From Misconceptions to Constructed Understanding
The Fourth International Seminar on Misconceptions Research
(1997)

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Keywords: scientific epistemological beliefs, learning environment, constructivism
General School Subject:
Specific School Subject:
Students:

Macintosh File Name: Tsai-Interplay
Release Date: 10-22-97 B, 12-5-97 C

Editor: Abrams, Robert
Publisher: The Meaningful Learning Research Group
Publisher Location: Santa Cruz, CA
Volume Name: The Proceedings of the Fourth International Misconceptions Seminar - From Misconceptions to Constructed Understanding
Publication Year: 1997
Conference Date: June 13-15, 1997
Contact Information (correct as of 12-23-2010):
Web: www.mlrg.org
Email: info@mlrg.org

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The Interplay between Scientific Epistemological Beliefs and Preferences for Constructivist Learning Environments of Taiwanese Eighth Graders

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ABSTRACT: Science educators have identified an individual's epistemological beliefs about science as an essential feature of his (or her) conceptual ecology; these beliefs may shape his (or her) metalearning assumptions and then influence his (or her) learning orientations or preferences. This study was conducted to explore the interplay between students' scientific epistemological beliefs and their preferences for constructivist learning environments. Through analyzing forty-eight Taiwanese eighth graders' questionnaire responses, in-depth interview results and their reflections on a series of treatment lessons conducted by a combination of both traditional and constructivist instructional strategies, this study found that students having epistemological beliefs more oriented to constructivist views of science (as opposed to empiricist views about science) tended to show significantly stronger preferences to learn in the constructivist learning environments where they could (1) interact and negotiate meanings with others ($p<.05$), (2) integrate their prior knowledge and experiences with newly constructed knowledge ($p<.05$), and (3) meaningfully control their learning activities ($p<.001$). Qualitative details also revealed that students holding constructivist epistemological beliefs about science tended to employ more meaningful strategies when learning science, whereas students having epistemological beliefs more aligned to empiricism tended to use rote-like learning strategies to enhance their understanding. However, students' epistemological orientations were not significantly related to their achievement on traditional science tests. The main trust of the findings drawn from this study indicate that teachers need to be very aware of the student's epistemological orientation toward scientific knowledge, and to complement these preferences when designing learning experiences, especially to provide constructivist-based lessons to enhance science learning by students who are constructivist-oriented.

INTRODUCTION

In the past two decades, science educators have contributed substantially to a better understanding of students' scientific "misconceptions" or "alternative conceptions" (Helm & Novak, 1983; Novak, 1987; Wandersee, Mintzes & Novak, 1994). This research is particularly significant since most of us agree that the learners' prior knowledge highly influences how new knowledge is constructed (Ausubel, Novak & Hanesian, 1978). However, to fully account for the organizing role of prior knowledge in gaining new knowledge and skills, we should not limit our attention to students' alternative conceptions. Other aspects of their knowledge structures and patterns of reasoning are worth investigating, including philosophical and attitudinal variables. For example, there is research evidence that students' *Scientific Epistemological Beliefs* (SEB) play an essential role in determining their learning orientations toward science as well as the formation of their alternative conceptions (Edmondson, 1989; Hammer, 1995;

Songer & Linn, 1991), and science educators have identified an individual's SEB as an essential feature of his or her conceptual ecology (Demastes, Good & Peebles, 1995; Hewson & Hewson, 1984; Posner, Strike, Hewson & Gertzog, 1982; Strike & Posner, 1982). The student's SEB also influence the depth of his or her understanding about science content (Furnham, 1992) as well as the kinds of strategies or types of problem-solving decisions used to analyze anomalous data during scientific knowledge construction (Chinn & Brewer, 1993). These beliefs will very likely guide the student's metalearning assumptions. For example, Roth and Roychoudhury (1994) state that:

> [I]f science is presented to students as a body of knowledge, proven facts, and absolute truths, then they will focus on memorizing facts and think that all knowledge can be ascertained through specific proof procedures embedded in the scientific method. If, on the other hand, students experience science as a continuous process of concept development, an interpretive effort to determine the meaning of data, and a process of negotiating these meanings among individuals, then students might focus on concepts and their variations. (p.6)

Hence, students' SEB may shape their metalearning beliefs and consequently influence their learning orientations or preferences. Moreover, we should note that in science classrooms, how the teacher explains scientific ideas and organizes information can be important as a model in determining students' SEB and their learning preferences. That is, the learning environment created by the science teacher also plays a role in shaping students' perceptions of the way science is practiced and how new knowledge is created. Eric, a subject in a study by Tobias (1990) wrote the following essay to reflect on his experiences when he was enrolled in a college physics course.

> The class consisted basically of problem solving and not of any interesting or inspiring exchange of ideas. The professor spent the first 15 minutes defining terms and apparently that was all the new information we were going to get on kinematics...... I still get the feeling that unlike a humanities course, here the professor is the keeper of the information, the one who knows all the answers. This does little to propagate discussion or dissent. The professor does examples the "right way" and we are to mimic this as accurately as possible. Our opinions are not valued, especially since there is only one right answer, and at this level, usually only one [right] way to get it. (pp. 20-21)

Eric's reflection could be interpreted as follows. First, the learning environment directed by the professor may misguide how Eric views scientific knowledge by leading him to think that scientific knowledge is a collection of absolute truths. Second, perhaps Eric has SEB close to a constructivist view of science, so he is not comfortable in such a science classroom emphasizing didactic methods, a learning environment opposite to his preferences. Students' learning environment preferences, to a certain extent, also represent their beliefs about what constitutes learning and how knowledge is created. As an example, a high school student in Gunstone's study (1991) who strongly asserted that science was a collection of proven facts and formulae did not see any advantage of the "conceptual change" teaching strategy even after he had really experienced it. The preceding discussion gives us some clues for the interaction between students' SEB and their preferences for certain learning environments.

Currently, constructivist learning environments are highly advocated by science educators (Appleton, 1997; Fosnot, 1996; Treagust, Duit & Fraser, 1996).

Students' scientific epistemological beliefs have been recognized as an important component of science learning environments (Roth & Lucas, 1997). This study is an attempt to explore the interplay between a group of Taiwanese eighth graders' SEB and their preferences for constructivist learning environments, with applications of the improvement of science teaching and learning.

METHODOLOGY

Subjects

This research was conducted with an initial sample of 202 eighth graders from four different classes in a junior high school near Taipei City in Taiwan, R.O.C. One may argue that eighth graders may not have strong beliefs about the epistemology of science. Therefore, in order to choose appropriate information-rich subjects of this project, the following criteria were employed to filter these students: (1) they were above-average achievers, (2) they expressed a strong *certainty* or *confidence* about their SEB based on questionnaire responses (Pomeroy's questionnaire, 1993). This set of criteria were used since the students would be expected to have proper self-awareness about their learning preferences as well as their SEB. Students' science achievement was represented by their scores on two school-wide science examinations. Among those who met the above criteria, a total of forty-eight students from the four participating classes were randomly selected for this study. This final sample included 18 females and 30 male students.

Instruments

A Chinese-version of Pomeroy's questionnaire (1993) was administered to assess students' certainty or confidence of SEB. The questionnaire consists of bipolar agree-disagree statements on a 5-1 Likert scale, ranging from empiricist to constructivist views about science. The empiricist views about science tend to support that: (1) scientific knowledge is unproblematic and it provides *right* answers, (2) scientific knowledge is *discovered* by the *objective* data gathered from observing and experimenting or from an universal scientific method (3) scientific knowledge is additive and bottom up, and evidence accumulated carefully will result in sure knowledge (Carr et al, 1994; McComas, 1996; Strike & Posner, 1985), whereas the constructivist views assert that scientific knowledge is *constructed* (or *invented*) by scientists, its status is tentative and its development experiences a series of revolutions or paradigm-shifts (Kuhn, 1970; Tsai, 1996a). The final questionnaire for this study was developed by selecting Pomeroy's items representing "traditional views of science" (empiricist views) and "nontraditional views of science" (constructivist views), a total of 17 items. Pomeroy (1993) reported that the internal consistency for these two parts of the questions were moderately high (Cronbach's α=.651, and .591 respectively). The following two statements are sample items, cited from the questionnaire.

1. Science is the ideal knowledge in that it is a set of statements which are objective; i.e., their substance is determined entirely from observation. (identified as traditional or empiricist views)
2. Non-sequential thinking, i.e., taking conceptual leaps, is characteristic of many scientists. (identified as nontraditional or constructivist views)

To assess respondents' certainty or confidence about their SEB, after making a choice for each question, they were asked to answer the following question:

"Concerning this choice, I am: (1) guessing (2) uncertain (3) fairly certain (4) sure." The questions that elicited responses of "fairly certain" or "sure" were viewed as confident items, and the students with over three quarters of items in the questionnaire which were identified as confident were viewed as appropriate subjects for this study.

To assess students' preferences for constructivist learning environments, a Chinese-version of the Constructivist Learning Environment Survey (CLES) originally developed by Taylor and Fraser (1991) was administered. The CLES contains four scales (seven items for each scale): (1) negotiation scale, (2) prior knowledge scale, (3) autonomy scale and (4) student-centredness scale. Taylor and Fraser reported the α-reliability to be .85, .69, .73 and .73 for each scale of CLES. The following four questions are sample items for CLES instrument.

1. In this class, I prefer to ask other students about their ideas. (negotiation scale)
2. In this class, I prefer to see if what I learned in the past still makes sense to me. (prior knowledge scale)
3. In this class, I prefer to do investigations in my own way. (autonomy scale)
4. In this class, I prefer the teacher to show the correct method for solving problems. (student-centredness scale, stated in a reverse manner).

Each CLES item has a five point Likert scale with categories ranging from "very often" (5) to "never" (1). The translation of Pomeroy's questionnaire and CLES was validated by two Chinese-speaking researchers and the researchers tried to rephrase the questionnaire statements (especially Pomeroy's questionnaire) so that these eighth graders could understand the questions without any difficulty. Further, these Chinese-version questionnaires showed adequate reliabilities in a pilot study conducted in the same junior high school (all α reliability coefficients were around .75). In addition, further evidence of the validity of the questionnaire items was obtained by interviewing a subset of twenty students who took the questionnaire and it was concluded that their SEB and learning preferences as educed from interview questions were consistent with their responses on the questionnaires (Tsai, 1996a). Some of the interview details will also be presented in this paper later.

Scoring

Students' responses of confident items on Pomeroy's questionnaire (i.e., showing students' strong certainty or confidence) were scored as follows. For the "constructivist-perspective" items, a "strongly agree" response was assigned 5 and a "strongly disagree" response was assigned a score of 1. Items representing an empiricist view were scored in a reverse manner; that is, a "strongly agree" response was assigned 1 and a "strongly disagree" response was assigned a score of 5. Thus, on the total questionnaire, students having strong beliefs about constructivist views would have higher *average* scores. A similar scoring system was applied to the results of the CLES questionnaire; consequently, students showing strong preferences for constructivist learning environments would earn higher total scores on CLES scales. Their CLES responses were also consistent with their reflections on treatment lessons (lasting two hours) conducted by a combination of both traditional (e.g., one-direction lecturing without carefully relating to students' prior knowledge) and constructivist instructional strategies (e.g., student-controlled small group discussion and negotiation), as shown in Table 1.

Table. 1. The consistency between students' reflections on their learning activity preferences for the treatment lesson and their CLES scores (n=48).

	Prefer a constructivist learning activity in the treatment lesson	Prefer a traditional learning activity in the treatment lesson	No specific learning activity is preferred in the treatment lesson
Top 20% CLES (n=10)	7 (70%)	1 (10%)	2 (20%)
Bottom 20% to top 20% CLES (n=29)	11 (38%)	8 (28%)	10 (34%)
Bottom 20% (n=9)	3 (33%)	3 (33%)	3 (33%)

□

This table shows that the top 20% CLES group, those who were ranked as the top 20% CLES total scores (of all scales) among those final subjects, had a higher proportion of students who preferred a constructivist-oriented learning activity (70%), whereas the bottom 20% CLES group, those who were ranked as the bottom 20% CLES scores among the students, had a much lower percentage of students who showed their preferences for a constructivist instructional strategy (33%) and had a relatively higher proportion (compared to the top 20% CLES group) of students preferring traditional learning activity (33%). These results basically show a consistency between students' self-reflections about their preferences of actual learning activities and their CLES questionnaire responses. By and large, this study examined a one-dimensional assessment of students' SEB and their preferences for constructivist learning environments; namely, a continuum from empiricist to constructivist perspectives.

RESULTS AND DISCUSSIONS

In order to acquire quantitative results about the interplay between students' SEB science and their learning environment preferences, the relationships between students' responses on Pomeroy's questionnaire and their scores on the CLES instrument were explored; the correlation coefficients are presented in Table 2.

Table 2. The correlation between students' epistemological views about science and their preferences for constructivist learning environments (n=48)

	NEGO	PRIRKNW	ATNMY	STDTCTR
EPSTMO	.36*	.29*	.52***	-.15

* p<.05, ** p<.01, *** p<.001

Note.

EPSTMO: Students' scientific epistemological beliefs (SEB), resulting from their responses on Pomeroy's questionnaire (1993)
NEGO: CLES negotiation scale
PRIRKNW: CLES prior knowledge scale
ATNMY: CLES autonomy scale
STDTCTR: CLES student-centredness scale

Students' responses to Pomeroy's questionnaire were significantly correlated with their scores on three of the four scales of the CLES. Students holding epistemological beliefs more close to constructivist views about science tended to show a significantly stronger preference to learn in the constructivist environments where they could (1) interact with others, negotiate meanings, and build consensus with others (NEGO; $r = .36$, $p<.05$), (2) have enough time to integrate their prior knowledge and experiences with newly constructed knowledge (PRIRKNW; $r = .29$, $p<.05$), and (3) have opportunities to exercise deliberate and meaningful control over their learning activities and to some extent think independently (ATNMY; $r = .52$, $p<.001$). That is, there is a positive relationship between "knowledge constructivist" and "learning constructivist" orientations, in Hashweh's terminology (1996, p.49). However, there was no significant correlation between students' epistemological beliefs about science and the extent of their preferences to experience learning as a process of creating and resolving personally problematic experiences (CLES student-centredness scale). That is, knowledge constructivists did not tend to prefer student-centered learning activities more than those who scored higher on the knowledge empiricist dimension, and many of them, whether they were categorized as knowledge constructivists or empiricists, still tended to rely on teachers' authority for lesson planning. By and large, the quantitative results reveal that there was an interplay between students' scientific epistemological beliefs and their preferences for constructivist learning environments. This interaction indicates that students who express a philosophical perspective close to a constructivist view of science may benefit most from constructivist science teaching. It further implies that an appropriate view about constructivist epistemology of science may be an essential prerequisite for implementing constructivist-based instructional strategies. Recent research assert that students' epistemological beliefs (either in general or about science) may mainly come from their formal schooling (Gallagher, 1991; Tsai, 1996a, 1996b). As a result, if formal schooling does not carefully inform the constructivist epistemology for students, it is expected that the practice of constructivism in science education could not be quite successful.

Students' in-depth interview details confirm the interplay between students' SEB and learning preferences. Students ranked as top 15% on Pomeroy's questionnaire (labeled as "knowledge constructivist" subjects) have the following responses.

> R(Researcher): Describe (or imagine) a science classroom situation (including the teacher and students) where you felt (or feel) as though you were (or are) really learning or you could learn best?
>
> S1: The teacher should be flexible in teaching. The teacher and students should cooperate with each other and enjoy studying something together.

> Students, as small groups, should discuss together and then tell the teacher their ideas or conclusions. Then, the teacher can adjust our ideas. He [or she] cannot just tell us the final answer.
>
> S3: Teachers should tell us just the big ideas. The rest of the ideas should leave to us to explore by ourselves. Teachers should give us opportunities to discuss the ideas and they also should give us enough time to conceptually understand these ideas.

On the other hand, students ranked as bottom 15% on Pomeroy's questionnaire (labeled as "knowledge empiricist" subjects) have the following responses to the same interview question.

> S2: The teacher should try his [or her] best to explain his [or her] ideas as clear as possible.
>
> S4: The teacher should tell us very clearly what to memorize. Also, we should have very good textbooks.

It is clear that knowledge constructivist subjects tended to agree that they could learn best by discussing with others, and to certain extent, constructing their own knowledge, sharing the basic characteristic of constructivist learning environments. These preferences may come from the fact that they believed that scientific knowledge was constructed by people's negotiation and a series of human decision-making. On the other hand, knowledge empiricist subjects tended to highlighted that the clarity of teachers' lecturing was an important indicator for their learning preferences.

Students' responses about the ways they checked whether they had already known some scientific concepts raised another potential finding for this study.

> R (Researcher): How do you ensure that you have already known something? For example, when you learn the concept about "density," how do you ensure that you have already understood the concept of density?
>
> S3 (knowledge constructivist subject): I can solve all of the problems about the concept of density without referring to the solutions provided by textbooks or reference books. I use the key concept, not the memorization, to solve the problems. If I can do so, I think I have already understood it.
>
> S11 (knowledge constructivist subject): First, I can use two or three methods to solve the same problem. And then, I can tell others students how to solve it, not just the problem-solving procedures.
>
> S16 (knowledge empiricist subject): If I get a pretty good grade in the exam, I think I quite understand the concept. (R: What does it mean by a pretty good grade?) I think, in general, above 80 (on the basis of 100).
>
> S2 (knowledge empiricist subject): If I finish practicing all of the problem sets or the tutorial exercises in the resource books and there is no serious difficulty for me to solve them, I am sure that I have already understood it.
>
> S12 (knowledge empiricist subject): If the problems about the concept of density are given to me and then I can quickly know how to solve them, this means that I have already understood it.

In fact, most knowledge constructivist subjects had similar responses as those stated by S3 and S11, whereas many knowledge empiricist subjects showed the same ideas as those presented by S16, S2 and S12. According to the qualitative details above, knowledge constructivist students tended to employ some meaningful learning strategies when learning science. First, they tried to explain to others what they had already known (e.g., S11). The interaction with others was an important way for them to ensure their understanding. Further, they took a more active manner in learning science; for example, S3 tried to solve all of the problems by herself without referring to the solutions offered by textbooks or reference books. That is, she intended to meaningfully control her learning activity. They also highlighted the use basic big ideas, not memorization, to solve problems or understand natural phenomena (e.g., S3). Finally, they tried to use different methods to solve the same problem (e.g., S11), which may have helped them to organize a more consistent and flexible knowledge structure of scientific concepts. All of these could be viewed as meaningful learning orientations. Only one knowledge constructivist student simply used the capability to successfully solve numerous stereotypical tutorial problems as the criterion to assess her understanding. However, empiricist students tended to use their performance on examinations (e.g., S16) and the ability to solve various tutorial problems (e.g., S2 and many others) as the criteria to evaluate their learning. They may have tried to familiarize these facts by repeated problem-solving practices or perhaps rote memorization. This further implies knowledge empiricist subjects tended to use rote-like learning strategies to enhance their understanding.

It was also informative to find that these students' epistemological orientations toward science were not significantly correlated with their science achievement measured by traditional tests (r=.04, n.s., n=48). That is, students having more constructivist-oriented SEB were not necessarily higher achievers, whereas students holding empiricist SEB were not necessarily relatively lower achievers. This, as proposed by Novak (1985), implies that the traditional way of testing or evaluation cannot effectively differentiate the meaningfulness of students' science learning.

This study was not conducted by a true experimental research design; hence, it is limited to correlation analyses between students' scientific epistemological beliefs and learning preferences. However, the research results support findings revealed by earlier studies (e.g., Edmondson, 1989; Hammer, 1995; Roth & Lucas, 1997; Songer & Linn, 1991), which strongly suggest that students' scientific epistemological beliefs were an essential component in determining students' learning preferences or orientations. The main thrust of the findings derived from this study indicate that teachers need to be highly aware of the student's epistemological orientation toward science, and to complement these preferences when designing learning experiences, especially to provide constructivist-based lessons to enhance science learning by students who are constructivist-oriented.

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