shows teachers' beliefs about teaching science, learning science, and the nature of science, as categorized. More than a half of the teachers held 'traditional' beliefs about teaching science, learning science and the nature of science. On the other hand, constructivist-oriented pedagogical views and philosophical perspectives were rarely expressed by the teachers. In particular, only four teachers had constructivist views about the nature of science. This indicates that although the practice of constructivism has been proposed by science educators for more than 15 years (Bodner 1986, Tsai 1998b, Tobin 1993), few teachers had constructed relevant conceptual frameworks. It is also interesting to find that if we examined any individual category across three belief systems, there was almost the same proportion of teachers classified into the category. For example, about 30 per cent of teachers were identified as being in the 'process' category for beliefs about teaching science, learning science, and the nature of science.

Table 5 shows teachers' possible combinations of belief systems among teaching science, learning science, and the nature of science. Fifteen among the 37 teachers expressed consistent 'traditional' beliefs across teaching, learning and

Table 3. The framework of categorizing teachers' beliefs about the nature of science.

Category	*Perspective and descriptors*
Traditional	Science provides correct answers, or science represents the truth.
	Descriptors: accurate description; neutral or objective observations; objective interpretations; truths.
	Sample interview transcript: Science comes from objective observations of natural phenomena. It provides accurate answers.
Process	Scientific knowledge is discovered through 'the' scientific method or by following codified procedures.
	Descriptors: 'the' scientific method; codified procedures; process of discovery; following scientific rules.
	Sample interview transcript: Scientific knowledge is formulated through the scientific method. Scientists followed certain procedures to form scientific knowledge.
Constructivist	Science is a way of knowing, and it is invented through scientists' agreed conventions and paradigms.
	Descriptors: invented reality; imaginative acts; theory-laden observations; constructed through social negotiations.
	Sample interview transcript: Science is developed from scientists' imaginative acts. However, they can not develop scientific knowledge based on whatever they imagine. Therefore, scientists' social negotiations also play an important role on the knowledge development.

Table 4. Teachers beliefs about teaching, learning and science ($n = 37$).

	Traditional	*Process*	*Constructivist*
Teaching science	21 (57%)	10 (27%)	6 (16%)
Learning science	22 (59%)	10 (27%)	5 (14%)
Nature of science	21 (57%)	12 (32%)	4 (11%)

science. These traditional views may be viewed as a whole when they interpreted the activities in science classrooms. Similarly, four teachers asserted consistent 'process' views, and two teachers expressed congruent 'constructivist' beliefs across teaching, learning and science. However, it is also plausible to find that some teachers' beliefs about teaching, learning and science may not show such high consistency. For example, there were five teachers who held 'traditional' views about teaching science and learning science, but had 'process' views about the nature of science. Nevertheless, it was very rare that teachers' beliefs were totally different across teaching, learning and science. In this study, only two among the 37 teachers had totally divergent beliefs among the three belief systems. One had 'process' views of teaching, 'constructivist' views of learning but 'traditional' views of science. The other one had 'constructivist' views of teaching, 'process' views of learning, but 'traditional' views of science.

Table 5. Possible combinations among teachers' beliefs of teaching, learning and science ($n = 37$).

Teaching science	*Learning science*	*Nature of science*	*N*
Traditional	Traditional	Traditional	15
Traditional	Traditional	Process	5
Process	Process	Process	4
Process	Process	Traditional	3
Constructivist	Constructivist	Constructivist	2
Constructivist	Constructivist	Process	1
Constructivist	Process	Process	1
Process	Traditional	Traditional	1
Traditional	Constructivist	Constructivist	1
Process	Traditional	Process	1
Constructivist	Process	Constructivist	1
Process	Constructivist	Traditional	1
Constructivist	Process	Traditional	1

Table 6. The relationships among teachers' beliefs of teaching, learning and science.

Relationships		*N (%)*	*Total*
Nested	Teaching sci. Learning sc. ⟷ Nature of sci.	21 (57%)	21
Related	Teaching sci. ⟷ Learning sci.	9 (24%)	
	Learning sci. ⟷ Nature of sci.	3 (8%)	14
	Teaching sci. ⟷ Nature of sci.	2 (5%)	
Divergent	Teaching sci. Learning sci. ✕ Nature of sci.	2 (5%)	2

Based on the results in table 5, table 6 provides a summary of the interplay among teachers' beliefs about teaching science, learning science and the nature of science. Twenty-one among the 37 teachers showed congruent beliefs about teaching, learning and science. The proportion of these teachers was almost 60 per cent of the sample. For these teachers, their beliefs about teaching, learning and science could be viewed as a whole, while one belief system was highly related to another. This study, hence, calls these consistent belief systems as 'nested epistemologies'. The 'nested epistemologies' include teachers' pedagogical beliefs of teaching and learning science, as well as epistemological beliefs toward science. The nested epistemologies may influence how teachers perceive the implementation of science classes. Tsai (2000) also found that science students' views about the nature of science were nested with their perceptions of learning environments in science. For those teachers who did not demonstrate consistent beliefs across teaching, learning and science, most of them still expressed congruent beliefs across two belief systems (a total of 14 teachers, called as 'related' in table 6). For instance, nine of the teachers had similar beliefs toward teaching science and learning

Table 7. Teachers' belief relationships, sorted by teaching experiences.

Teaching experiences	*Belief relationships*	*N*
Less than 4 years	Nested	1
	Related	3
	Divergent	1
4–8	Nested	8
	Related	7
	Divergent	1
9–13 years	Nested	8
	Related	3
	Divergent	0
More than 13 years	Nested	4
	Related	1
	Divergent	0

science. For these teachers, their beliefs of teaching, learning and science, in some way showed some linkages. The results shown in table 6 also suggest that when two and only two among the three teachers' belief systems were consistent (i.e. the 'related' relationships in table 6), teachers' views of teaching and learning were more likely to be closely aligned than other possible combinations. Finally, as described previously, only two teachers' beliefs about teaching, learning and science did not show any consistency, called as 'divergent' in table 6.

A recent study by Boulton-Lewis *et al*. (2001) showed remarkably similar results on Australian teachers as those found in this study. Boulton-Lewis *et al*. explored 16 secondary teachers' beliefs of teaching and learning, and found that 12 teachers' (75 per cent) beliefs about teaching and learning were congruent. According to table 6 in the present study, 30 among the 37 teachers (81 per cent) showed consistent beliefs about teaching and learning (21 teachers from the 'nested' group and 9 from the first layer of the 'related' group). This implies that many teachers' beliefs about teaching and learning show a good consistency, despite the fact that a huge cultural difference exists between Taiwan and Australia. Boulton-Lewis *et al*.'s (2001) study also revealed that the teachers holding inconsistent beliefs about teaching and learning usually had a higher position or goal about teaching than that about learning. Similarly, five among the seven teachers in the present study who had incongruent beliefs about teaching and learning (i.e., the final seven layers in table 5) expressed a higher position about teaching than that about learning. For instance, three of them held a 'constructivist' perspective about teaching while a 'process' view about learning. This suggests that teachers, if not showing consistent views about teaching and learning, often place a higher position or goal about their own teaching than their students' learning.

Table 7 further provides a simple analysis about teachers' belief relationships and teaching experiences. It is interesting to find that the 'nested' epistemologies tended to be found in teachers of greater teaching experience. For example, among the five of the most junior science teachers (i.e., less than 4 years of teaching), only one showed 'nested' epistemologies. However, the 'nested' epistemologies were found on eight among the 11 teachers of 9–13 years of teaching, and four among the five of the most senior teachers (i.e., more than 13 years of teaching). The

proportion of the 'nested epistemologies' teachers seemed to increase as the teaching experiences progressed. Nevertheless, among the four most senior science teachers who were categorized as 'nested', three of them showed a consistent 'traditional' view about teaching, learning and science, while the other one expressed a consistent 'process' view. Moreover, according to table 5, two teachers revealed 'nested' 'constructivist' epistemologies. A further examination found that one was in the most junior science teaching group (less than 4 years), while the other one was in the 4–8 years of teaching experiences. This finding may have come from the fact that these relatively junior science teachers may have encountered more constructivist ideas in teacher education programmes or relevant workshops. In Taiwan, junior or novice teachers, in general, were a group of teachers who more actively participated in teaching workshops and related seminars. Another possibility was the idea that these teachers' limited teaching experiences might help them easily accept innovative thoughts of instruction, for example, the constructivist view. A further exploration addressing on this may be very potential to understand the dynamics of teachers' beliefs.

Discussion and implications

Most teachers in this study expressed a traditional – empiricist or logical positivist – view of science, similar to the findings derived from previous studies (e.g., Gallagher 1991, Lederman 1992). The study completed by Donnelly (1999) also showed that many science teachers held a belief that scientists place a stronger emphasis on established knowledge and perceive uncertainty as threatening. Science teachers in this study also showed a similar, that is, traditional-oriented, conception about teaching science and learning. This finding was also revealed by earlier research (e.g. Aguirre *et al*. 1990). In this view, the teacher is simply a presenter of the factual content of scientific knowledge, transferring knowledge to students, while learning is a process of knowledge reproduction. This study suggests that these conceptions are held by teachers of different cultures and various educational systems (Gustafson and Rowell 1995, Koballa *et al*. 2000).

The fact that many teachers hold traditional views of teaching science, learning science, and the nature of science, may stem from the problem of their own school science experience. The science classes, laboratory exercises, relevant activities in teacher education programmes may have reinforced the 'traditional' views. For example, Hodson (1998) cautions that extensive use of the algorithm recipes of laboratory work leads students to believe in *a* method of science. Also, the high success of school science experiments shapes the illusion of certain knowledge in science. Tsai (1999) also provided a case about how students may distort the nature of laboratory activities in common science classrooms. An eighth grader in the study reflected that:

> The only purpose of school laboratory exercises is to help me memorize the scientific truths . . . I cannot see any other benefit of school laboratory work. Often, I think doing laboratory in science classrooms is a waste of time. If our experimental results fit the laws presented in the texts or by teachers, we have to memorize them. On the other hand, if our lab results do not fit the expected outcomes, we have to discard or distort our results, and finally try to memorize all of the 'scientific truths' listed in science texts . . .

Many teachers may have acquired similar experiences and views while science students. These experiences, then, may impose an effect on their beliefs of teaching, learning and science. Moreover, Trumbull and Slack (1991) believed that teachers failed to develop constructivist-oriented ideas about teaching and learning due to the fact that they had all experienced success in the existing, i.e. traditional-oriented, educational environments. Therefore, these teachers may not perceive potential insights about constructivist conceptions of learning and teaching. Gustafson and Rowell's (1995) study also revealed that some teachers possessed a belief that students' learning preferences may mirror their own and they believed that students should approach science in those ways. Hence, it is recommended that teacher education programmes need to discuss a variety of conflicting conceptions of teaching, learning, and science for preservice science teachers.

The next issue educators face is how to change teachers' 'traditional' beliefs about teaching, learning and science. Abd-El-Khalick and Lederman (2000) have proposed ways of improving science teachers' conceptions of the nature of science, including implicit and explicit approaches. The implicit approach uses science-based inquiry activities, and the explicit approach utilizes elements from the history and philosophy of science in the instructional processes. This study further suggests that teachers' beliefs about the nature of science, in many cases, are related to their beliefs of learning and teaching. That is, these beliefs are viewed as 'nested epistemologies'. Changing teachers' beliefs of teaching and learning science may be a prerequisite of changing their beliefs about science, or vice versa; changing teachers' beliefs about the nature of science may be a prerequisite of changing their beliefs about teaching and learning science. Developing teachers' understanding about the constructivist epistemologies may be an essential component of teacher education programs. Flores *et al.*'s (2000) study has suggested that passing from empiricist and behaviourist perspectives of teaching science towards constructivism is a difficult and complicated transformation. Research about teachers' progressive transitions about teaching, learning and science may be important for further exploration. Earlier studies mainly focused on teachers' belief change about the nature of science (e.g. Abd-El-Khalick and Lederman 2000); therefore, researchers are encouraged to find ways of improving teachers' conceptions about teaching and learning science. For example, providing opportunities for teachers of different pedagogical perspectives to critically discuss and reflect on their pedagogies may be a potential way of changing teachers' beliefs of teaching and learning.

This study further hypothesizes that teachers' beliefs about teaching and learning toward one discipline are discipline- or content-dependent. That is, one teacher may have beliefs toward teaching science that are very different from those of teaching history. However, this study suggests that the teacher's beliefs of learning science, teaching science and the nature of science are very likely to be closely aligned, while his or her beliefs of learning history, teaching history and the nature of history may be also closely related in another way. That is, the 'nested epistemologies' are discipline-dependent, but this hypothesis, clearly, needs further research.

Although this study showed some evidence that teachers' beliefs of teaching science, learning science and the nature of science are interrelated, it does not necessarily mean that teachers' beliefs of learning science and the nature of science necessarily influence the 'action' of teaching science. For example, while earlier

studies have revealed that there may be a consistency between teachers' beliefs about the nature of science and instructional practice (Brickhouse 1989), these correspondences, in many cases, are more complicated than originally assumed (Duschl and Wright 1989, Lederman 1992, 1999, Mellado 1997). Mellado's (1998) study also demonstrated that there was not a general consistency between preservice science teachers' pedagogical views of teaching science and their classroom behaviour. Research is needed to clarify the relationships between teachers' beliefs and teaching practice. In other words, science educators face a more pressing question: the relationship between teacher beliefs and teacher action. Nevertheless, this study believes that science teachers' beliefs about teaching, learning and science, at least, impose some effects on teachers' 'perceptions' of the practice of science instruction.

Finally, the framework of analysing teachers' beliefs about learning, teaching and science employed in this study, as that proposed by Koballa *et al*. (2000), does not imply a developmental sequence; however, it may be useful for researchers to analyse teachers' beliefs about teaching, learning and science. Science educators and researchers of science teacher education are encouraged to deeply explore teachers' beliefs of teaching, learning and science with a larger sample of teachers of various experiences and cultural backgrounds.

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Notes

1. In this paper, 'beliefs', 'views' and 'conceptions' are used interchangeably.
2. Some synonyms and similar terms were represetned by the same descriptor. For example, correct answer, accurate description and precise explanation were coded into a descriptor of 'accurate description' about teachers' beliefs about the nature of science.
3. The process approach is called as 'discovery learning approach', while the constructivist approach is called as 'conceptual change approach' by Hewson and Hewson (1987).

References

Abd-El-Khalick, F., Bell, R. L. and Lederman, N. G. (1998) The nature of science and instructional practice: making the unnatural nature. *Science Education,* 82 (4), 417–437.

Abd-El-Khalick, F. and Lederman, N.G. (2000) Improving science teachers' conceptions of nature of science: a critical review of the literature. *International Journal of Science Education*, 22 (7), 665–701.

Aguirre, J. M., Haggerty, S. M. and Linder, C. J. (1990) Student-teachers' conceptions of science, teaching and learning: a case study in preservice science education. *International Journal of Science Education*, 12 (4), 381–390.

Bodner, G. M. (1986) Constructivism: a theory of knowledge. *Journal of Chemical Education*, 63 (10), 873–878.

Boulton-Lewis, G. M., Smith, D. J. H., McCrindle, A. R., Burnett, P. C. and Campbell, K. J. (2001) Secondary teachers' conceptions of teaching and learning. *Learning and Instruction*, 11 (1), 35–51.

Brickhouse, N. W. (1989) The teaching of the philosophy of science in secondary classrooms: Case studies of teachers' personal theories. *International Journal of Science Education*, 11 (4), 437–449.

Donnelly, J. (1999) Interpreting differences: the educational aims of teachers of science and history, and their implication. *Journal of Curriculum Studies*, 31 (1), 17–41.

Duschl, R. A and Wright, E. (1989) A case study of high school teachers' decision making models for planning and teaching science. *Journal of Research in Science Teaching*, 26 (6), 467–501.

Flores, F., Lopez, A., Gallegos, L. and Barojas, J. (2000) Transforming science and learning concepts of physics teachers. *International Journal of Science Education*, 22 (2), 197–208.

Gallagher, J. J. (1991) Prospective and practicing secondary school science teachers' knowledge and beliefs about the philosophy of science. *Science Education*, 75 (1), 121–133.

Gustafson, B. J. and Rowell, P. M. (1995) Elementary preservice teachers: constructing conceptions about learning science, teaching science and the nature of science. *International Journal of Science Education*, 17 (5), 589–605.

Hewson, P. W. and Hewson, M. G. (1987) Science teachers' conceptions of teaching: Implications for teacher education. *International Journal of Science Education*, 9 (4), 425–440.

Hewson, P. W. and Hewson, M. G. (1988) An appropriate conception of teaching science: A view from studies of science learning. *Science Education*, 72 (5), 597–614.

Hodson, D. (1998) Becoming critical about practical work: changing views and changing practice through action research. *International Journal of Science Education*, 20 (6), 683–694.

Holt-Reynolds, D. (2000) What does the teacher do? Constructivist pedagogies and prospective teachers' beliefs about the role of a teacher. *Teaching and Teacher Education*, 16 (1), 21–32.

Jenkins, E. W. (2000) Constructivism in school science education: Powerful model or the most dangerous intellectual tendency? *Science & Education*, 9 (6), 599–610.

Kang, N.-H. and Keys, C. W. (2000) *An Investigation of Secondary School Science Teachers' Beliefs About and the Practices of Hands-on Activities*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA.

Koballa, T., Graber, W., Coleeman, D. C. and Kemp, A. C. (2000) Prospective gymnasium teachers' conceptions of chemistry learning and teaching, *International Journal of Science Education*, 22 (2), 209–224.

Leach, J., Millar, R., Ryder, J. and Sere, M. G. (2000) Epistemological understanding in science learning: the consistency of representations across contexts. *Learning and Instruction*, 10 (6), 497–525.

Lederman, N. G. (1992) Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching*, 29 (4), 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.

Maor, D. and Taylor, P. C. (1995) Teacher epistemology and scientific inquiry in computerized classroom environments. *Journal of Research in Science Teaching*, 32 (8), 839–854.

Matthews, M. R. (2000) Editorial (Special issue on constructivism, epistemology and the learning of science). *Science & Education*, 9 (6), 491–505.

Mellado, V. (1997) Preservice Teachers' classroom practice and their conceptions of the nature of science. *Science & Education*, 6 (4), 331–354.

Mellado, V. (1998) The classroom practice of preservice teachers and their conceptions of teaching and learning science, *Science Education*, 82 (2), 197–214.

Millar, R. and Driver, R. (1987) Beyond processes. *Studies in Science Education*, 14, 33–62.

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

NOLA, R. (1997) Constructivism in science and in science education: A philosophical critique. *Science & Education*, 6 (1), 55–83.

OSBORNE, J. F. (1996) Beyond constructivism. *Science Education*, 80 (1), 53–82.

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

STAVER, J. R. (1998) Constructivism: Sound theory of explicating the practice of science and science teaching. *Journal of Research in Science Teaching*, 35 (5), 501–520.

TILLEMA, H. H. (1994) Training and professional expertise – bridging the gap between new information and preexisting beliefs of teachers. *Teaching and Teacher Education*, 10 (6), 601–615.

TIRRI, K., HUSU, J. and KANSANEN, P. (1999) The epistemological stance between the knower and the known. *Teaching and Teacher Education*, 15 (8), 911–922.

TOBIN, K. (Ed.) (1993) *The Practice of Constructivism in Science Education* (Washington, D.C.: AAAS).

TRUMBULL, D. and SLACK, M. J. (1991) Learning to ask, listen, and analyze: using structured interviewing assignments to develop reflection in preservice science teachers. *International Journal of Science Education*, 13 (2), 129–142.

TSAI, C.-C. (1996) *The Interrelationships between Junior High School Students' Scientific Epistemological Beliefs, Learning Environment Preferences and Cognitive Structure Outcomes*. Unpublished doctoral dissertation, Teachers College, Columbia University, New York.

TSAI, C.-C. (1998a) An analysis of scientific epistemological beliefs and learning orientations of Taiwanese eighth graders. *Science Education*, 82 (4), 473–489.

TSAI, C.-C. (1998b) Science learning and constructivism. *Curriculum and Teaching*, 13 (1), 31–52.

TSAI, C. C. (1999) 'Laboratory exercises help me memorize the scientific truths': A study of eighth graders' scientific epistemological views and learning in laboratory activities. *Science Education*, 83 (6), 654–674.

TSAI, C.-C. (2000) Relationships between student scientific epistemological beliefs and perceptions of constructivist learning environments. *Educational Research*, 42 (2), 193–205.