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The Effect of the RADEC Model on Conceptual Understanding of Polycyclic Aromatic Hydrocarbons (PAHs) Topic

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ABSTRACT

This study was conducted to analyze the conceptual understanding of students and their struggle on Polycyclic Aromatic Hydrocarbons (PAHs) compounds topic through the implementation of the RADEC Model. Respondents consisted of 37 students from Chemistry Education Department and 33 students from the Chemistry Department at a university in Bandung, Indonesia. This study is an experimental study with a pre-experimental type. Data on conceptual understanding were obtained through pre-tests and post-tests, while data on students' difficulties were obtained through survey. The data were analyzed using SPSS 24. It was found that there was an increase in the conceptual understanding of the students of Chemistry Education and Chemistry Department in the medium category with n-gain values of 0.33 and 0.38, respectively. The results of inferential analysis through the Wilcoxon Test with Asymp. Sig. (2-tailed) were <0.05 for the two groups of students indicating differences in the pre-test and post-test results with a higher average post-test score. Friedel-Crafts acylation is a concept that is difficult to understand by students from the Chemistry Education Department and the Chemistry Department with the same percentage of 33%. Chemistry Department students also have difficulty understanding the electrophilic substitution concept with a percentage of 33%. As a practical implication, this study successfully showed the effective implementation of the RADEC model, serving as an innovative and beneficial learning approach. The model offered substantial support to students in grasping complex topic such as PAHs compounds.

Keywords: Conceptual understanding, difficulty analysis, PAHs topic, RADEC model

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INTRODUCTION

Learning organic chemistry is considered challenging for students and the biggest issue is the topic involving many structures and reaction mechanisms (Crucho et al., 2020; Durmaz, 2018). Students felt struggle to understand organic chemistry because all topics are conveyed during classroom sessions through the traditional lecture method (Garg, 2019). Studies showed that low performance in chemistry was associated with negative attitudes toward ineffective instructional techniques (Musengimana et al., 2021). Students did not like chemistry because lecturers often used the traditional lecture method when solving problems on the board. Studies showed that 65% of students had low interest in organic chemistry at the beginning of each semester (Garg, 2019). Polycyclic Aromatic Hydrocarbons (PAHs) compounds topic was full of organic chemistry concepts which must be understood. PAHs are characterized by rings that share carbon atoms and a common aromatic pi electron cloud (Fessenden & Fessenden, 1986), such as naphthalene or camphor. Naphthalene is often used as a deodorizer, antiseptic, and moth repellent (Chen et al., 2018). The example of naphthalene or camphor can be seen in Figure 1.

Studies have reported that the topic of PAHs is difficult for students to understand because it consists of concepts related to resonance or electron delocalization (Carle & Flynn, 2020; Duis, 2011). Electron delocalization occurs in the benzene ring. This is the main aspect causing the reactivity of the benzene ring (Solomon & Fryhle, 2011). The concept of resonance is difficult to understand because students must be able to describe several resonance structures and electron flow. Carle et al. (2020) reported that many studies have revealed some students' misconceptions about resonance, such as the change in resonance structures and the perception that resonance structures exist as an equilibrium. Nartey and Hanson (2021) state that students need better performance in organic chemistry. Based on their survey, an organic compound with a ring structure, such as benzene and PAHs, was the hard topic to teach.


(a)

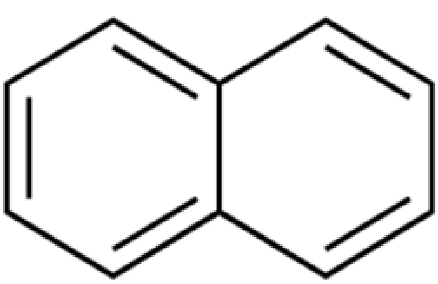

(b)

Figure 1. (a) Camphor (naphthalene); (b) The structure of naphthalene

Students' conceptual understanding should be built during the learning process because students who do not go through it find it difficult to understand what they are learning. Students' ability to understand the concepts on the topic of PAHs compounds referred to in this study includes the competence to remember, understand, apply, analyze, evaluate and create. These competences are parts of the dimensions of cognitive processes that can be assessed based on the Revised Bloom's Taxonomy (Anderson & Krathwohl, 2001).

Conceptual understanding is a complex activity that includes understanding simple scientific concepts and refers to students' competence to apply and relate these concepts to scientific phenomena in a meaningful way (Schwedler & Kaldewey, 2020). Therefore, conceptual understanding is one of the best predictors of academic success. Unfortunately, even students in higher education still struggle to understand basic concepts (Jeongho et al., 2017; Schwedler & Kaldewey, 2020). According to Sozbilir (2004), students tend to want university teaching to focus more on their conceptual understanding.

To help students achieve conceptual understanding regarding the topic of PAHs compounds, it is necessary to improve the quality of learning through the application of learning models with stages that are easy to memorize, understand, and to apply, as well as suitable with the situation and conditions of the COVID-19 pandemic. Students' competence to understand concepts can be obtained through the lecture process (Anderson & Krathwohl, 2001). One model that can be an alternative to improve students' conceptual understanding is the RADEC Model. RADEC is an abbreviation of the learning stages in this model, namely Read, Answer, Discuss, Explain, and Create. This model was first introduced by Sopandi (2017) at an international seminar in Malaysia.

The application of the RADEC Model is suitable for the learning context in Indonesia (Pratama et al., 2019) and in the conditions of the COVID-19 pandemic (Lestari et al., 2021). The number of people who carry out activities using the Internet is increasing on an annual basis. In 2019, the number of users was around 64.8% of the total population of Indonesia. Lecturers should use this phenomenon to improve the quality of learning because students are familiar to use ICT tools (Farrell & Hamed, 2017). The RADEC model has high flexibility to be integrated into face-to-face, blended, and full online learning (Sukardi et al., 2021). In the conditions of the COVID-19 pandemic, learning through the RADEC model can be carried out by searching for information through Google, distributing pre-learning questions using Google Classroom, discussing through Zoom, and creating projects at home.

RADEC Model facilitates the development of knowledge in the form of conceptual understanding because, at the Read stage*,* students can explore the concepts that serve as the learning materials. If this stage does not facilitate the students, peers and lecturers must provide explanations to increase conceptual understanding at the Discuss and Explain stages. The development of attitudes is illustrated through interactions with teachers and among students in the Discuss, Explain, and Create stages. The teacher becomes a facilitator in discussions and peer-teaching among students. Students who have understood the concept through the Read stage are obliged to give explanations to students who do not understand the concepts. The students' skills are illustrated through the Read stage, which can improve reading skills. The Answer stage can improve writing skills, the Discuss and Explain stages can enhance cooperation and speaking skills, while the Create stage can improve project design skills (Handayani et al., 2019; Sopandi et al., 2021).

The RADEC model can improve conceptual understanding of concept-laden learning topic (Ma'ruf et al., 2020; Rohmawatiningsih et al., 2021; Siregar et al., 2020; Sujana et al., 2021). However, this study is conducted on school students, and there is no analysis on the application of the model at the university level on topics related to PAHs compounds. Judging from the characteristics of the RADEC Model, which requires students to explore information from various literature on their own, it is the concept of active learning that students must do. If the literature search for students is limited to school books, teaching materials from teachers, and Google, then a more comprehensive literature search can lead to the advancement of knowledge available in Scopus, Web of Science, Google Scholar, ERIC, and others. The effect of applying the RADEC model on students' conceptual understanding of the topic of PAHs has not been studied. Therefore, this can be the novelty of this research. In addition to conceptual understanding, this study also analyzes students' struggle in understanding the topic of PAHs compounds through the application of RADEC Model, especially at the Read stage. This is necessary because students are unfamiliar with learning methods that apply the RADEC Model, and we need to know what difficulties the students face. Based on this background, the following research questions were formulated:

i. What are the conceptual understanding of students on PAHs topic before and after the application of the RADEC model?
ii. What are the struggles of students on understanding PAHs topic, specifically in the Read stage?

MATERIALS AND METHODS

Study Design

This experimental study was conducted using pre-experimental type. The design used was the One-Group Pretest-Posttest Design (Creswell & Creswell, 2018) and the subjects were students taking their fifth-semester courses at a university in Bandung. The students were from the Chemistry Education Department and the Chemistry Department. Both departments have obtained Indonesian National Accreditation in the Very Good category. Respondents consisted of 37 students from Chemistry

Education Department and 33 students from the Chemistry Department who took the Structure and Reactivity of Polyfunctional Organic Compounds Course at a university in Bandung, Indonesia.

Course Information

PAHs topic is part of the topics in organic chemistry course. The detailed information of the course can be seen in Table 1.

Table 1
The information of PAHs topic in organic chemistry course

	Information
Department	Chemistry Education Department and the Chemistry Department
Course Title	Structure and Reactivity of Polyfunctional Organic Compounds
Course Prerequisite	Structure and Reactivity of Monofunctional Organic Compounds
Course Schedule	Every Thursday (7:00 AM and 8:40 AM)
Credit Course	2 (two) credits (2 x 50 minutes)
Course Objectives	In PAHs topic, the course objectives are as follows: i. Identifying the PAHs compounds and determining nomenclature & criteria for PAHs. ii. Analyzing the reactivity of PAHs. iii. Drawing electrophilic substitution reactions for PAHs. iv. Drawing sulfonation reactions of naphthalene. v. Drawing Friedel-Craft acylation reaction. vi. Predicting the effect of bound groups (activating groups and deactivating groups) on PAHs compounds.
Media, Text, and Resource Requirements	Bifunctional Compounds (Ward, 1994), Organic Chemistry (Fessenden & Fessenden, 1986), Organic Chemistry (Solomon & Fryhle, 2011)

Treatment

The course was carried out during the COVID-19 pandemic, so the application of the RADEC Model and the collection of research data were carried out online. The course that applied the RADEC Model were carried out via the Zoom Meeting platform, while the pre-learning questions and teaching materials were distributed through the university's Learning Management System, called SPOT (*Sistem Pembelajaran Online Terpadu*). The stages of RADEC model in the course that implemented it are presented in Table 2.

Table 2
The stages of the RADEC Model in organic chemistry course

Pre-learning Activities	
Read	Students read information from various literature and teaching materials on the topic of PAHs based on the directions provided on SPOT.

Table 2 *(Continue)*

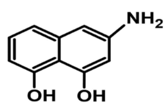
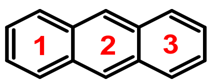
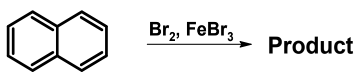
Pre-learning Activities	
Answer	Students answer the pre-learning questions available on SPOT. The questions are based on the information obtained at the Read stage.
Preliminary Activities	
i. Lecturer opens lecture activities. ii. Lecturer starts the class by reviewing the material previously learned and then showing pictures related to the PAHs topic. iii. Lecturer inform students the learning objectives.	
Main Activities	
Discuss	i. Students discuss the answers to pre-learning questions and cases that become the subject of study. ii. Lecturer identifies part of the task most students struggle with, and then explain the particular section at the Explain stage.
Explain	i. Students explain their work by using the share-screen and annotate features. Other students give questions or responses. ii. Answering questions from the lecturer. iii. Listening to the explanation from lecturer. iv. Lecturer ensures that the students' explanation is scientifically correct. v. This stage can also be conducted by showing videos, doing simulations, and making demonstrations.
Create	i. Lecturer facilitates students to discuss the implementation of project ideas. ii. Students design projects based on ideas that have been proposed and agreed upon, and also the knowledge that has been gained in learning activities.
Closing Activities	
Students and lecturer make conclusions and reflections together. Then, the lecturer provides students with encouragement and moral messages to keep the spirit of learning, inform the material for the upcoming meeting, and ends the class with a prayer.	

Data Collection and Analysis

Research data collection, namely pre-test and post-test data, was carried out through Quizizz platform. The pre-test was given at the beginning of the course, while the post-test was given at the end. The pre-test and post-test questions were taken from a question bank owned by a team of organic chemistry lecturers in the university. Some examples of pre-test and post-test questions are presented in Table 3. In addition, to find out students' difficulties in understanding the topic of PAHs through reading activities, the researchers conducted a reading survey through an open questionnaire containing questions about difficult-to-understand course materials.

The analysis of quantitative data namely the pre-test and post-test to determine the effect of the implementation of the RADEC

Table 3
Some examples of pre-test and post-test questions

No.	Pre-test and Post-test Question	Topic	Cognitive Level
1.	Determine the name of this PAHs compound structure based on IUPAC! 	Nomenclature of PAHs	Applying (C3)
2.	What number is the position of reactivity of anthracene on the benzene ring? 	The reactivity of PAHs	Analyzing (C4)
3.	Determine the product that is potentially formed in the following reaction: 	Electrophilic substitution reactions for PAHs	Creating (C6)

Model on conceptual understanding was conducted using normalized gain/n-gain (<g>) from Hake (1998). The n-gain interpretation is presented in Table 4.

Table 4
n-gain interpretation

Category	Limitation
High	<g> > .7
Medium	.3 ≤ <g> ≤ .7
Low	<g> < .3

Moreover, the differences in conceptual understanding of students before and after the course were analyzed using a Wilcoxon Test. Wilcoxon Test is used to determine the difference between the average of the pre-test and post-test scores. The analysis of the data was conducted using nonparametric test because, after the normality test using SPSS, it was found out that the data used in this study were not normally distributed. The results of the normality test can be seen in Table 5.

Based on the number of respondents in each class, which was less than 50 students, the normality test used was the Shapiro-Wilk Test. The test results of both classes show the value of Sig. <0.05, so it can be

Table 5
Test of normality

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	*df*	Sig.	Statistic	*df*	Sig.
Chemistry Education	.378	36	.000	.853	36	.000
Chemistry	.259	32	.000	.722	32	.000

Note. df = degrees of freedom (Total respondent – 1); Sig. = significance.

interpreted that the data is not normally distributed. The statistical hypothesis for the different tests is that "there is a significant difference between the average pre-test and post-test scores of students in course on the topic of PAHs."

The results of the reading survey were analyzed descriptively and the analysis stage started with tabulating the answers about difficult-to-understand lecture materials into several groups. Furthermore, the number of students experiencing difficulties with the lecture materials was converted into a percentage (%). For qualitative data, the collection was carried out through observation and lecture recordings. According to Creswell and Creswell (2018), qualitative data was used to support quantitative data. Based on the observation and lecture recordings, the data were analyzed descriptively. This analysis was useful in designing detailed descriptions for classroom situations through the implementation of the RADEC model.

Threats

The RADEC model can serve as an innovative learning model that helps students understand a complex topic such as PAHs compounds. The internal threat from practical implementation using the model includes the readiness of students. According to Hung (2016), readiness is indeed an important issue in teaching and learning. Furthermore, when using the model, students must give extra time and effort to answer the pre-learning questions before the course meeting. In this study, the pre-learning questions were developed to accommodate cognitive processes in line with Revised Bloom Taxonomy. To minimize this threat, lecturers motivate students to read information from various literature and teaching materials. These help students gain information in answering the pre-learning questions easily in under five days. On the Read stage, students search and read information from various literature on PAHs topic. To avoid confusion among students on the details of the topic read at home and facilitate them to search the information from various literature, lecturers provided directions on SPOT. Attention must be given to compatibility between the pre-test and post-test questions which assessed conceptual understanding with the learning goals. To reach the compatibility between the questions discussion should be conducted with lecturers before the courses are held.

The external threat from practical implementation using the RADEC model included (i) the course was carried out online because the application and the collection of data were carried out during the COVID-19 pandemic. Extra attention was provided to the course carried out through the Zoom Meeting platform, while the pre-learning questions and teaching materials were distributed through the Learning Management System, called SPOT; (ii) The internet network availability of students was an external threat in this study. To overcome this threat, lecturers were always brief and reminded students to prepare and check the internet network availability before course meetings; (iii) The study subjects were students from two different departments and their accreditation level was important. To gain the information on accreditation level, the certificate from Indonesian National Accreditation Institution was emphasized and the departments obtained Indonesian National Accreditation in the Very Good category.

RESULTS AND DISCUSSIONS

Results

Conceptual Understanding of Students. In the PAHs compound course, six topics were discussed, namely, (i) introduction, nomenclature, and criteria for PAHs, (ii) the reactivity of PAHs, (iii) electrophilic substitution reactions for PAHs, (iv) sulfonation reactions of naphthalene, (v) Friedel Craft acylation reaction, and (vi) the effect of bound groups (activating groups and deactivating groups) on PAHs compounds. The average pre-test and post-test scores of Chemistry Education Department and the Chemistry Department are presented in Figure 2.

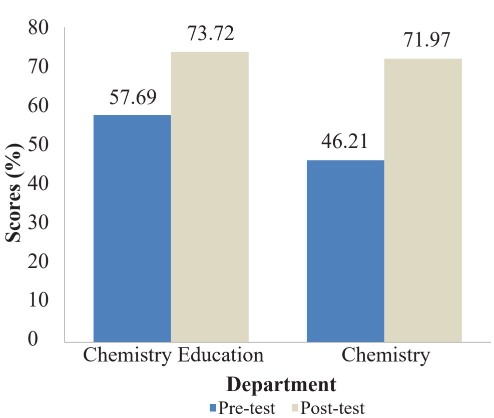


Figure 2. The average pre-test and post-test scores

Based on the research results presented in Figure 2, it can be seen that the students from the Chemistry Education Department and Chemistry Department have an average post-test score that is higher than the average pre-test score on the topic of PAHs compound with the implementation of the RADEC Model. Most questions that were answered correctly in the pre-test and post-test were about the introduction of PAH compounds, terminology, and criteria. Meanwhile, the topic of electrophilic substitution reactions was the topic that students from both Departments answered incorrectly. Based on the average score, the n-gain score obtained from the two groups of students is 0.33 for Chemistry Education Department students and 0.38 for Chemistry Department students.

Analysis of pre-test and post-test data using the n-gain formula aims to determine the effectiveness of the implementation of the RADEC Model on students' conceptual understanding. The results of the Wilcoxon Test can be seen in the Table 6. Table 6 shows Asymp. Sig. (2-tailed) < 0.05 for both groups of students. Based on this, it can be interpreted that the statistical hypothesis is accepted, or there is a significant difference

Table 6
The results of the Wilcoxon Test

Test Statistics	Chemistry Education	Chemistry
Z	-3.929	-3.784
Asymp. Sig. (2-tailed)	0.000	0.000

between students' average pre-test and post-test scores on the topic of PAHs.

Struggle of Students. Data on the struggle of students to understand topic are presented in Figure 3. Based on the data in Figure 3, it can be seen that Topic 5, the Friedel Craft acylation reaction, is the most difficult topic for students from both departments to understand. This result is not in line with the frequency of questions that students answered incorrectly, that is Topic 3 (electrophilic substitution reactions for PAHs). Although Friedel Craft's acylation reaction is considered a complex topic for many students, the facts show that they can solve the problems about the topic. The topic that gets the lowest percentage in the questionnaires is Topic 2 (Reactivity Position of PAHs) for Chemistry Education Department students and Topic 4 (Naphthalene Sulfonation Reaction) for Chemistry Department students.

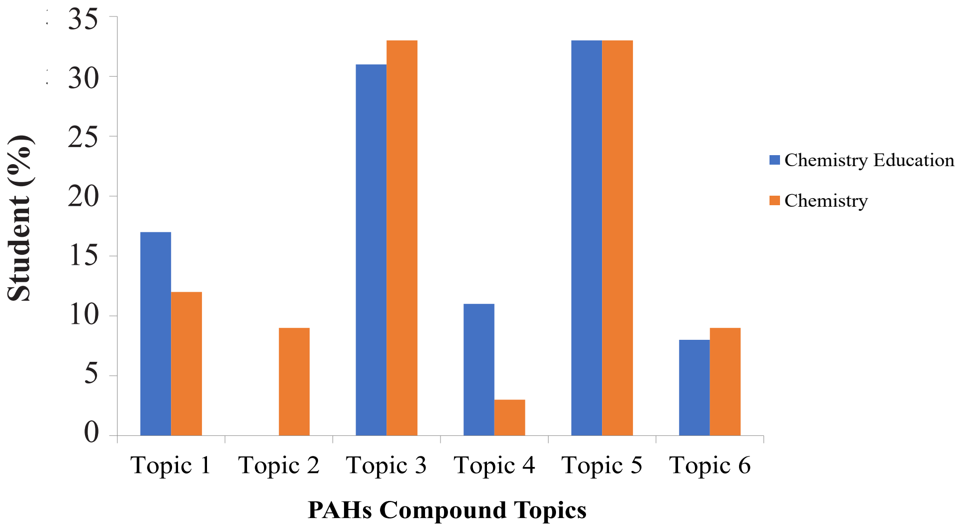


Figure 3. The percentages of students struggle on PAHs compound topics

Note. Topic 1 = introduction, nomenclature, and criteria for PAHs; Topic 2 = the reactivity of PAHs; Topic 3 = electrophilic substitution reactions for PAHs; Topic 4 = sulfonation reactions of naphthalene; Topic 5 = Friedel Craft acylation reaction; Topic 6 = the effect of bound groups (activating groups and deactivating groups) on PAHs compounds.

Discussions

Conceptual Understanding of Students on PAHs Compounds Topic through the Implementation of the RADEC Model. The n-gain scores of the two groups of students are interpreted to be in the medium category based on Hake (1998). The different test shows a significant difference with the average post-test score higher than the pre-test. The results indicate that the RADEC model effectively improves the conceptual understanding of students in both departments.

The effectiveness of the treatment given to respondents can be proven when the treatment was given to both groups with different learning situations (Sholahuddin et al., 2021). In this study, students from the Chemistry Education Department conducted courses in the morning, while students from the Chemistry Department conducted courses in the afternoon. The increase in students' conceptual knowledge can be identified through the post-test average score, which is higher than the average pre-test score. The pre-test and post-test contained questions that accommodated the competence in the cognitive process dimension. The questions in Topic 1 (introduction, nomenclature, and criteria for PAHs compounds) were the questions most students answered correctly. In contrast, the questions in Topic 3 (electrophilic substitution reactions) were the questions that most students answered incorrectly. However, the number of students who answered incorrectly decreased during the post-test. This result illustrates that the topic's difficulty level affects students' conceptual understanding (Herga et al., 2016).

The effectiveness of the RADEC Model in improving students' conceptual understanding can be seen from the stages of the RADEC Model that can accommodate students' cognitive processes according to the Revised Bloom's Taxonomy. This mental process is an indicator of student conceptual understanding. Based on Weay et al. (2016), Revised Bloom's Taxonomy acts as the cognitive taxonomy that can assess students' achievement and conceptual understanding. The description of the stages of the RADEC model that accommodates the cognitive processes based on the Revised Bloom's Taxonomy is as follows:

Read (R).

At this stage, students actively seek information from relevant sources, and the process of extracting information is guided through pre-learning questions. Pre-learning questions guide students to use the information obtained from the reading activities as essential concepts (Sopandi et al., 2021). To help students understand a topic, teachers must provide crucial questions that can guide students to explore and find basic concepts related to the topic (Sukardi et al., 2021). In this study, the distribution of pre-learning questions was done through SPOT. Incorporating reading activities into the tasks of students was an essential aspect of addressing their requirements for effective learning, given the limited availability of time for both face-to-face and online lectures. Meanwhile, the demands of active learning that can provide feedback for students are essential (Parker & Loudon, 2013).

Answer (A).

At the Read stage, students explore various information based on the directions from the pre-learning questions. Meanwhile, at the Answer stage, students answer the pre-learning questions. The engagement of students in responding to pre-learning questions during the Answer stage facilitates a self-assessment of their reading habits. This process enables them to determine whether they approach reading with diligence or lethargy, identify any challenges in comprehending the reading material, and ascertain their preferences towards the course material activities (Sopandi et al., 2021). According to Revised Bloom Taxonomy by Anderson and Krathwohl (2001), the Read and Answer stages accommodate all the cognitive processes because the making of the pre-learning questions refers to the cognitive level of the taxonomy. However, students might have different skills and learning styles, as stated in the Multiple Intelligences and Learning Styles concepts. Therefore, the lecturer does not require students to be able to correctly answer all pre-learning questions at the Answer stage. Still, students are given the freedom to respond based on relevant and reliable sources. Some pre-learning questions on the topic of PAHs compounds that were made according to the level of cognitive processes according to Revised Bloom's Taxonomy can be seen in Table 7.

Table 7
Pre-learning questions of PAHs topic based on revised bloom's taxonomy

Pre-learning Questions	Level of Cognitive Process
What is PAHs compound?	Remember (C1)
Explain the classification of polycyclic compounds based on their aromaticity, types of constituent atoms, and ways of joining the rings!	Understand (C2)
Learn the concept of reactivity in PAHs and determine the reactivity of pyrene!	Apply (C3)
Anthracene and phenanthrene are also aromatic compounds because they require aromatic compounds. Prove that statement!	Evaluate (C5)

Discuss (D).

The Discuss stage is filled with group discussions about the results of the students' respective work on pre-learning questions and cases that become the course material. However, in this study, lectures were conducted online, so the discussion activities were carried out through question-and-answer activities among students accommodated by the teacher. Discussions between lectures and students help students achieve better conceptual understanding (Chan et al., 2016). This Discuss stage trains the cognitive processes of students at the analyzing (C4) and evaluating level (C5) in Revised Bloom Taxonomy. At the Discuss stage, lecturers ensure that there is communication among students to obtain the correct answer (Sopandi et al., 2021). Subsequently, the specific section of the assignment was discerned where most students encounter difficulties and proceed to address the portion during the Explain stage.

Explain (E).

Based on the question-and-answer activity at the Discuss stage, lecturers identified parts of PAHs compounds topic yet to be understood by students, or elements in which students still had misconceptions. A misconception is an understanding of a concept that is different from the generally agreed scientific knowledge (Nakhleh, 1992). Finally, at the Explain stage, the lecturer tried to correct the misconceptions about the differences between aromatic and non-aromatic polycyclic compounds that still became a misconception for the students. In the initial process, the teacher gives students the question about the term of aromatic compound. It stimulates students to analyze the concepts of a conjugated double bond, the bond length in the ring structure of PAHs, and the delocalized electrons that create the characteristic of aromatic compound. The lecturer gave guiding questions to students to confirm the misconceptions that occur. Guiding questions act as an assistance from the teacher so that students can understand a phenomenon or solve problems and provide results to improve academic competence (Kapon, 2016). The lecturer provided guiding questions based on the fact that the students claimed to be able to distinguish polycyclic aromatic compounds and non-aromatic polycyclic compounds through the appearance of the compound structure.

However, they were not able to explain the causes that determine the properties of polycyclic aromatic compounds and non-aromatic polycyclic compounds. One of the fundamental sources of learning difficulties and chemical misconceptions is the failure of students to understand the emergent properties of chemical compounds and their interactions (Tümay, 2016).

Create (C).

At this stage, students were asked to make several reactions to PAHs based on the concepts learned from the previous RADEC model stage. These reactions include electrophilic substitution reaction 1, electrophilic substitution reaction 2, naphthalene sulfonation reaction, and Friedel craft acylation reaction. The stage accommodates the Create cognitive level (C6) in Revised Bloom Taxonomy. Creating is uniting the parts to form work or product with a connection between the parts (Anderson & Krathwohl, 2001). In according with the Create cognitive level in Revised Bloom's Taxonomy, the Create stage in the RADEC Model provides an opportunity for students to use the knowledge they have mastered to plan creative ideas (Sopandi et al., 2021). In this study, students were asked to predict the products formed and to make some reaction equations through the concepts learned in writing reaction equations. The supporting concepts include the position of the reactivity of the compound and the bound group. The Create cognitive level in Revised Bloom Taxonomy required organizational and planning skills for products or manufacturing steps (Mansur et al., 2019). This was in line with the Create stage of the RADEC model, which accommodated students to design projects (Ma'ruf et al., 2020).

RADEC Model has the possibility to apply to other topics or subjects. Ma'ruf et al. (2020) applied the RADEC Model to train students in making natural watercolors. Making natural watercolors was the project that students must conduct on the colloidal topic and another study using the RADEC model was from Sujana et al. (2021). The conceptual understanding of chemical representations was analyzed by making waste filters or chemical products that could absorb waste in the sea by using the RADEC model in the classroom. According to Handayani et al. (2019), the model required students to read, understand, think, and analyze their reading sources by answering the pre-learning questions. In mathematics, it facilitated students in discussing the problem of the formula to count the area of triangles, squares, and circles (Sopandi et al., 2021).

The RADEC model was created to improve the quality of learning processes (Sopandi, 2017). The novelties and uniqueness Model (1) Required students to actively seek information before classroom sessions. Students explored the information from various literature and the process was guided through pre-learning questions. Pre-learning questions acted as "clues of conceptual knowledge" that should be mastered (Sukardi et al., 2021). Students should answer the pre-learning questions after the reading activity and also focus on learning content. This impacted the improvement of conceptual understanding directly. (2) The development of the model is based on the fact that there was several learning dominated by lecture activities. Meanwhile, interaction in the classroom was dominated by the presentations of lecturers. The implementation of the model enhanced pre-existing knowledge before the classroom sessions. Consequently, during the in-class sessions, students actively participate in sharing and discussing the information acquired beforehand. (3) The model can be viewed as a technology-based learning model, where students learned teaching materials searched on the internet before classroom sessions (Sukardi et al., 2021). In addition, classroom discussions were carried out through the Zoom Meeting platform. (4) The RADEC model was suitable to apply in a blended format considered to be the most effective learning method adopted by higher education institutions (Rasheed et al., 2020). The Read and Answer stages were carried out online while the Discuss and Explain stages were conducted offline in the classroom. Furthermore, the Create stage was performed online or offline depending on the agreement of students in each group.

The Struggle of Students in Understanding PAHs Topic. Information on the struggle of understanding PAHs topic through the application of the RADEC model, specifically at the Read stage, should be analyzed because the implementation in organic chemistry is relatively new. Data were obtained when the course through Zoom Meeting was about to begin, which was after the Read and Answer Stage. At this time, the students had not received explanations from the teacher, or the opportunity to have discussions with other students. Thus, the knowledge gained was not maximized. Based on Social Constructivist Learning Theory, a person has a zone between competence that can be achieved alone, and competence that can be achieved with the help of others called the Zone of Proximal Development (ZPD). In this zone, learning in class are carried out through the Discuss, Explain, and Create Stages. After getting help from other people, teachers, and peers, students can reach their potential competence (Vygotsky, 1978). Courses activities help students find solutions about the difficult topics they struggle. They act as scaffolding to strengthen students' conceptual understanding and help students achieve the ability to complete assignments smoothly and independently (Wass & Golding, 2014; Xi & Lantolf, 2021).

PAHs compounds topic had a characteristic related to the topic taught in the previous semester, namely benzene. Consequently, students had to recall their memories on benzene, which PAHs topic was more complex than benzene which was only one member of a large number of aromatic compounds (Fessenden & Fessenden, 1986). A more extensive and in-depth discussion of aromatic compounds was on PAHs topic. This was the cause of struggle in studying PAHs from a topic point of view. In addition, electron resonance and delocalization are important topics when discussing compounds with ring structures. It has been reported that resonance is a fundamental concept in organic chemistry and is one of the most difficult concepts to understand (Carle & Flynn, 2020; Duis, 2011). Therefore, teachers need to assess not only the conceptual understanding of their students, but also the difficulty of the material their students will learn (Rusek & Vojíř, 2019). The problem with topics is the reason why many students and adults dislike science, particularly chemistry and physics (Childs et al., 2015).

Several reasons contributed to the struggles experienced by higher education students in understanding organic chemistry concepts relying on memorization as the primary learning method (Garg, 2019; Horowitz et al., 2013). However, it is worth noting that other learning approaches existed beyond pure memorization. The RADEC model provided an effective approach where students learned independently at home by reading before attending classroom sessions. As a result of this pre-learning activity, students acquired a more profound knowledge of the subject matter compared to those who did not engage in prior reading when the teaching-learning process began in the classroom. This approach empowered students to enhance their understanding and actively contribute during classroom discussions (Sopandi & Sutinah, 2016). Another reason is students cannot engage in the learning environment (Shea, 2016) because the traditional lecture method dominates in classrooms and resulting in lack of interaction. This leads to a lack of development of the various skills necessary to live in the 21st century, such as communication and collaboration. Lack of interaction also makes students feel bored and struggle on understanding the concepts.

The RADEC model has tried to overcome the struggle of students on understanding the concepts through pre-learning questions (Sopandi et al., 2021). The presence of pre-learning questions to overcome organic chemistry concepts is in line with the Guided Reading Questions used by Kennedy (2016). Guided Reading Questions are used to help students focus on the main points and core concepts of the course. These questions form the basis of class discussion and guidance in reading enabling students to become successful readers (Long & Szabo, 2016). Pre-learning questions serve as scaffolding for students to read complex texts successfully. After giving sufficient instruction before the lesson, students can then read the text successfully. Lecturers can also guide students during the reading process (Young, 2018).

CONCLUSION

In conclusion, this study was conducted to show an improvement in the conceptual understanding of students after learning with the RADEC model. This means that RADEC Model's stages effectively accommodate students' cognitive processes on the topic of PAHs compounds. The model supported students in preparing for the complex topic of PAHs compounds by reading the topic first. Meanwhile, unmastered topic was explained through Discuss, Explain, and Create stages. Through scaffolding from lecturers and peers, students were assisted in achieving increased conceptual understanding. This study also found that the topic of Friedel Craft acylation reactions was the most difficult topic for students from the Chemistry Education Department to understand and the same topic, namely Friedel Craft acylation reactions and the topic of electrophilic substitution reactions of PAHs compounds, was the most difficult topic for students from the Chemistry Department to understand.

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