Science Epistemological Beliefs of Form Four Students and Their Science Achievement Using Web-Based Learning

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Abstract: *Epistemological beliefs affect student motivation and learning. They have been found to play a significant role in the acquisition of the capacity to control and direct one's cognitive processing (Lindner, 1993). In particular, science epistemological belief is considered an important factor in science achievement and positive science attitudes among students (Cobern, 1991). Based on the premise above, the purpose of this study was (1) to examine the science epistemological beliefs of Form Four students in Malaysia, and (2) to find out if there was a significant difference in the science achievement of students with high science epistemological beliefs and those with low belief when learning science using different Web-based modules. The sample comprised 169 students from ten schools in the state of Perak. The instrument used in this study was the "Nature of Scientific Knowledge Scale" developed by Rubba (1977). Six factors of the science epistemological beliefs, that is amoral, creative, developmental, parsimonious, testable and unified, were analysed using descriptive statistics. Results showed that the highest ranked factor was testable, followed by unified, creative, developmental and amoral. The lowest ranked factor was parsimonious. Analysis of t-tests for independent means showed that the science achievement of students with high science epistemological beliefs who followed the constructivist approach was significantly higher than those who followed the direct instruction approach. However, there was no significant difference between the science achievement of students with low science epistemological beliefs who followed the constructivist approach and those who followed the direct instruction approach. 2-way ANOVA analysis showed that the interaction effect between type of approach for web-based learning and science epistemological beliefs was significant, suggesting that the effect of the type of web-based learning approach is dependent on the science epistemological beliefs held by the students.*

INTRODUCTION

What makes some students better achievers in science than others? What is the effect of learning approach on students' science achievement? The body of literature available indicates that the answer to that question is neither simple nor fixed. Throughout the years where science education has developed and progressed in different countries, numerous factors have been researched and the findings are that they are varied and some are inter-related. One of the areas science educators have increasingly been concerned about, and that has developed significantly over the past three decades, is the epistemological beliefs held by learners and how they affect learning. Among other factors that have been examined are self-efficacy beliefs, achievement goal orientation, motivation, attitude toward science, choice of learning strategy, learning styles, and locus of control.

REVIEW OF RELATED LITERATURE

Definition of Epistemological Belief

Literature gives a varied definition of personal epistemological beliefs, depending on the type of study conducted. Schreiber (2004) noted that research on students' epistemological beliefs has grown significantly together with the development of models of epistemological beliefs. While some studies focus on beliefs about knowing and learning, others focus on the nature of knowledge. With regards to this, Schommer-Aikins, Mau, Brookhart and Hutter (2000) emphasized that while there appears to be a debate over the inclusion of learning beliefs as part of personal epistemology, both beliefs about learning and beliefs about knowledge seem to have a critical impact on student learning. In general, epistemological beliefs that focus on the nature of knowledge include beliefs about the origin of knowledge, the formation of knowledge and the characteristics of knowledge (Saunders, Cavallo & Abraham, 1999). According to Pajares (1992), personal beliefs are constructed from experience and used to interpret new experiences and information, and to guide subsequent action.

To date, extensive studies have been conducted to examine epistemological beliefs of both teachers and students in school subject areas such as science, mathematics and history. But, as Elder (1999) pointed out, there seems to be a lack of agreement in its definition even when one refers to epistemological beliefs in a particular subject area. Currently, a point of common understanding however is that beliefs are multi-dimensional and complex rather than uni-dimensional in nature (Schommer, 1994; Schommer-Aikins, Mau, Brookhart & Hutter, 2000). Besides that, an important point to note is that beliefs can be thought of independently, as well as together (Schreiber, 2004).

In this study, science epistemological beliefs refer to beliefs about the nature of scientific knowledge as proposed in the model developed by Rubba and Anderson (1978). The six factors identified are amoral (scientific knowledge itself cannot be judged as morally good or bad), creative (scientific knowledge is partially a product of human creativity), developmental (scientific knowledge is tentative), parsimonious (scientific knowledge attempts to achieve simplicity of explanation as opposed to complexity), testable (scientific knowledge is capable of empirical test), and unified (the specialized sciences contribute to interrelated network of laws, theories, and concepts).

Epistemological Beliefs and How Students Learn

Studies on the relationship between students' epistemological beliefs and their academic performance are well established and on-going (Filisetti & Fives, 2003). A review of literature by Schommer (1994) revealed that "epistemological beliefs may either help or hinder learning" as the beliefs "affect the degree to which individuals: (a) actively engage in learning, (b) persist in difficult tasks, (c) comprehend written material, and (d) cope with ill-structured domains" (p. 302). She believed that these attributes play a crucial role in higher-level learning. Roulet (1998) further suggested that epistemological beliefs play a major role in the organisation and interpretation of one's knowledge.

In discussing self-regulated learning, Lindner (1993) stressed that epistemological beliefs interact dynamically with five other components, that is, motivational set, metacognition, learning strategies, contextual sensitivity and environmental control, in affecting the acquisition of the capacity to control and direct one's cognitive processing. Hofer (2001) also found that epistemological beliefs affect student learning on the whole because they affect student motivation and the choice of strategy used in learning tasks.

Specifically in the case of learning science, Saunders, Cavallo and Abraham (1999) stated that a person's science epistemological beliefs may affect how a person approaches the task of learning. A student who believes that science knowledge consists of isolated, factual information is likely accept 'facts' without questioning and memorize 'facts' without concern for understanding. On the other hand, a student who believes that science knowledge is complex is more likely to keep an open mind to new information and may exert more effort in understanding and connecting what has been taught. Therefore, if one were to compare the thinking that occurs in students with 'naive' beliefs to the ones with 'sophisticated' beliefs, one might say that the latter is of a higher order. Consequently this affects the student's achievement in science (Roth & Roychoudhury, 1994; Saunders et al., 1999; Schommer-Aikins et al., 2000). Meanwhile, studies on how epistemological beliefs affect conceptual understanding and conceptual change have also been well documented (Qian & Alvermann, 1995; Qian & Alvermann, 2000). Findings show that students with 'naive' epistemological knowledge may not be able to obtain an integrated understanding on science concepts. According to them, having high science epistemological knowledge facilitates conceptual understanding and conceptual change. Similar findings are also documented in Songer and Linn's (1991) research on the relationship between a student's science epistemological knowledge and the degree to which he/she integrates knowledge.

Science Teaching and Learning

Traditional science teaching which is based on an objectivist view of knowing and learning emphasizes direct transmission of 'truths' where the teacher is the 'sage on the stage', and students are generally passive receivers of knowledge and emphasis is on getting the 'right' answers (Roth & Roychoudhury, 1994). According to Joyce, Weil and Showers (1992), this is very much a behaviourist approach whereby the teaching-learning process follows the stimulus-response-reinforcement pattern. The teacher is the key figure in the classroom. The learning environment is, therefore, highly structured with much emphasis on the teacher handing out tasks for students to do, after explaining the relevant concepts.

In contrast to that, constructivist science classrooms are said to better resemble actual realities in science in that knowledge is obtained through the interpretation of data and negotiation of meaning from classroom experiences. Learning involves social interaction, use of authentic tasks and primary sources of materials that incorporate multiple perspectives. It also encourages reflection and social negotiations in constructing meaning in learning environments that reflect the complexity of the real world (Jonassen, 1994; Honebein, 1996).

The body of literature on the effect of various approaches on science achievement seem to give varied views on the effectiveness of the direct instruction approach as compared to other approaches, including the constructivist approach. Reviews conducted by Brophy and Good (1987) and Sipe (1995) seem to indicate that direct instruction is more effective than other methods. Other studies suggest that the constructivist approach helps students to understand scientific concepts more deeply and to remember them better (Gatlin, 1998; Morris, 1998; Christianson, 1999; Miller, 1999).

Web-based Learning Environments

With the current development in the use of the Internet for teaching and learning purposes, science educators now have the option of incorporating web-based learning. As in the traditional face-to-face mode, there are also a variety of ways to use the web for teaching and learning. It ranges from the objectivist type where students read notes and answer questions topic after topic (where links are linear), to the other end of the continuum where students obtain knowledge from multiple sites and are required to synthesize, analyse, and evaluate information obtained (as in referential type of hypertext or hypermedia).

However, the Web, with its special attributes such as synchronous and asynchronous communication tools, better fits a more constructivist type of learning environment. It enables students to collaborate with each other and also to communicate with experts in the field of study. Time and distance do not present any barrier or constraint to the learning process. Further, it allows the learner to decide the direction, pace and sequence of learning (Jamaludin, 1999).

Reeves (1998) noted that the advantage of using a constructivist approach in science learning involving computer technology is that complex cognitive learning strategies are activated. This enables the learner to be actively involved in constructing and restructuring knowledge, not just reproducing knowledge. Student learning therefore is active and at a higher order.

A meta-analysis conducted by Chen and Rada (1996) on eighteen research papers examining the interaction between learners and different forms of hypertext in experimental designs showed that hypertext does not have any significant advantage over other types of media. However, other studies have reported an increase in academic achievement among students who engage in complex and ill-structured hypertext learning environments (Jacobson & Spiro, 1995; Bills, 1997; Chen, 1998; Hueth, 1998).

In summary, the literature suggests that it is important and worthwhile to seriously consider designing science learning environments that take into consideration students' science epistemological beliefs. Further, Web-based learning offers instructional designers greater flexibility in incorporating various approaches to suit different types of students and to achieve different learning outcomes.

PURPOSE OF THE STUDY

The purposes of this study were to examine:

(1) the science epistemological beliefs of Form Four(10th grade) science students,
(2) differences in the science achievement of students with high science epistemological beliefs and those with low beliefs when learning science using different Web-based modules, and
(3) the main and interaction effects of web-based learning approach and type of science epistemological beliefs.

Understanding the influences on students' performance is one of the primary concerns of educational research (Filisetti & Fives, 2003). Since epistemological beliefs have been recognised as an important factor in science achievement, it is hoped that findings of this study would give science educators a better insight into the profile of epistemological beliefs held by Form Four students in the science stream. In addition to that, findings would help place the relative effect of different approaches in web-based learning on students with different science epistemological beliefs.

METHODOLOGY

Research Design

The study utilised a quasi-experimental 2 X 2 pre-test-post-test factorial design. The dependent variable investigated is the science achievement of Form Four students, the independent variable is the web-based learning approach and the moderator variable is science epistemological beliefs. The treatment involved the use of web-based modules to learn science. One approach was the direct instruction approach while the other was the constructivist approach. The students were allowed to access the modules only during school hours under the supervision of the researcher. The time taken to finish the modules was five to six hours over a period of four weeks for the direct instruction approach and seven to eight hours for the constructivist approach. Science epistemological beliefs was categorised into two groups that is high science epistemological beliefs and low science epistemological beliefs.

The research paradigm is as shown below:

O_1à X_1 à O_2
O_3à X_2 à O_4

where O_1 *and* O_3 are pre-tests and O_2 *and* O_4 are post-tests; X_1 represents the direct instruction approach for web-based learning and X_2 represents the constructivist approach.

The 2 X 2 factorial design utilized is as shown below:

	X_1	X_2
g_1		
g_2		

where X represents the type of treatment and g represents the moderator variable that is epistemological beliefs.

Research Questions

The research questions in this study were:

(1) How do the various factors of the science epistemological beliefs rank among Form Four science students?

(2) Using web-based learning, what is the effect of the constructivist approach as opposed to the direct instruction approach on the science achievement of students with different science epistemological beliefs?

(3) What is the effect of the type of approach for web-based learning and science epistemological beliefs on students' science achievement?

Null hypotheses were formulated and tested for research question (2)

Sample

The sample comprised 169 Form Four students from ten schools in the state of Perak. They were basically from two types of school, that is, boarding schools and day schools. All schools were chosen based on the availability of computer laboratories and Internet access facilities. In order to fulfil the requirements of the quasi-experimental research design, the schools were matched so that the samples for the two groups were equivalent in terms of students' academic ability as indicated by their Form Three standardized national examination, *Penilaian Menengah Rendah,* results. The vast difference in academic achievement of students from the boarding schools and the day schools will later be observed in the findings as large S.D. values were obtained in the science achievement test conducted.

Development of Web-based Modules

The web-based modules were based on the following topics taken from the upper secondary Biology syllabus: (1) Cell Biology, (2) Genetics, (3) Cell Division, and (4) Biotechnology. Issues in the biotechnology field such as human cloning and genetically modified food were incorporated in the modules. Content for the two treatment groups was the same; the only difference was the approaches, that is, one was based on the direct instruction approach and the other on the constructivist approach.

The direct instruction module involved the following sequence: (1) the orientation phase using an advanced organiser to present topics, (2) presentation of concepts from simple to complex, (3) guided practice and (4) free practice. The hyperlinks were linear in nature. On the other hand, the constructivist module had the following attributes: (1) the orientation phase using current issues in biotechnology, (2) questions posed to get students to give their opinions on issues being discussed, (3) multiple perspectives on issues, and (4) links to basic concepts in context to issues discussed (knowledge-in-context or 'just-in-time learning). The type of hyperlink used was the referential type to give students a greater control over the sequence of learning. Two threaded asynchronous discussions were included whereby students could post their opinions anonymously online and also reply to other students' responses.

The differences in interface design were minimised by ensuring both modules had the same navigation buttons and option to send e-mail to the teacher. The surface design characteristics that were maintained for both modules include background colour, font size and colour, and the type and total number of images. Three educational multimedia developers checked the prototype modules in terms of screen design while three experienced science teachers validated the content. Based on feedback obtained, the modules were improved content wise and presentation wise. Beta testing was carried out using students from the same age group. From observations, student logs and interviews conducted, further improvements were made to the modules before they were used in the actual study.

Instrumentation

The 'Nature of Scientific Knowledge Scale' (NSKS) developed by Rubba (1977) was used to measure the students' science epistemological beliefs. The questionnaire is paper and pencil based containing 48 items with a five-point Likert scale. There are eight items in each of the six sub-scales, that is, amoral, creative, developmental, parsimonious, testable and unified. Out of the eight items in each sub-scale, four are positively worded while the other four are negatively worded. To obtain scores, the responses for negatively worded items were recoded accordingly.

The minimum score for each sub-scale is 8.00 while the maximum score is 40.00. The minimum total score is 48.00 and the maximum is 240.00. As the neutral score is 144.00, a student who obtains a score that is less than the neutral score is deemed to possess low science epistemological beliefs while the students who scores higher than the neutral score is considered to have high science epistemological beliefs.

According to Rubba (1977), the content validity of this scale was established by a panel comprising nine experts in their own fields, that is, two science philosophers, two science educators, two scientists, two upper secondary school teachers and a psychometric consultant. The reliability of the NSKS has been extensively tested using student samples from grades nine to sixteen. The alpha coefficient of the scale is given in Table 1.

Table 1. *Reliability coefficient of the NSKS*

Sample	N	r_{kk}
Grade 9 General Science	101	0.65
Grades 9–10 Biology	311	0.74
Grades 10–11 Chemistry	111	0.74
Grades 11–12 Physics	36	0.77

The questionnaire used in this study was a Bahasa Melayu version, translated and tested by Norjoharudeen (1996). The reliability of the Bahasa Melayu version was established to have a coefficient of +.87 using the test-retest method. The alpha computed for this study was +.78.

The students' science achievement was measured using a written test that comprised 25 multiple-choice questions (50 percent of the total marks) and two essay-type questions (50 percent of the total marks). The total mark in this study was 100. An expert biology teacher and two experienced biology teachers validated the test, which covered all topics in the web-based modules. The value for Cronbach's alpha for the multiple-choice part was .71. The difficulty index for the questions ranged from .33 to .80 while the discrimination index ranged from .30 to .90. The multiple choice questions tested the three lower levels in

Bloom's cognitive domain that is, knowledge, understanding and application whereas the two essay type questions tested the students' ability to analyse, synthesize and evaluate knowledge. The essay-type questions were marked by two teachers with experience in marking the Biology paper at the Form Five standardized national examination (SPM) level. The inter-rater reliability was .85. The same questions were used for both pre-test and post-test and the science achievement was measured using the gain score. The test was conducted one week after treatment and the time allocated was one and a half hours.

Data Analysis

Descriptive statistics was used to examine the students' science epistemological beliefs. In order to rank the six factors for science epistemological beliefs, the mean and standard deviation for each factor were obtained. T-test for independent means was used to test the research hypotheses. Since the samples were homogenous as obtained from Levene's test for equality of variances, t-test for pooled samples was used. Two-way ANOVA was used to test the significance of the main and interaction effects of the treatment together with science epistemological beliefs on the science achievement of the Form Four students.

FINDINGS AND DISCUSSION

Rank Order of Science Epistemological Beliefs

Table 2. *Rank order of science epistemological beliefs*

Science epistemological belief	Mean	Standard deviation
Testable	32.29	3.29
Unified	31.49	3.87
Creative	27.55	4.94
Developmental	25.94	3.72
Amoral	24.71	4.37
Parsimonious	24.35	3.53

The science epistemological beliefs of the Form Four science students are shown in Table 2. Results showed that the highest ranked factor was 'testable', followed by 'unified', 'creative', 'developmental' and 'amoral'. The lowest ranked factor was 'parsimonious'.

The finding that 'testable' ranked highest suggests that the students have been well-exposed to the use of science experiments during the course of their studies and that they strongly believe that scientific knowledge is capable of empirical testing. This is in line with scientists' belief that in order to make a genuine scientific claim, the claim must be testable by public observational experience. The high ranking accorded to the factor 'unified' shows that the students consider the structure of scientific knowledge to be coherent and inter-related rather than disparate, weakly connected pieces of knowledge. The lowest ranking obtained for the factor 'parsimonious' showed that the students in this study do not ascribe much to the notion that scientific knowledge attempts to achieve simplicity of explanation.

The Effect of Type of Web-based Learning on Science Achievement of Students with High Epistemological Beliefs

Table 3. *T-test of science achievement of students with high epistemological beliefs*

Treatment	n	mean	S.D.	t	df	Sig (2-tailed)
Constructivist	64	20.98	8.85	4.664	125	.000*
Direct instruction	63	13.76	8.60			

* Significant at $p < .05$

As seen in Table 3, the t-value obtained was 4.664 ($p<.05$). There is a significant difference between the mean for science achievement of students with high epistemological beliefs who followed the constructivist approach as compared to those who followed the direct instruction approach. The mean for 64 students who followed the constructivist approach was 20.98 (S.D. = 8.85) while the mean for 63 students who followed the direct instruction approach was 13.76 (S.D. = 8.60). The effect size was calculated based on the formula $\frac{meanconstructivist - meandirectinstruction}{SDdirectinstruction}$

as given by Joyce *et al.* (1992). The value obtained was 0.84, which is considered to be large. One could therefore say that there is strong evidence to show that high epistemological beliefs students who follow the constructivist web-based learning approach have a higher science achievement than those who follow the direct instruction approach.

The Effect of Type of Web-based Learning on Science Achievement of Students with Low Epistemological Beliefs

Table 4. *T-test of science achievement of students with low epistemological beliefs*

Treatment	n	mean	S.D.	t	df	Sig (2-tailed)
Constructivist	16	18.20	8.20	1.072	39	.290
Direct instruction	26	15.23	8.73			

As seen in Table 4, there is no significant difference between the mean in science achievement of students with low epistemological beliefs who followed the constructivist approach when compared to the mean for those who followed the direct instruction approach. The mean for those who followed the constructivist approach was 18.20 (S.D. = 8.20) while the mean for those who followed the direct approach was 15.23 (S.D. = 8.73). The effect size obtained was 0.34, which may be considered small.

However, a point to note here is that the sample sizes for the two groups were not equal and also less than 30, therefore, the findings obtained should be interpreted with caution. The probability of a Type II error (of not rejecting the null hypothesis when it is in fact false) occurring is possible due to small sample sizes.

Findings of the analysis of variance for web-based learning approach and science epistemological beliefs are as shown in Table 5. The F-value obtained for type of approach is significant, that is, $F(1, 164) = 10.085$, $p < .05$. However, the F-value obtained for science epistemological beliefs is found to be not significant, that is $F(1, 164) = .168$, $p = .682$. The interaction effect for type of web-based learning approach and science epistemological belief is found to be significant, with $F(2, 164) = 11.540$, $p < .05$.

Main and Interaction Effects of Web-based Learning Approach and Science Epistemological Beliefs

Table 5. *Two-way ANOVA for web-based learning approach and science epistemological beliefs*

Source	Sum of squares	df	Mean square	F	Sig.
Main effect					
Web-based learning approach	760.255	1	760.255	10.085	.002*
Science epistemological beliefs	12.666	1	12.666	.168	.682
2-way interaction Web-based learning approach and science epistemological beliefs	1739.969	2	869.985	11.540	.000*
Explained	1776.423	3	592.141	7.855	.000*
Error	12363.428	164	75.387		
Total (Corrected)	14139.851	167			

* Significant at $p < .05$

The interaction effect between web-based learning approach and science epistemological beliefs is shown in Figure 1. Students with high science epistemological beliefs and also those with low beliefs obtained higher means for science achievement when learning using the constructivist approach as compared to the direct instruction approach. When direct instruction was used for web-based learning, the mean for science achievement of students with low beliefs was higher than that for students with high beliefs. On the other hand, when the constructivist approach was used, the mean for science achievement of students with high beliefs was higher than the mean for science achievement of those with low beliefs.

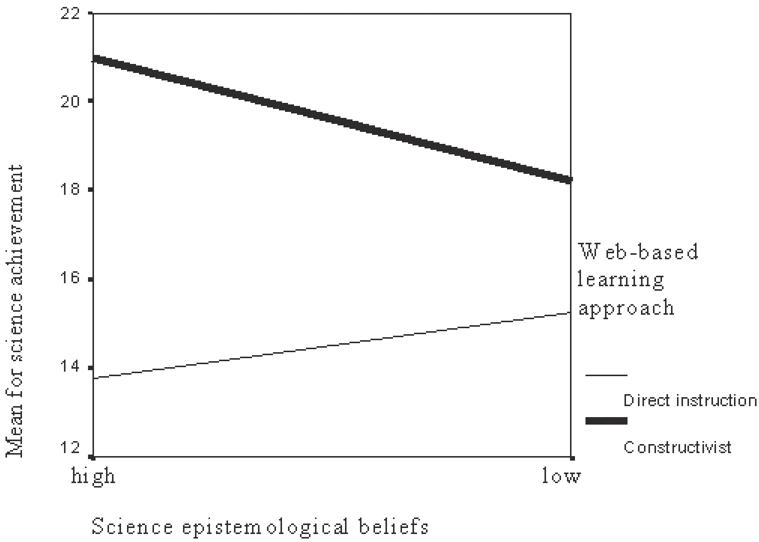

Figure 1. *Two-way interaction between web-based learning approach and science epistemological beliefs*

These findings corroborate with the views of Songer and Linn (1991), Qian and Alvermann (1995) and Qian and Alvermann (2000) reviewed earlier. It appears that students with dynamic or high science epistemological beliefs are more willing to be cognitively involved in investigating the status of knowledge claims. As a result they are able to perform better in ill-structured learning environments such as the constructivist web-based learning environment where multiple perspectives on current issues are presented in a tentative manner.

CONCLUSION

The findings from the analysis of inferential statistics in this study strongly suggest that students with high science epistemological beliefs achieve better science results in a constructivist web-based learning environment. However, the expectation, as gathered from the review of literature, that students with low science epistemological studies should fare better in a direct instruction web-based learning environment is not established here. The interaction effect between the web-based learning approach and science epistemological beliefs indicates that the effect of the former is dependent on the type of science epistemological beliefs held by the students. Students with high epistemological beliefs are more likely to benefit from a constructivist web-based learning environment.

Limitations of the Study

This study covered selected topics in the upper secondary syllabus that is Cell Biology, Genetics, Cell Division, and Biotechnology. The effect of web-based learning approach on other topics might or might not produce similar results. Further, respondents in this study were limited to students from schools which had access to computer laboratories and Internet facilities. The extent to which the findings might be generalised to students from other schools is therefore limited.

Suggestions for Further Research

To obtain a clearer picture of how high science achievers differ from the low achievers in their epistemological beliefs, a causal comparative study comparing the epistemological beliefs profile may be conducted. Also, research using a 2 X 2 factorial design to compare students' science achievement using web-based learning for low and high science ability as well as low and high epistemological beliefs could be carried out. This would enable one to examine the main and interaction effects of science ability and epistemological beliefs.

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