Assessing Students' Conceptual Understanding of the Relationship between Solubility and Polarity of Organic Compounds

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Abstract

Solubility and polarity of organic compounds are the important principles of organic chemistry. These fundamental concepts are used for introducing solvent selection for purification, as well as analysis techniques, etc. Therefore, these topics are important for students to learn, however, in the past, polarity and solubility have been reported as difficult topics for students to learn. So, knowing how students' understanding or misconceptions of these concepts will be useful information for developing activities to enhance students' learning with the concept. This study investigates how students understand the relationship between solubility and polarity during the extraction of plant pigments by various solvents. High school students who already learned the concept of solubility, polarity, and covalent bonds were chosen for this study. The extraction activity was set up for students to perform in each group, after finishing the laboratory activity, students were asked to complete opened-ended questions and interview to explain how the plant pigment can be extracted by solvents. The students' answers were analyzed using thematic analysis, and their explanations were categorized into groups based on the feature that included in the explanation. The results showed that only 50 percent of students answer correctly by link the effect of the solvent polarity and plant pigment to explain the solubility during the extraction. However, their answers still lack the explanation about intermolecular force between solvent and solute. While the students, who are in 50 percent, have a partial understanding of these concepts since they provided the explanation with the alternative conception. In conclusion, although students have already learned the concept of polarity and solubility, some of them could not link the concept of polarity and solubility and they also hold some alternative concepts.

Keywords*: *Extraction, Plant pigment, Polarity, Solubility

1. Introduction

Chemistry is a crucial subject that many concepts are basic principles for learning in other fields such as material science, engineering, environmental science, and medicine (Eilks & Hofstein, 2013). Besides, there are many chemical concepts relate to our everyday life, so understanding concepts in chemistry causing us to grasp and can explain various issues in our lives such as consumption of energy resources, sustainable industrial development, and solving climate change, etc. (Eilks & Hofstein, 2013). There are five general branches in chemistry include analytical chemistry, physical chemistry, inorganic chemistry, biochemistry, and organic chemistry (Neuman Jr, 1999). Organic chemistry is a part of chemistry that involves the description of the physical and chemical properties of organic compounds (Neuman Jr, 1999). Many concepts of this part are employed in many areas such as the pharmaceutical industry, doctors, veterinarians, and dentists (O' Dwyer & Childs, 2010).

Organic chemistry is a popular part, and many concepts are abstract and difficult for the students to learn (Eilks & Hofstein, 2013; Johnstone, 1974). For learning organic chemistry, students need to have basic knowledge in general chemistry such as a covalent bond, molecular structure, chemical reaction, chemical and physical properties, acid-base, and electrostatic potential surface (Duis, 2011; Ealy, 2018). Concept of polarity and solubility are one of the fundamental principle for learning organic chemistry (Montes, Lai & Sanabria, 2003). Those concepts are important for solvent selection since the solubility of organic solvent involves the efficiency of purification and analysis techniques such as solvent extraction, Thin-layer chromatography (TLC), (Shugrue, Mentzen & Linton, 2015).

Previously, many researchers revealed that polarity and solubility concepts are difficult for students to learn (Duis, 2011; Montes-González, Cintron-Maldonado, Pérez-Medina, Montes-Berríos & Román-López, 2010; Montes et al, 2003; O' Dwyer & Childs, 2014; Shugrue et al, 2015). Therefore, there are many learning activities which were developed in order to enhance students learn those concept (Montes-González

et al, 2010; Montes et al, 2003; Passarelli, 2009; Shugrue et al, 2015). Most of the learning activities are laboratory and hands-on activities that students can perform and observe the results by their naked eyes such as using the dissolution of colored dyes (Shugrue et al, 2015). In this way, students can link the phenomena (macroscopic level) to the concept of solubility and/or polarity. In Thailand, generally, Thai students learn solubility and polarity of organic compounds through the lecture-based classroom. Therefore, it is interesting to know whether students can link, integrate, and understand the relationship between solubility and polarity of organic compounds in the real situation.

The propose of this study was to investigate how student explains and relate the concept of solubility and polarity on solvent extraction. Plant pigments extraction by solvents activities were used as a situation for the student to explore. The solubility of plant pigment in the solvent during the extraction process depends on the polarity of the pigment and solvent. So, the extraction of plant pigments can be used as an activity for students to explore the concept of solubility and polarity. After the students performed pigment extraction and observed the results, they were assessed their understanding of the concepts and the relationship between solubility and polarity during the extraction of plant pigments by solvents. Moreover, students' alternative concepts (misconception) related to solubility and polarity of organic compounds were also analyzed and reported.

2. Objectives and Research questions

This study aims to assess students' understanding of the concepts of solubility and polarity of organic compounds, the following research objectives, and research questions that were posed for this study.

Research objective

To investigate students' conceptual understanding of the relationship between solubility and polarity of organic compounds during the extraction of plant pigments by the solvent.

Research question

What particulate explanations do students generate to explain the concepts relating to the solvent extraction of plant pigments?

3. Materials and Methods

3.1 Research Design

This study was conducted using the qualitative method. Students were assigned to answer two open-ended questions to assess their conceptual understanding of the relationship between solubility and polarity of organic compounds after they performed the experiment (Figure 2). Also, they were interviewed to investigate their conceptual understanding of those concepts. The overall process of this study is shown in Figure 1

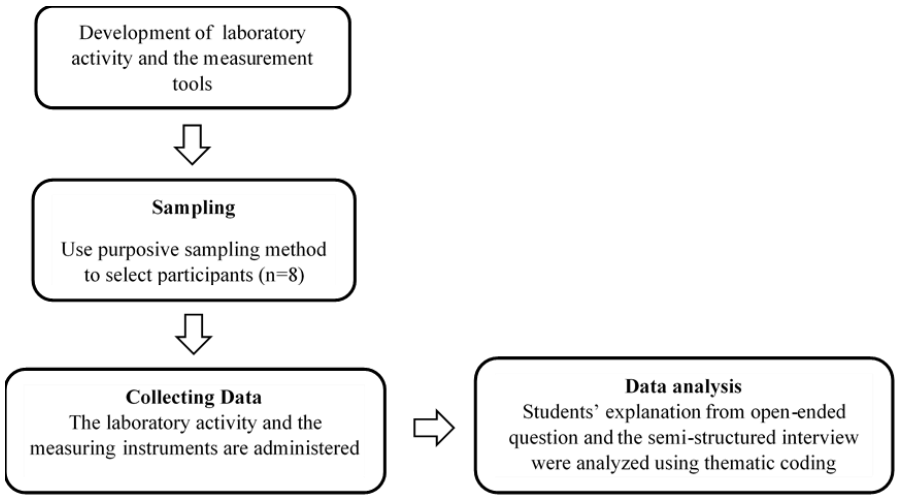

Figure 1 The overall processes of this study

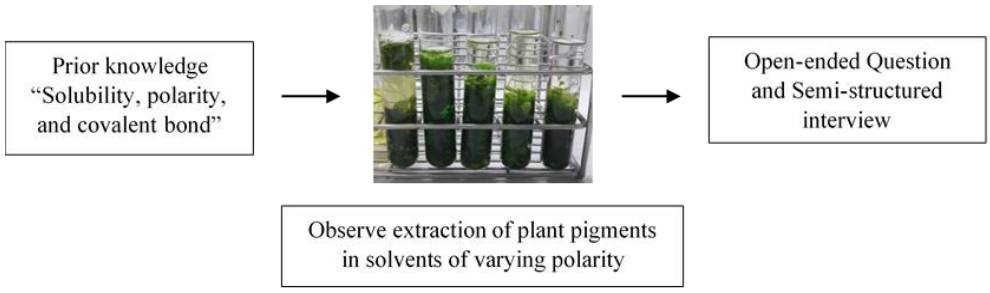

Figure 2 The research design showing the process of the learning activities

The research design on this study shown in Figure 2. Students who have prior knowledge about solubility, polarity, and covalent bonds were imposed to carry out laboratory activities. During the activities, they have to observe the extraction of plant pigment by solvents which have different polarities. Then, they were assigned to answer the open-ended questions about these concepts and interviewed to investigate their understanding.

3.2 Participants

The purposive sampling was conducted for choosing a sample of this study. The participants were high school students (Matthayom 6 students) who already learned the concept of solubility, polarity, and covalent bonds from the previous level (Matthayom 4). The concepts are important for students to explore and apply those concepts to explain the extraction of plant pigments by the solvent. This study chose the science-math program students who study in Matthayom 6 because for Thai's curriculum organic chemistry is usually taught at this level. Eight students who have background as described above volunteered to participate in the activity including two male and six female students.

3.3 Description of the laboratory activities

The laboratory activity allows students to investigate the solubility of plant pigment in various solvents. Students were assigned to carry out the solvent extraction experiment using different polarities of pigments. In this activity, anthocyanin from red cabbage and chlorophyll from spinach were chosen for students to study. Students performed experiment according to the provided material and method.

Material and equipment:

Material and equipment:	**Reagent**
1. Leave of Spinach	1. Water
2. Red cabbage	2. Ethanol
3. 100 ml Beaker	3. 2-propanol
4. 20 mL Test tube	4. Acetone
5. Test tube stand	5. Hexane

Method:

(1) The extracted plant include spinach and red cabbage is cut into small pieces (Figure 3).
(2) 5 g of those sample were mixed with 10 mL of each type of solvents in 25 mL glass test tubes.
(3) Soak the mixtures 15 minutes, then pour the extracted solution into another tube.
(4) Observe the experimental results by comparing the solution intensity.

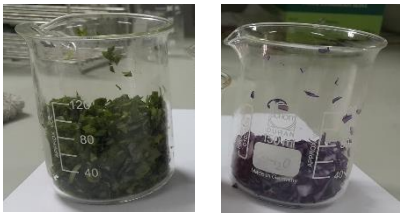

Figure 3 Spinach and red cabbage were used as the sample for the pigment extraction process

Students are challenged to extract the pigment using various solvents. Then, they observed the different color intensity of extracted solution and compared the extractability of each solvent. The pigments extractability of each solvent lead students to the conclusion of the polarity of plant pigments.

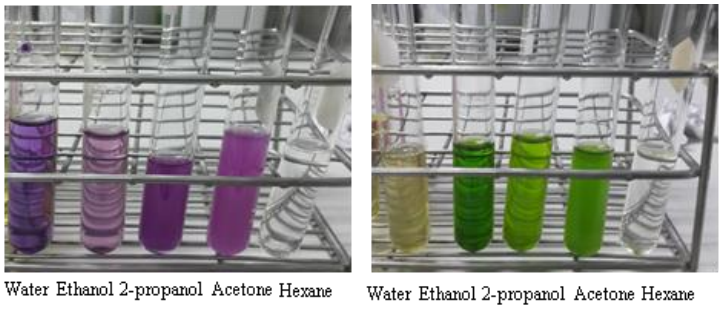

Figure 4 The extracted solutions of pigment which have different polarity (Anthocyanin and chlorophyll) by solvents of varying polarity showing the different color intensity of the solution

3.4 Data collection

In this study, the qualitative data consist of students' answer from the open-ended questions and the semi-structured interview, were collected to answer the research question. The summary of tools that were used to answer each research question are presented in Table 1

Table 1 The summary of the research question and tools that were used

Research question	Tools
What particulate explanation do students generate to explain the effect of solubility and polarity of plant pigment on the extraction of those by solvent?	1. Open-ended questions 2. Interview questions

Open-ended Question

The open-ended questions were used to assess students' conceptual understanding, how they apply the knowledge of polarity to explain the solubility of the organic compound on plant pigments extraction. There are two concepts that students were assessed include solvent extraction and extraction of plant pigment. The open-ended questions comprise of two items are shown in Table 2.

Table 2 The summary of the conceptual test in each item

Items	Concepts	Questions
1	Solvent extraction	For solvent extraction, choosing the proper solvent is very important for the highly effective solvent extraction process, could you explain how to select the proper solvent?
2	Extraction of plant pigment	From the experiment, do you think whether pigment having different polarity will have the same solubility in the different solvent, explain your idea?

Semi-structured Interview

For students to be able to explain more detail about their explanation, the semi-structured interview was conducted to explore the ideas, patterns, or concepts that can indicate students' understanding of these concepts. They also were asked to extend their explanation from the open-ended answer. The main interview questions shown in Table 3. During the interview, students' explanations were recorded using the recorder.

Table 3 The main interview questions for the semi-structured interview.

Items	Concepts	Questions
1	Solvent extraction	What concept(s) did you learn from the extraction of plant pigments in various solvents?
2	Extraction of plant pigment	How do you understand the relationship between molecular polarity and solubility?

3.5 Data analysis

Open-ended Question

The open-ended question is developed under two chemical concepts. This test is conducted to collect the students' explanations about the concept of solvent extraction and extraction of plant pigment. The explanations of both concepts were analyzed using thematic coding, groups of students' answers were identified depending on their ideas, pattern, or concepts. The groups of students' answers indicated that how they understand the concept of solubility and polarity, and howthey perceive the relationship between solubility and polarity of organic compounds.

Semi-structured Interview

The data from the interview was analyzed using thematic coding, the qualitative data are analyzed. Each audio record file was transcribed verbatim, the transcripts were managed using thematic coding. Students' explanations were identified using their ideas, description patterns, or concepts that were used to support their answers.

4. Results and Discussion

According to the open-ended questions, the answers of 8 students about solvent extraction and solubility and polarity of the organic compound were analyzed using thematic analysis in order to investigate how students explain the effect of solubility and polarity of plant pigment on the extraction process. There are two questions that cover the topic of solvent extraction and solubility and polarity of the organic compound. The results are presented as follows:

- **Solvent extraction concept**

The first question is relevant to the solvent extraction process. The question is "For solvent extraction, choosing the proper solvent is very important for the highly effective solvent extraction process, could you explain how to select the proper solvent". From this analysis, the explanations about the concept of solvent extraction were identified as three groups. The first group consists of students (n=4) who correctly explained how to select the proper solvent for solvent extraction. For high effective solvent extraction, solvent selecting should be concerned about choosing the solvent which has the same polarity to solute (like dissolves like). Students' explanation in this group provided the correct answer and reason to support their answer as shown below:

"For high effective solvent extraction process, we have to choose the solvent which has the same polarity to solute because solute will dissolve in the solvent of the same polarity"

"Consider to the polarity of solute whether it can dissolve in polar or nonpolar solvent"

Although the explanations indicated that students perceive the relationship between solubility and polarity in order to extract substance, they still lack providing the reason related to intermolecular force between solvent and solute. It might be due to learning this concept does not emphasize the interaction between solvents and solutes, so that make students do not perceive the relevance of intermolecular force during the dissolving process.

The second group of students (n=3) who thought that choosing the solvent which has the same polarity to solute will increase the effectiveness of the solvent extraction process since using the solvent, which has the same polarity to the solute, a chemical reaction will take place. Commonly, dissolution refers to a physical change which is the forming of a homogenous mixture that the solute dissolves in the solvent (Montes-González et al, 2010). Even though this group of students also perceived the relationship between solubility and polarity in order to extract substance, they hold alternative conception about this process. All students thought that the dissolving process involves a chemical reaction as they provided the explanation:

"If the compound is a polar molecule, we should choose the polar solvent since a chemical the reaction will take place"

"Different solute structure will react with different solvent"

"Solvent will react with the only solute which has the same polarity with solvent"

Considering to students' answer, it is noticeable that their alternative conception similar to the study of Barke, Hazari & Yibarek (2009) which reported that the separation of the chemical reaction and physical process is the one of chemistry content that students have alternative conceptions. In the final group, student (n=1) provided the wrong explanation. The student stated that the high polar molecule can dissolve in the solvent better than the non-polar molecule. Considering to student's answer, the student also perceives the relationship between solubility and polarity, but could not provide the correct explanation as the student explained:

"Each pigment has a different polarity, high polar molecule dissolve in solvent better than nonpolar molecule"

From the explanation, it is possible that the student knows about the relationship between solubility and polarity, but the student could not remember or maybe the student holds a misunderstanding about the relationship.

According to the interview, students were asked "what concept(s) did you learn from the extraction of plant pigments using various solvents?". Most of the students could explain the concepts relating to the experiment, their answer mentioned the polarity or solubility concepts. As they said:

"Observing the effect of molecular polarity on their solubility"

"Polarity of substance and how to determine the polarity of compound"

"Use of substance (pigment) solubility in various solvents in order to identify the polarity of substance"

The results indicated that using the extraction of plant pigments activity can lead students to apply and link the concept of solubility and polarity.

- **Extraction of plant pigment**

For the second question, students were asked about the experimental result which is "From the experiment, do you think whether pigment having different polarity will have the same solubility in the different solvent, explain your idea". From this analysis, the explanations about these concepts were identified as two groups. The first group of students (n=5) who applied the concepts of solubility and polarity to explain the extraction of plant pigments in various solvents. All of their explanation mentioned to the polarity of pigment and solvents, as they explain:

"Different because pigment having high polarity will dissolve in water or high polar solvent, but the nonpolar pigment cannot dissolve in those solvents"

"Anthocyanin is a high polar molecule will dissolve in water, chlorophyll has medium polarity so well dissolve in ethanol and 2-propanol"

It can be seen that students could apply their background knowledge about polarity and solubility to explain other phenomena. The reason that most students can provide the correct answer might be the effect of the visible results from extraction could help students to compare the solubility of each pigment.

The second group comprises of students (n=3) who explained the extraction of plant pigment process using the molecular structure of pigment by mention to "*functional group"*. As they answered:

"Different pigment has different solubility because the molecule has different functional group"

From their explanation, students attempted to support their answer by providing the reason related to the functional group of organic compounds. However, their explanations are not completely correct

because even organic molecule has the same functional group in the structure, it can have different polarity depending on other factors such as the number carbon atom, etc.

According to the interview, students were asked to extend the explanation from the open-ended answer which the question is "how do you understand about the relationship between molecular polarity and solubility?". There is an interesting answer from the interviewee. For example, some of them mentioned catching of solvent and solute as the student said:

> *"Extraction process, the solute is caught by solvent so the same polarity of solvent and solute can enhance the effectiveness of extraction"*.

Intermolecular forces between solute and solvent are the main factors that affect the solubility of the solute. From the explanation, it can deduce student perceives about the interaction between solvent and solute, but they cannot explain in term of intermolecular force between solvent and solute.

5. Conclusion

This study aims to assess students' conceptual understanding of solubility and polarity of organic compounds using plant pigment extraction processes in order to investigate the relationship between solubility and polarity of compounds. The result indicated that most students perceive the relationship between solubility and polarity of the organic compound. Moreover, they could apply the concept of polarity to explain the dissolving phenomena. Although the result presented that students have conceptual understanding of these concepts, most of their answers still lack the explanation about the intermolecular force which is the important reason to explain the interaction between solute and solvent. Besides, the finding showed that some of the students' explanation has alternative conceptions, especially the idea that the dissolving process involves chemical reaction. For teaching these concepts, teacher should design the activity that students can link the concept of solubility and polarity. The activity also should make students differentiate between chemical reaction and physical changes. Moreover, the activity should be able to lead students to construct the connection between microscopic (molecular structure) and macroscopic (solubility).

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