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Development of knowledge, awareness, critical thinking and argumentation of the 9th grade's students taught socio-environmental issues using mixed methods based on adapted problem-based learning

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Abstract The effects of two methods of teaching five socio-environmental issues on knowledge, awareness, critical thinking, and argumentation of 98 students of the 9th grade's students was investigated. The experimental group consisted of 49 students who learned using the mixed methods based on the adapted problem-based learning approach. A control group of another 49 students learned using the traditional teaching method. The research instruments included 10 lesson plans that tackle the five socio-environmental issues, five plans for each group with each plan given for 2 h of learning a week; a knowledge questionnaire; an awareness questionnaire; a critical thinking test, and an argumentation test. The major findings revealed that male and female students in the experimental group and control groups showed development in argumentation from the first to the sixth test and showed gains in knowledge, awareness, and critical thinking. Male students had more knowledge and awareness than female students, but there were not differencest in critical thinking and argumentation in both sexes. The experimental group showed more knowledge, awareness, critical thinking, and argumentation than the control group, w.hereas, the relationship between sex and learning model was found to be not significant.

Keywords: socio-environmental issues, mixed methods based on adapted problem-based learning, knowledge, awareness, critical thinking

Introduction

Our world today faces many critical problems. One major challenge is the degeneration of the environment and natural resources brought about by an expanding economy, especially in the industrial and agricultural sectors. Natural resources are destroyed or degraded, causingpollution that results in

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unusual changes in world temperature in many countries. Scientific evidence points to, human activities as the major cause of global warming, particularly the emission of greenhouse gases such as carbon dioxide, methane, nitrous oxide, and chlorofluorocarbon. These gases are produced by the burning of fossil fuels such as petroleum, coal and natural gases. (WMO, 2003). Global warming has consequent impacts on the environment such as the increase in sea water level due to the melting glaciers in the world polar zone (UNESCO and UNEP, 2011), drought, lack of water, desert expansion, and severe weather conditions (e.g., heavy rains, floods and cyclones) (Leighton, 2011). Mitigation, prevention, resolution, and adaptation to the changing environment are essential and educating the citizens, particularlymstudents, becomes crucial.The educational process can give knowledge and understanding and can change values, attitudes, awareness, and behaviors of students (UNESCO, 2014). In other words, environmental education can raise environmental awareness, promote sustainable development, improve the capacity of people to address environment and development issues, and generate effective action (Simon, 2000).

In pedagogy, teaching through a discussion of controversial topics has been recognized in the international science education community (Kolsto, 2006; Levinson, 2006). The controversial topics in science education are called socio-scientific issues (SSI) (Sadler, 2004). Most science classrooms are engaging in activities that focus on contemporary social issues that require scientific knowledge for informed decisionmaking (Sadler and Zeidler, 2005). This SSI must necessarily include students' active participation in developing argumentation skills, the ability to differentiate science from non-science issues, and the recognition of reliable evidence and data (Zeidler and Nichols, 2009). Socio-scientific issues involve the deliberate use of scientific topics that require students to engage in dialogue, discussion, and debate. They are usually controversial in nature but have the added element of requiring a degree of moral reasoning or the evaluation of ethical concerns in the process of arriving at decisions regarding possible resolution of those issues (Sadler, 2004; Zeidler and Sadler, 2008). These are some general characteristics of SSIs: they are important to society; have a basis in science; involve forming opinions; are frequently media-reported; address local, national, and global dimensions with attendant political and societal frameworks; involve values and ethical reasoning; may involve consideration of sustainable development and may require some understanding of probability and risks; and offer no "right" answers (Ratcliffe and Grace, 2003).

Newton *et al.* (1999) provide several compelling reasons for the explicit teaching of argumentation in science classrooms. First, an argument is the process by which scientific knowledge is developed and verified. Argumentation is the discourse of those who practice science. When students engage in argument, they begin to understand the norms and language of scientific debate and how knowledge is constructed in science. Second, the students actively participate in a discussion and are able to talk about their emerging scientific understanding. The development of the ability to argue will promote science learning because speaking and writing about science will build conceptual understanding. Third, the ability of young people to reason, think critically, understand and present arguments in a logical and coherent way both orally and in writing allows them to fully participate in society and is a desirable outcome of education in a democratic society. In teaching and learning about SSI, many methods are used for promoting argumentation ability and some higher order thinking such as critical thinking and analytical thinking. These methods from recent research studies are modified or adapted from original teaching methods: scientific method (Klachayan *et al.,* 2015), 5E-learning cycle approach (Wonganan *et al.,* 2015), 7E-learning cycle approach (Sirasungnoen *et al.,* 2015), and problem-based learning approach (Maneethong *et al.,* 2016).

The problem-based learning (PBL) approach is one type of inquiry and intellectual procedure emphasizing learner-centered activities and self-generating knowledge and understanding according to the constructivist view (Jonassen, 1991). Problem-based learning is a student-centered instructional method driven by an ill-structured, realistic problem on which students collaborate in order to develop feasible solutions (Hmelo-Silver, 2004). It creates a learning environment where students are active in the learning process (Lambros, 2004). The teacher assumes the role of a facilitator or guide, assisting students through the learning process with prompts, guidance, and resources (Savin-Baden, 2003). This PBL approach has a specific number of steps of learning, which varies according to experts. Two models implemented in many classrooms are the Delisle model (1997) and the Daniel model (2003). The Delisle model describes six steps: connecting with the problem, setting up a structure, visiting the problem, revisiting the problem, producing a product or performance, and evaluating performance and the problem. The Daniel model, on the other hand, has five: defining the problem, seeking information, generating options and selecting a solution, presenting the solution, and debriefing the experience. In this study, the researcher modified the Daniel model suitable for teaching socio-environmental issues.

Current research identifies various socio-scientific issues, mostly concerning human or animal issues such as abortion, cloning of genetically modified organisms, organ transplantation, euthanasia, and commercial surrogacy. Several studies that tackled these issues using the mixed methods based on the modified problem-based learning approach gave some interesting findings. First, the students showed gains in higher order thinking-analytical thinking or critical thinking, from before learning and indicated development in argumentation ability from the first to the third test. Second, the experimental group indicated higher order thinking and argumentation more than or equal to that exhibited by the control group who learned using the traditional teaching method (Daokhuntod and Sriwilai, 2015; Koatsopa *et al.*, 2016; Maneethong *et al.*, 2016; Boonnonetae and Suksringarm, 2016; Suebsunthon *et al.*, 2015; Tauychan *et al.*, 2016). However, these studies had some problems related to student adaptation to the new teaching method, less intervention time, and class management. Thus, one proposal is to have less student learning time for each issue in a week, i.e., 2 hour learning, and have them learn more issues.

In this study, the researcher selected five socio-environmental issues: rice straw burning, chemical usage in farming, dam construction for flood prevention, tree cutting for road construction, and construction of coal power plant. Two hours in a week was used to learn each issue using mixed methods based on the adapted PBL approach.

Objectives were to study argumentation of students as a whole and as classified according to sex who learned socio-environmental issues using mixed methods which based on the adapted problem-based learning approach and traditional teaching method, to compare knowledge, awareness, and critical thinking before and after learning socio-environmental issues using the two mentioned learning methods of the students as a whole and as classified according to sex, and to compare knowledge, awareness, critical thinking and argumentation of the students with different sexes and methods of learning socio-environmental issues.

Materails and methods

Population and Sample

The population consisted of 869 students of the 9^{th} grade's students from 16 classes with heterogeneous ability grouping in the first semester of academic year 2016, They were attending Phadung Naree School in Maung District, Mahasarakham Province, Thailand.

The sample consisted of 98 students from the 9^{th} grade's student from two classes, 49 students each, who were selected using cluster random sampling technique with a class considered as sampling unit.

Study Variables

Independent variables were the learning model with two methods: mixed methods based on the adapted problem-based learning approach and traditional teaching method, as well as students' sex.

Dependent variables consisted of knowledge, awareness, critical thinking, and argumentation.

Instruments

The research instruments used for the study were lesson plans, a knowledge questionnaire about the five socio-environmental issues, an awareness questionnaire about the five socio-environmental issues, a critical thinking test, and an argumentation test. Detailed information about each instrument is given below.

Five lesson plans on five socio-environmental issues, (rice straw burning, chemical usage in farming, dam construction for flooding prevention, tree-cutting for road construction, and construction of coal power plant) were prepared. Mixed methods such as induction, answer-question, small group discussion, large group discussion, and lecture, based on the adapted PBL approach were used for the experimental group. Another five lesson plans on the same issues using traditional teaching method were prepared for the control group. Each plan designated 2 hours of learning in a week. Also, each plan has an evaluation of argumentation development using the argumentation test for 30 minutes.

The researcher developed a yes-no knowledge questionnaire about the five socio-environmental issues with 50 items, discriminating values(r) ranged between 0.53 and 0.84, and reliabilities between 0.864 and 0.896.

The researcher constructed a rating-scale awareness questionnaire on the fivesocio-environmental issues with 25 items, discriminating values(r) ranged between 0.63 and 0.88, and reliabilities between 0.845 and 0.886.

The researcher made a critical thinking test based on the Cornell Critical Thinking Test, Level x, constructed by Ennis *et al.* (1985), with four alternatives and 40 items. The test contained four subscales: credibility of sources and observations, deduction, induction, and assumption identification, with difficulty values ranging between 0.430 and0.730, discriminating values between 0.313 and 0.504, and reliabilities between 0.798 and 0.850.

The researcher made six argumentation tests based on Lin and Mintzes (2010). Each test has four questions on each socio-environmental issue. The first five tests were used for the five lesson plans and required 30 minutes to complete. The sixth test was used for a post-test measure with 60 minute completion time.

Data Collection

Preparation

The two selected classes of the 9th grade's students were randomly assigned to an experimental group and a control group. Each group contained male and female students. Three research instruments, except for the argumentation test, were administered to the students as a pre-test measure.

Teaching and Learning

The experimental group and the control group were taught by the researcher using the mentioned lesson plans for 5 weeks. The experimental group was taught on Monday morning and the control group was taught on Thursday morning for 2 hours a week. At the end of each lesson plan, an argumentation test was administered to the group for 30 minutes.

Evaluation

After the termination of the teaching and learning session, the two groups were tested by using the previously described instruments as a post-test measure.

Data Analysis

All of the collected data scores from pre-test and post-test measures as well as the argumentation scores from each lesson plan were analyzed.

The scores of knowledge, awareness, and critical thinking were tested for the difference between the pre-test and post-test measures using the paired t-test as per whole students, male students and female students from each group.

The argumentation scores from the first to the fifth test of the five lesson plans and from the sixth test of each group were analyzed to see the argumentation development of each group using mean and standard deviation.

The pre-test scores and the post-test scores of four test instruments were analyzed to test the hypothesis that students with different sexes and learning models had different knowledge, awareness, critical thinking and argumentation, using the F-test (two-way MANCOVA and ANCOVA).

Before testing the stated hypothesis, all data collected from pre-test and post-test measures were analyzed for testing assumptions of MANCOVA and ANCOVA in these areas: correlation between dependent variables, normality, homogeneity of variance, homogeneity of variance-covariance matrices and homogeneity of regression slope. The testing results supported all areas of the assumptions.

Results

The whole students, male students, and female students of each group showed gains in knowledge overall and in the five issues (Table 1), awareness overall and in five issues (Table 2) and critical thinking ioverall (Table 3) and in four subscales (Table 3) , from before learning (p<.001).

Also, each group of students showed argumentation development from the first to the sixth test.

Table 1. Overall knowledge

Knowledge Total	**Pretest (n = 49)**			**Post-test (n = 49)**			**t**	**p**
	X̄	S.D.	%	X̄	S.D.	%		
Rice straw burning	2.94	658.	29.40	8.16	799.	81.60	33.699-	<001.*
Use of chemicals in farming	2.82	697.	28.20	8.41	537.	84.10	45.301-	<001.*
Cutting trees to build roads	2.88	696.	28.80	8.39	639.	83.90	44.388-	<001.*
Dam construction for flooding prevention	2.94	719.	29.40	8.49	681.	84.90	41.480-	<001.*
Construction of coal power plant	2.79	816.	27.90	8.22	511.	82.20	38.817-	<001.*
Total	14.37	1.667	28.74	41.67	1.519	83.34	94.015-	<001.*
Knowledge (male)	Pretest (n = 12)			Post-test (n = 12)			t	p
	X̄	S.D.	%	X̄	S.D.	%		
Rice straw burning	3.00	738.	30.00	8.65	492.	86.50	30.138-	<001.*
Use of chemicals in farming	3.17	718.	31.70	8.67	492.	86.70	28.260-	<001.*
Cutting trees to build roads	3.08	792.	30.80	8.75	452.	87.50	22.115-	<001.*
Dam construction for flooding prevention	3.17	778.	31.70	8.83	369.	88.30	25.215-	<001.*
Construction of coal power plant	3.00	603.	30.00	8.58	514.	85.80	21.482-	<001.*
Total	15.42	1.505	30.84	43.50	1.000	87.00	54.603-	<001.*
Knowledge (female)	Pretest (n = 37)			Post-test (n = 37)			t	p
	X̄	S.D.	%	X̄	S.D.	%		
Rice straw burning	2.92	640.	29.20	8.00	817.	80.00	26.558-	<001.*
Use of chemicals in farming	2.70	661.	27.00	8.32	529.	83.20	37.028-	<001.*
Cutting trees to build roads	2.82	650.	28.20	8.27	652.	82.70	38.212-	<001.*
Dam construction for flooding prevention	2.86	713.	28.60	8.74	721.	87.40	33.886-	<001.*
Construction of coal power plant	2.73	871.	27.30	8.11	458.	81.10	32.401-	<001.*
Total	14.02	1.589	28.04	41.08	1.396	82.16	79.593-	<001.*

Table 2. Overall awareness

Awareness Total	Pretest (n = 49)			Post-test (n = 49)			t	p
	$\bar{X}$	S.D.	%	$\bar{X}$	S.D.	%		
Rice straw burning	13.79	1.619	55.16	23.16	921.	92.64	-35.113	<001.*
Use of chemicals in farming	14.06	1.663	56.24	23.43	889.	93.72	-36.681	<001.*
Cutting trees to build roads	14.06	1.713	56.24	23.53	1.082	94.12	-35.410	<001.*
Dam construction for flooding prevention	13.69	1.873	54.76	23.49	1.043	93.96	-32.179	<001.*
Construction of coal power plant	14.08	1.498	56.32	23.75	879.	95.00	-34.513	<001.*
Total	69.69	4.228	55.75	117.36	2.619	93.88	-67.745	<001.*
Awareness (male)	Pretest (n = 12)			Post-test (n=12)			t	p
	$\bar{X}$	S.D.	%	$\bar{X}$	S.D.	%		
Rice straw burning	13.67	1.874	54.68	23.83	389.	95.32	-18.546	<001.*
Use of chemicals in farming	14.25	1.712	57.00	23.25	621.	93.00	-21.107	<001.*
Cutting trees to build roads	13.92	1.880	55.68	24.08	1.083	96.32	-17.285	<001.*
Dam construction for flooding prevention	13.75	1.602	55.00	24.00	853.	96.00	-19.041	<001.*
Construction of coal power plant	14.00	1.595	56.00	24.00	853.	96.00	-16.248	<001.*
Total	69.58	4.166	55.66	119.17	1.193	95.33	-37.488	<001.*
Awareness (female)	Pretest (n = 37)			Post-test (n = 37)			t	p
	$\bar{X}$	S.D.	%	$\bar{X}$	S.D.	%		
ice straw burning	13.84	1.554	55.36	22.94	941.	91.76	-30.657	<001.*
Use of chemicals in farming	14.00	1.667	56.00	23.48	960.	93.92	-30.693	<001.*
Cutting trees to build roads	14.10	1.679	56.40	23.35	1.033	93.40	-31.484	<001.*
Dam construction for flooding prevention	13.67	1.972	54.68	23.32	1.056	93.28	-26.511	<001.*
Construction of coal power plant	14.11	1.486	56.44	23.67	884.	94.68	-30.269	<001.*
Total	69.73	4.305	55.78	116.78	2.699	93.42	-58.026	<001.*

Table 3. Overall critical thinking abilities

Critical thinking	**Pretest (n = 49)**			**Post-test (n = 49)**			**t**	**p**
Total	$\bar{X}$	S.D.	%	$\bar{X}$	S.D.	%		
1.Finding underlying assumption	3.59	1.189	35.90	8.33	625.	83.30	32.620-	<001.*
2.Deductive reasoning	2.51	1.082	25.10	7.76	1.164	77.60	24.137-	<001.*
3.Inductive reasoning	4.96	1.471	49.60	8.45	818.	84.50	18.017-	<001.*
4.Formulates plausible hypothesis	3.77	1.159	37.70	7.53	1.002	75.30	24.542-	<001.*
Total	14.84	2.267	37.10	32.06	1.897	80.15	102.413-	<001.*
Critical hinking	Pretest (n = 12)			Post-test (n = 12)			t	p
(male)	$\bar{X}$	S.D.	%	$\bar{X}$	S.D.	%		
1.Finding underlying assumption	3.50	1.243	35.00	8.33	492.	83.30	17.861-	<001.*
2.Deductive reasoning	2.08	668.	20.80	7.75	1.138	77.50	13.675-	<001.*
3.Inductive reasoning	5.67	1.231	56.70	8.58	515.	85.80	7.765-	<001.*
4.Formulates plausible hypothesis	3.92	996.	39.20	7.58	793.	75.80	14.310-	<001.*
Total	15.42	1.505	38.55	33.50	1.000	83.75	54.603-	<.001*
Critical thinking	Pretest (n = 37)			Post-test (n = 37)			t	p
(female)	$\bar{X}$	S.D.	%	$\bar{X}$	S.D.	%		
1.Finding underlying assumption	3.62	1.187	36.20	8.32	669.	83.20	27.230-	<001.*
2.Deductive reasoning	2.64	1.599	26.40	7.76	1.188	77.60	20.154-	<001.*
3.Inductive reasoning	4.73	1.484	47.30	8.41	896.	84.10	16.755-	<001.*
4.Formulates plausible hypothesis	3.73	1.217	37.30	7.51	1.070	75.10	20.301-	<001.*
Total	14.73	2.341	36.82	32.00	1.810	80.00	86.337-	<001.*

The male students indicated more knowledge overall and in three issues: rice straw burning, dam construction for flooding prevention, and construction of coal power plant (Table 4); awareness overall and in rice straw burning, than female students (p.012) (Table 5). However, students with different sexes did not show differences in knowledge of the two remaining issues, awareness of four remaining issues, critical thinking overall and in the four subscales, and argumentation.

Table 4. Comparison of knowledge on socio-environmental problems

Knowledge	Source of variation	SS	df	MS	F	p	Partial eta squared
Rice straw	Pretest	049.	1	009.	008.	794.	001.
burning	Sex	8.781	1	8.781	12.18	001.*	116.
	Learning model	17.223	1	17.223	4	<001.*	204.
	Interaction	338.	1	338.	23.80	495.	005.
	error	67.020	93	721.	9		
					469.		
Use of	Pretest	1.190	1	1.190	1.176	281.	012.
chemicals in	Sex	1.178	1	1.178	1.164	283.	012.
farming	Learning model	30.222	1	30.222	29.87	<001.*	243.
	Interaction	017.	1	017.	1	897.	<001.
	error	94.093	93	1.012	017.		
Cutting trees	Pretest	059.	1	059.	071.	790.	001.
to build	Sex	751.	1	751.	914.	342.	010.
roads	Learning model	29.734	1	20.734	36.16	<001.*	280.
	Interaction	794.	1	794.	4	328.	010.
	error	76.465	93	822.	965.		
Ddam	Pretest	719.	1	719.	1.053	307.	011.
construction	Sex	4.528	1	4.528	6.032	012.*	067.
for flooding	Learning model	24.939	1	24.939	36.52	<001.*	282.
prevention	Interaction	435.	1	435.	7	.427	007.
	error	63.495	93	683.	637.		
Construction	Pretest	.263	1	263.	355.	553.	004.
of coal power	Sex	25.957	1	25.957	25.05	<001.*	748.
plant	Learning model	35.209	1	35.209	5	.<001.	.796.
	Interaction	1.343	1	1.296	339.8	*	116.
	error	96.378	93	1.036	5	.329	
					1.251		

Table 5. Comparison of awareness about socio-environmental problems

Awareness	Source of variation	SS	df	MS	F	P	Partial eta squared
Rice straw burning	Pretest	2.086	1	2.086	1.941	167.	020.
	Sex	6.352	1	6.352	5.911	017.*	060.
	Learning model	16.198	1	16.198	15.072	<.001	139.
	Interaction	603.	1	603.	562.	*	006.
	error	99.949	93			.456	
Use of chemicals in farming	Pretest	690.	1	690.	602.	440.	006.
	Sex	445.	1	445.	389.	534.	004.
	Learning model	43.187	1	43.187	37.684	<001.	288.
	Interaction	057.	1	057.	.049	*	.001
	error	108.582	93	1.146		825.	
Cutting trees to build roads	Pretest	2.461	1	2.461	1.849	177.	019.
	Sex	102.	1	102.	077.	782.	001.
	Learning model	89.498	1	89.498	67.250	<001.	420.
	Interaction	1.133	1	1.133	851.	*	037.
	error	123.768	93	1.331		428.	
Dam construction for flooding prevention	Pretest	409.	1	469.	412.	522.	004.
	Sex	2.653	1	2.653	2.332	130.	024.
	Learning model	67.451	1	67.451	59.296	<001.	389.
	Interaction	684.	1	684.	601.	*	006.
	error	105.790	93	1.138		440.	
Construction of coal power plant	Pretest	129.	1	129.	109.	742.	001.
	Sex	1.282	1	1.282	1.089	209.	012.
	Learning model	61.345	1	61.345	52.173	<001.	359.
	Interaction	002.	1	002.	002.	*	<001.
	error	109.511	93	1.178		969.	

The experimental group statistically showed more knowledge, awareness, critical thinking, and argumentation than the control group ($p<.001$) (Table 6).

The interactions variables sex and learning model were not significantly differed (Table 7).

Table 6. Comparison of overall knowledge, awareness, and argumentation ability after learning under different methods

Univariate tests							
Learning outcome	Source of variation	SS	df	MS	F	p	Partial eta squared
Knowledge	Before learning	9.507	1	9.507	1.872	175.	019.
	model	1083.415	1	1083.415	213.307	<001.*	692.
	error	482.534	95	5.079			
Awareness	Before learning	5.111	1	5.111	820.	368.	.009
	model	2045.098	1	2045.098	328.030	<001.*	775.
	error	502.277	95	6.234			
Critical thinking	Before learning	167.607	1	167.607	79.199	<.001*	.455
	model	885.024	1	885.024	148.482	<001.*	815.
	error	201.046	95	2.116			
Argumentation	Before learning	70.803	1	70.803	89.839	<001.*	.486
	model	5.860	1	5.860	7.435	008.*	073.
	error	74.870	95	788.			

Discussion

This study was illustrated the positive influence of the mixed methods based on the adapted PBL approach on knowledge, awareness, critical thinking, and argumentation of the students.

First, after the 9th grade's students learned the five socio-environmental issues using the mixed methods based on the PBL approach, it was observed that the students gained higher post test scores on the areas of knowledge, awareness, and critical thinking. The students were reported to have developed their argumentation skill, which was supported by a similar study under which a group of secondary school students were exposed to three socio-scientific issues for 3 weeks. These students learned to solve problems using the mixed methods, which was deemed to have good potential for promoting higher order thinking, analytical thinking, or critical thinking. In that study, the students were observed to have higher argumentation development as evidenced by the higher post-test score pretest score (Daokhuntod and Siwilai, 2015; Koatsopa *et al.*, 2016; Maneethong *et al.*, 2016; Boonnonetae and Suksringarm, 2016; Suebsunthon *et al.*, 2015). This might be due to the adapted PBL approach, one method of intellectual procedures emphasizing learner-centered activities and self-generating knowledge and understanding by the learner based on the constructivist view (Jonassen, 1991). The students learned in a group during small group discussions and experienced various learning activities such as question-answer, induction, reading assigned information sheet, lecture, and large group discussion. They practiced argumentation with small group members and used critical thinking to reach the final group decision according to the social constructivist view (Mahoney, 2003). Particularly, a small group discussion could develop the students' critical thinking and argumentation (Dawson and Venville, 2008). Also, the students could develop knowledge about socio-environmental issues from reading assigned information sheets. After a discussion on advantages and disadvantages of socio-environmental issues, they could develop awareness of the risk these issues have on human welfare.

Second, the male students showed more knowledge and more awareness than the female students. This may be attributed to the fact that males and females have differences in biological dimension and socio-cultural dimension (Erickson and Erickson, 1984). Basically, male students are interested in science activities and are familiar with the science world during childhood more than female students. They could perceive effects of science and technology on living things as well as humans and environments from various media channels such asnewspapers, magazines, journals, television, etc. These experiences could result in male students having knowledge and awareness.

However, the two sexes did not indicate any differences in critical thinking and argumentation. This was supported by other findings that male and female students who learned socio-scientific issues did not have different critical thinking and argumentation abilities (Gongkaew, 2011; Koatchompu, 2011; Wongyotha, 2012). This might be due to both sexes learning from small group discussion, during which they argue about socio-environmental issues, which could promote critical thinking and argumentation (Dawson and Venville, 2008).

Finally, the students exposed to socio-environmental issues using the mixed methods based on the adapted problem-based approach were found to have higher achievement than those who learned from conventional teaching. The first group of students were observed to have higher scores in knowledge, awareness, critical thinking, and argumentation than those who were exposed to the traditional teaching method. Similar results were reported in other studies that confirmed greater student learning socio-scientific issues using the mixed methods, (Daokhuntod and Siwilai, 2015; Koatsopa *et al.*, 2016; Maneethong *et al.,* 2016; Boonnonetae and Suksringarm, 2016; Suebsunthon *et al.*, 2015; Tauychan *et al.*, 2016). This might be due to the use of the adapted PBL approach.

Table 7. Comparison of overall knowledge, awareness, and argumentation ability

Multivariate tests							
Source of variation	Test statistic	Value	F	Hypothesis df	Error df	p	Partial eta squared
Prior knowledge of learning	Pillai 's Trace	.001	017.	4	87	999.	001.
	Wilks' Lambda	001.	017.	4	87	.999	.001
	Hotelling's Trace	.001	017.	4	87	999.	001.
	Roy's Largest Root	001.	017.	4	87	999.	001.
Prior awareness of learning	Pillai 's Trace	028.	630.	4	87	642.	028.
	Wilks' Lambda	972.	630.	4	87	642.	028.
	Hotelling's Trace	029.	630.	4	87	642.	028.
	Roy's Largest Root	029.	630.	4	87	642.	028.
Prior critical thinking of learning	Pillai 's Trace	.499	21.692	4	87	<.001*	.499
	Wilks' Lambda	501.	21.692	4	87	<001.*	499.
	Hotelling's Trace	997.	21.692	4	87	<001.*	499.
	Roy's Largest Root	997.	21.692	4	87	<001.*	499.
Prior argumentation of learning	Pillai 's Trace	497.	21.460	4	87	<001.*	.497
	Wilks' Lambda	503.	21.460	4	87	<.001*	497.
	Hotelling's Trace	987.	21.460	4	87	<001.*	497.
	Roy's Largest Root	.987	21.460	4	87	<001.*	497.
Sex	Pillai 's Trace	.171	4.499	4	87	002.*	.171
	Wilks' Lambda	829.	4.499	4	87	002.*	171.
	Hotelling's Trace	207.	4.499	4	87	002.*	171.
	Roy's Largest Root	207.	4.499	4	87	.002*	171.
Learning model	Pillai 's Trace	097.	49.922	4	87	<.001*	.697
	Wilks' Lambda	303.	49.922	4	87	<001.*	697.
	Hotelling's Trace	2.295	49.922	4	87	<001.*	697.
	Roy's Largest Root	2.295	49.922	4	87	<001.*	697.
Interaction	Pillai 's Trace	050.	1.149	4	87	339.	050.
	Wilks' Lambda	950.	1.149	4	87	339.	050.
	Hotelling's Trace	053.	1.149	4	87	339.	050.
	Roy's Largest Root	053.	1.149	4	87	339.	050.

Recommendation

The mixed methods which based on the adapted PBL approach is an effective tool to teach and learn about socio-environmental issues as it enhances knowledge, awareness, critical thinking, and argumentation of the students. This method is based on learner-centered activities, self-generating knowledge and understanding, and social constructivist view. The teachers, therefore, should be encouraged and supported to implement this method in their teaching of socio-environmental issues at the high school level.

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