Exploring Integrated Science Process Skills in Chemistry of High School Students*

การสำรวจทักษะกระบวนการทางวิทยาศาสตร์ขั้นบูรณาการในเคมีของนักเรียนระดับชั้นมัธยมศึกษาตอนปลาย

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Abstract

One of the most important goals in science education is to develop students' science process skills, which is inseparable from the content knowledge of science learning. Integrated science process skills are a part of an inquiry to understand science concepts at the high school level. This study aimed to explore high school students' integrated science process skills in chemistry, which are identifying and controlling variables, formulating hypotheses, defining variables operationally, experimenting, interpreting data and making conclusions, and to examine the relationship between these five skills for improving chemistry learning activities. The Integrated Science Process Skills Test (ISPST) was developed by researchers and the reliability (KR20) of the test was 0.78. The ISPST was administered to three

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groups of 11th grade students (*N*=374) from the academic years 2012 to 2014. Data was analyzed by the use of Means, Kruskal-Wallis H Test, Mann-Whitney U Test, and Spearman's rho using SPSS. The results indicated that the students' integrated skills were at a medium level. There was no significant difference at .05 level in their skills over three years, as well as no significant difference at the .05 level between male and female students. Each integrated skill had a significant and positive relationship, but at a low level (r=.126 - .419, p < .05). Surprisingly, the identifying and controlling variable skills had a very low (r=.126 -.160, p < .05) to no relationship (r=.044, p > .05) with the others. It is recommended that chemistry teachers should provide a classroom climate which helps develop integrated science process skills and include interrelated skills in practice.

Keywords: chemistry, high school students, integrated science process skills

บทคัดย่อ

การพัฒนาทักษะกระบวนการทางวิทยาศาสตร์เป็นเป้าหมายหนึ่งที่สำคัญของการจัดการเรียนรู้วิทยาศาสตร์ ซึ่งไม่สามารถแยกจากเนื้อหาความรู้ทางวิทยาศาสตร์ สำหรับในระดับมัธยมศึกษาตอนปลายทักษะกระบวนการทางวิทยาศาสตร์ขั้นบูรณาการเป็นส่วนสำคัญในการสืบเสาะเพื่อให้เกิดความเข้าใจแนวคิดทางวิทยาศาสตร์ งานวิจัยนี้จึงมีวัตถุประสงค์เพื่อสำรวจทักษะกระบวนการทางวิทยาศาสตร์ขั้นบูรณาการในเนื้อหาทางเคมีของนักเรียนระดับชั้นมัธยมศึกษาตอนปลาย ได้แก่ ทักษะการกำหนดตัวแปร ทักษะการตั้งสมมุติฐาน ทักษะการกำหนดนิยามเชิงปฏิบัติการ ทักษะการทดลอง และทักษะการตีความและลงข้อสรุป และศึกษาความสัมพันธ์ระหว่างทักษะขั้นบูรณาการทั้ง 5 ทักษะเพื่อนำมาใช้ในการปรับปรุงการจัดกิจกรรมการเรียนรู้เคมี เครื่องมือที่ใช้คือ แบบทดสอบทักษะกระบวนการทางวิทยาศาสตร์ขั้นบูรณาการซึ่งพัฒนาขึ้นโดยผู้วิจัย มีความเชื่อมั่น (KR20) เท่ากับ 0.78 เก็บข้อมูลกับกลุ่มตัวอย่างนักเรียนระดับชั้นมัธยมศึกษาปีที่ 5 จำนวน 374 คน ในปีการศึกษา 2555-2557 วิเคราะห์ข้อมูลโดยใช้โปรแกรมสถิติสำเร็จรูป ในการหาค่าทางสถิติได้แก่ ค่าเฉลี่ย การทดสอบของ Kruskal-Wallis การทดสอบของ Mann-Whitney U และสัมประสิทธ์สหสัมพันธ์สเปียร์แมน ผลการวิจัยพบว่าทักษะกระบวนการทางวิทยาศาสตร์ขั้นบูรณาการของนักเรียนอยู่ในระดับปานกลาง นักเรียนระดับชั้นมัธยมศึกษาปีที่ 5 ในแต่ละปีการศึกษาและเพศมีทักษะขั้นบูรณาการไม่แตกต่างกันที่ระดับ .05 และความสัมพันธ์ระหว่างแต่ละทักษะมีความสัมพันธ์กันอย่างมีนัยสำคัญที่ระดับ .05 ในทางบวกแต่อยู่ในระดับต่ำ (r=.126 - .419) โดยเฉพาะอย่างยิ่งทักษะการกำหนดและควบคุมตัวแปรมีความสัมพันธ์กับทักษะขั้นบูรณาการอื่น ๆ น้อยมาก ที่ระดับนัยสำคัญ .05 (r=.126 -.160) จนแทบไม่มีความสัมพันธ์ต่อกัน (r=.044, p > .05) ดังนั้นครูเคมีควรจัดบรรยากาศห้องเรียนที่ช่วยส่งเสริมการพัฒนาทักษะกระบวนการขั้นบูรณาการ รวมถึงการฝึกใช้ทักษะเหล่านี้แบบเชื่อมโยงมากขึ้น

คำสำคัญ: เคมี นักเรียนระดับชั้นมัธยมศึกษาตอนปลาย ทักษะกระบวนการทางวิทยาศาสตร์ขั้นบูรณาการ

Introduction

Science process skills are one of the important learning outcomes in science education. These skills play a crucial role in scientific literacy and understanding the way scientists work. Ostlund (1998) stated that science process skills are the tools that scientists use in their investigation to gain knowledge of natural phenomena. Hence, Özsgelen (2012: 283) stated science process skills are the thinking skills that scientists use to construct knowledge in order to solve problems and formulate results. Thus, science process skills include both mental and physical abilities. As Akinbobola & Afolabi (2010: p.234) described that the science process skills are "mental and physical abilities, and competencies which serve as tools needed for the effective study of science and technology". Additionally, Padilla (1990) reported that science process skills are a set of transferable abilities that are applicable to many science disciplines, and reflect the behaviors of scientists. It is important that in science learning there is a requirement to promote students' science process skills in all disciplines.

Learning with understanding in science involves using the science process skills such as testing the usefulness of possible explanatory ideas by using them to make predictions, collecting evidence to test the prediction and interpreting the results. If these skills are not well developed and, for instance, relevant evidence is not collected, or conclusions are based selectively on those findings which confirm initial preconceptions and ignore contrary evidence, then the emerging concepts will not help in the understanding of the world around. Therefore, the science process skills are inseparable in practice from conceptual understanding. Harlen (1999: 130) pointed out that the process skills play a central role in learning with understanding.

In the Thai science curriculum, science process skills are harmonized within all the indicators of every science learning standard, and are more emphasized in Standard 8.1 of Strand 8: Nature of Science and Technology (The Ministry of Education, Thailand, 2008: 149). The science processes skills focused in Thai science education are comprised of 13 skills (Rodrangka and Nuankeaw, 1999: 3-5), which are according to American Association for the Advancement of Science (AAAS) (American Institutes for Research in the Behavioral Science, 1971: 1). These skills are observing, classifying, measuring, using numbers, using space/time relationship, inferring, predicting, communicating, identifying and controlling variables, formulating hypotheses, defining variables operationally, experimenting, and interpreting data and making conclusions. They are divided into two groups: basic and integrated process skills.

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The first eight processes are the basic process skills. The last five are the integrated process skills. Basic science process skills are vital for science learning, scientific enquiry, and concept construction at the elementary school and middle school levels. But, integrated science process skills are more appropriate at the high school levels and in higher education levels. The basic skills are the prerequisites for integrated skills (Akinbobola and Aolabi, 2010: 33; Beaumont-Walters and Soyibo, 2001: 133).

In Thailand, there were several researches which explored the integrated science process skills of high school students using a paper-and-pencil test with open-ended questions or a subjective question format (e.g., Chaiyen, Bunsawansong, and Yutakom, 2007; Nakthong, Anuntasethakul, and Yutakom, 2007) and a multiple choice format (e.g., Rompayom, 2010). The content of the tests were related to general science (Rompayom, 2010), specific to the high school content such as chemical equilibrium (Chaiyen, Bunsawansong, and Yutakom, 2007) and cell processes (Nakthong, Anuntasethakul, & Yutakom, 2007).

However, the items of science process skills related to the general chemistry content for high school students have not been explored. In addition, comparisons between students' integrated science process skills in each school year for the same grade, as well as the interrelation between the five skills are rare. Therefore, this research attempted to investigate the Thai high school students' five integrated science process skills related to the chemistry content over a three year period for 11^{th} grade students, and to explore if the students' five skills had a relationship between each other. These findings would be useful for chemistry teachers preparing instruction for chemistry learning.

Research Aim and Questions

The research aim that guided this study was to explore Thai high school students' integrated science process skills over a three-year period. The research questions were:

1. What are the high school students' integrated science process skills in chemistry?
2. Is there a significant relationship between the five integrated science process skills?

Methodology

The research method employed in this study was a survey. It involved collection of data using an instrument called integrated science process skills test (ISPST).

Participants

The participants in this study were 374 Thai 11^{th} grade students from one public school. They were selected by a convenience sampling of schools from the public high schools in Thailand. These participants comprised three cohorts of students enrolled in a second semester of the 2012 (male=50, female=88, total=138), 2013 (male= 40, female=81, total=121), and 2014 (male=36, female=79, total=115) school year.

Instrument

The integrated science process skills test (ISPST) was developed by researchers to explore the integrated science process skills in chemistry of high school students. The test covers five integrated science process skills including: identifying and controlling variables, formulating hypotheses, defining variables operationally, experimenting, and interpreting data and making conclusions. The questions were based on the general high school chemistry content. The first draft comprised of 30 multiple choice items, six items for each skill. The test was examined for the content validity by three experts using an index of consistency (IOC). The items with the IOC above 0.50 were selected. Only three items had an IOC less than 0.50, however, these items were revised following the experts' suggestions. Then it was administered to 110 high school students. Finally the test comprised of 20 multiple choice items, four items for each skill. The reliability (KR20) of the test was 0.78, higher than the generally acceptable value of 0.7 (Worrakam, 2011: 297). The discrimination index of each test item ranked from 0.17 - 0.73, and the item difficulty index ranked from 0.32 - 0.79 as shown in Table 1. Only one item had a discrimination value less than 2.00 (0.17). However, this item had a difficulty index of 0.45, which is an acceptable value.

Table 1 Item difficulty (p) and item discrimination (r) of the test items

No.	*p*	*r*	No.	*p*	*r*	No.	*p*	*r*	No.	*p*	*r*
1	0.43	0.53	6	0.77	0.50	11	0.48	0.33	16	0.79	0.53
2	0.50	0.37	7	0.51	0.50	12	0.45	0.17	17	0.49	0.63
3	0.32	0.23	8	0.65	0.40	13	0.48	0.63	18	0.35	0.33
4	0.64	0.63	9	0.73	0.63	14	0.68	0.53	19	0.73	0.47
5	0.71	0.50	10	0.46	0.67	15	0.68	0.73	20	0.57	0.67

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Data Collection

Three hundred and seventy-four 11th grade students from three different academic year (2012 - 2014) were tested for their integrated science process skills using ISPST. The test length was approximately 25 - 35 minutes.

Data Analysis

The data was analyzed based on the research questions. The mean values were used to explain students' integrated science process skills according to school year, gender, and grade point average (GPA). Subsequently, the data was analyzed to explain the statistical difference among three academic years and gender. Because the data was not normally distributed, a nonparametric test, Kruskal-Wallis H Test was used for testing the equality of the means score for the three years (Suwan and Wisadsanguan, 2012), and the Mann-Whitney U Test was used for testing the equality of the means score for different genders (Suwan and Wisadsanguan, 2012).

The mean score of integrated science process skills was classified into three levels: high level (13-20) medium level (12-8) and low level (0-7).

For the relationship between those five integrated science process skills, the data of each skill was not normally distributed. The nonparametric statistic (Spearman's rho) was applied to find the correlation between the five skills (Suwan and Wisadsanguan, 2012). Table 2 provides a summary of the data analysis for each research question.

Table 2 Data Analysis for Each Research Question

Question	Analysis	Statistics
1. What are Thai 11th grade students' integrated science process skills related to the chemistry content?	Mean score by academic year, gender, GPA, and each skills	Means
	The mean score's difference between three academic years.	Kruskal-Wallis H Test
	The mean score's difference between genders.	Mann-Whitney U Test
2. Is there a relationship between the five integrated science process skills?	Relationship between five integrated science process skills.	Spearman's rho

Results

The results were described in the order of the research questions. First, the students' integrated science process skills, and then the relationship among those skills.

1. The Students' Integrated Science Process Skills

As shown in Table 3, the mean score of 11th grade students' integrated skills in 2012 through to 2014 school year (*M*ean=9.44, *S.D.*=3.61) was less than half of the total score (20). It was considered to be at a medium level. The results indicated that the students' mean score of 2014 (*M*ean =9.72, *S.D.*=3.84) was only slightly higher than that of 2013 (*M*ean =9.55, *S.D.*=3.45) and 2012 (*M*ean =9.09, *S.D.*=3.55), respectively. Females (*M*ean =9.65, *S.D.* =3.75) scored a slightly higher mean score than males (*M*ean =9.02, *S.D.* =3.30).

Table 3 Results of Students' Integrated Science Process Skills by Academic Year and Gender (Total score = 20)

Academic year	Gender	*Mean*	*N*	*S.D.*	Min	Max
2012	Male	7.86	50	3.04	3	15
	Female	9.80	88	3.64	1	18
	Total	9.09	138	3.55	1	18
2013	Male	9.25	40	3.17	3	16
	Female	9.70	81	3.60	3	17
	Total	9.55	121	3.45	3	17
2014	Male	10.36	36	3.30	3	15
	Female	9.43	79	4.04	1	17
	Total	9.72	115	3.84	1	17
Total	Male	9.02	126	3.30	3	16
	Female	9.65	248	3.75	1	18
	Total	9.44	374	3.61	1	18

Based on the GPA, the results indicated that the students who had a high GPA would have a higher score on integrated science process skills as shown in Table 4. The students who had a GPA more than 3.51 achieved higher scores on the ISPST (*M*ean =11.47, *S.D.*=3.49) than the others. The students who had a GPA between 3.01 - 3.50 (*M*ean =8.81, *S.D.*=3.34) achieved a score which was slightly less than the students who had a GPA between 2.51 - 3.00 (*M*ean =9.00, *S.D.*=3.09). However, they seemed not to be different.

Table 4 Results of Students' Integrated Science Process Skills by GPA

GPA	*Means*	*N*	*S.D.*	Min	Max
Higher than 3.51	11.47	118	3.49	4	18
3.01-3.50	8.81	121	3.34	1	16
2.51-3.00	9.00	72	3.09	1	15
2.00-2.50	6.87	31	2.68	3	15
Lower than 2.00	-	-	-	-	-
No data	7.75	32	3.41	2	15
Total	9.44	374	3.61	1	18

A Kruskal-Wallis H test was used to compare the students' integrated skills score for three years. The K-W test revealed that there was no statistical significant difference at the .05 level in scores between the different academic years, $\chi^2(2) = 2.58$, $p = .275$, with a mean rank score of 176.30 for 2012, 190.86 for 2013, 197.40 for 2014 year. For gender, the Mann-Whitney U test was used to compare the scores between the genders. The results indicated that the scores for integrated skills in males and females was not statistically significantly different at the .05 level ($U = 14063.0$, $p = .113$).

The results of each integrated science process skill indicated that 11^{th} grade students' ability on integrated skills was in decreasing order: formulating hypotheses (*M*ean = 2.24, *S.D.* = 1.12); experimenting (*M*ean = 2.22, *S.D.* = 1.28); interpreting data and making conclusions (*M*ean = 1.91, *S.D.* = 1.07); defining variables operationally (*M*ean = 1.64, *S.D.* = 1.07); and identifying and controlling variables (*M*ean = 1.42, *S.D.* = 1.05) as shown in Table 5.

Table 5 Results of Each Five Integrated Science Process Skill

Integrated Science Process Skills (full score)	Means (*S.D.*) in school year of			
	2012 (*n*=138)	2013 (*n*=121)	2014 (*n*=115)	Total(*N*=374)
Hy (4)	2.13 (1.06)	2.25 (1.18)	2.36 (1.14)	2.24 (1.12)
Va (4)	1.31 (1.03)	1.50 (1.09)	1.47 (1.03)	1.42 (1.05)
De (4)	1.71 (1.11)	1.53 (1.00)	1.69 (1.08)	1.64 (1.07)
Ex (4)	2.07 (1.31)	2.38 (1.29)	2.25 (1.23)	2.22 (1.28)
Co (4)	1.88 (1.04)	1.89 (1.02)	1.96 (1.16)	1.91 (1.07)

Note. Hy = formulating hypotheses; Va = identifying and controlling variables; De = defining variables operationally; Ex = experimenting; Co = interpreting data and making conclusions

For each integrated science process skills, the findings suggested that while students were able to provide correct hypothesis, if provided with a process of inquiry, but could not do the same with given experimental results. Students only knew that hypothesis stated the expected outcome of any experiment. They did not know that the hypothesis included a statement which showed the relationship of independent and dependent variables that could be tested. Students could not identify dependent, independent and controlling variables because they confused the terms, especially independent and controlling variables. Students were able to identify how to measure a variable of a given process of inquiry, but could not define a variable operationally. They could not design the experiment according to the hypothesis. Students made a conclusion without supporting evidence.

2. The Relationships between the Five Integrated Science Process Skills

The relationships between integrated science process skills were analyzed by the Spearman's rho correlation coefficient as shown in Table 6. The findings suggested that there was a positive result, statistically significant at the .01 level, but with weak relationships between: the formulating hypotheses skill and defining variables operationally skill (r =.329); formulating hypotheses skill and experimenting skill (r = .419); formulating hypotheses skill and interpreting data & making conclusion skill (r = .340); defining variables operationally skill and experimenting skill (r = .356); defining variables operationally skill and interpreting data & making conclusion skill (r = .308); experimenting skill and interpreting data & making conclusion skill (r = .365).There was a positive, but very weak relationship with the identifying & controlling variables skill and (i) defining variables operationally skill (r = .134), (ii) experimenting (r = .160) with a statistical significance at the .01 level, and (iii) formulating hypotheses (r = .126) with a statistical significance at the .05 level. While there were no relationships between the identifying and controlling variables skill and interpreting data and making conclusions skill (r = .044).

Based on the data of the Thai 11th grade students, all integrated science process skills had a positive relationship between each other, but at low levels except the skill of identifying and controlling variables which had very low and no relationships with the others.

Table 6 Correlation (Spearman's rho) of the Five Integrated Science Process Skills

	Hy	Va	De	Ex	Co
Hy	-	-	-	-	-
Va	.126*	-	-	-	-
De	.329**	.134**	-	-	-
Ex	.419**	.160**	.356**	-	-
Co	.340**	.044	.308**	.365**	-

* p < .05; **p < .01

Discussion

The integrated science process skills in chemistry of the Thai 11th grade students were considered to be at a medium level. This is consistent with the previous research studies (Chaiyen, Bunsawansong, and Yutakom, 2007; Nakthong, Anuntasethakul, & Yutakom, 2007). As Chaiyen, Bunsawansong, and Yutakom. (2007) reported that most of students' capabilities of integrated science process skills about chemical equilibrium were categorized to be unsuccessful; especially, operational definition, experimenting and interpreting data. Nakthong, Anuntasethakul, & Yutakom. (2007) reported that students lacked integrated science process skills related to cell and cell processes including formulating hypothesis, identifying variables, and drawing conclusions.Only about half of the students had the skills, but the others did not.

The findings also demonstrated that Thai high school students did not have a clear understanding about each integrated science process skill, essentially the skills of identifying variables and defining variables operationally. This result was consistent with the findings of Beaumont-Walters and Soyibo (2001: 138) that found the students' performance on integrated science process skills in a decreasing order was as follows: interpreting data, recording data, generalizing, formulating hypotheses, and identifying variables. It revealed that students find the identifying variable skill to be the most difficult.

It was generally accepted there was a statistical significant difference in students' performance on skills linked to grade level, higher grade level, higher performance (Beaumont-Walters and Soyibo, 2001: 139). The study at the same grade level but different school year showed that there was no statistical significant difference among school year. This can be used to support that the study of the students in the prior year can be used as fundamental results for preparing the activities or curriculum for the next coming year.

The findings based on gender difference revealed that there were no statistical significant differences in the 11^{th} grade students' gender. This was similar to work reported by Beaumont-Walters and Soyibo (2001: 139), when they worked with the high school levels (ninth and 10th grade) in Jamaica. However, it is inconsistent with the finding in the study of Aydinli et al. (2011: 3472) who found a statistical significant difference in the students (grade 6-8) score linked to their gender

The results about relationships among the five integrated science process skills showed that there was a positive, statistically significant, but low relationship between each skill. It could be mentioned that the five integrated science process skills have a relationship among each other. However, the process skills used in identifying and controlling variables was very low and no relationship with the others. The evidence from other research such as Shahali and Halim (2010: 145) revealed that the correlation between the sub-tests of each skill (including: formulating hypothesis, controlling variables, defining operationally, interpreting data and designing experiment) showed a positive, statistically significant, weak to moderate relationship between each other (r=.328-.536, p=.01). In this research the correlation of each skill is very low with some showing no relationship which suggests that the Thai students have integrated skills, but these are not integrated to each other.

Conclusions and Implications

The result show that about half of Thai 11^{th} grade students have a problem in integrating science process skills including: identifying and controlling variables, formulating hypotheses, defining variables operationally, experimenting, and interpreting data and defining variables operationally making conclusions. In particular, identifying and controlling variables are challenging skills. The lack of adequately developed science process skills is a problem for students in understanding scientific concepts and doing science (Nakthong, Anuntasethakul, & Yutakom, 2007: 392). Thus, the results of this research findings would recommend that chemistry teachers should provide a classroom climate which helps develop integrated science process skills Additionally, these skills should be based on a specific science concept. The skills could be taught in a way that incorporates the development of interrelated science process skills.

The chemistry teacher could provide a good climate by giving an opportunity for the students to think and do science experiments by themselves (Grace, 2007; Nakthong, Anuntasethakul, & Yutakom, 2007: 393), using cooperative learning (Saenpich, 2015: 1414), or using a simulated multimedia (Koomsao, 2013: 148) to support the development of science process skills.

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