Journal of Turkish Science Education, 2025, 22(1), 63-86.
DOI no: 10.36681/tused.2025.005

Journal of Turkish Science Education
http://www.tused.org
© ISSN: 1304-6020

The effect of mental model-based learning on the academic proficiency in school-level chemistry of pre-service teachers

Wiji Wiji

Universitas Pendidikan Indonesia, Indonesia, Corresponding author, maswiji@upi.edu, ORCID ID: 0000-0001-5492-4346

ABSTRACT

This research explores the effect of mental model-based learning on understanding school chemistry. The learning activity included group discussion, presentation and class discussion. Pre-service chemistry teachers (PCT) analyzed school chemistry topics in relation to essential underlying concepts. The development of mental models was monitored using a diagnostic test and observations. Most of PCT had two initial models, namely scientifically more accurate ones as in the concept of activation energy and dynamic equilibrium, and incomplete one as in the concept of limiting reagents, enthalpy, reaction speed, collision theory, acidity, chemical reaction, equilibrium constant and titration. PCT's mental models in school chemistry topics experience development with average scores ranging from 39.14 to 64.00. Wilcoxon signed-rank test with the significance level $\alpha = 0.05$ shows a significant difference between the median initial and final mental models.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received:
27.10.2023
Accepted:
18.07.2024
Available Online:
19.02.2025

KEYWORDS:
Mental model-based lecture, school chemistry, pre-service chemistry teacher, alternative conception, multiple representations.

To cite this article: Wiji, W. (2025). The effect of mental model-based learning on the academic proficiency in school-level chemistry of pre-service teachers. *Journal of Turkish Science Education, 22*(1), 63-86. DOI no: 10.36681/tused.2025.005

Introduction

Pre-service chemistry teachers (PCT) are equipped with knowledge of chemistry topics to support their professional competence. Chemistry topics are studied in three clusters: Basic, Advanced, and School Chemistry. Basic Chemistry courses aim to help PCT understand chemistry's facts, concepts, laws and theories, including those relating to structure, dynamics, energetics and kinetics, as a preparation for further chemistry study. Advanced Chemistry courses help PCT master organic, inorganic and biomolecules' structure, properties, kinetics and reaction mechanisms. On the one hand, School Chemistry courses aim to help PCT master the chemistry school topics based on the current school curriculum and shape them into a teachable and learnable form.

Chemistry is quite challenging to learn because it is abstract, complex and too symbolic (Chittleborough, 2004; Kajornklin et al., 2022; Ademola et al., 2023). Aydeniz et al. (2017) state that pre-service elementary science teachers cannot fully understand the particulate nature of matter. Research by Santos and Arroio (2016) indicated that the ability of high school and undergraduate students to understand chemistry at all levels of representation is quite concerning. Meanwhile, the inclination of representation competency is essential in encouraging achievements in chemistry (Stieff et al., 2016).

Several studies related to the learner's understanding of the core concepts of chemicals showed some alternative conceptions. The concept of atomic structure is dominated by the Bohr model (Adbo & Taber, 2009) and not by the model of quantum mechanics because it is hampered by the threshold concept of probability and quantization energy on first-year college students (Park & Light, 2009). Alternative concepts in chemical kinetics include the idea that when temperature rises, a reaction takes longer to complete; and that endothermic reactions occur more slowly than exothermic ones (Yan & Subramaniam, 2017). In chemical equilibrium, about 1 in 5 students held the alternative conception that the equilibrium constant increases when there is a change in the concentration of different species (Karpudewan et al., 2015). Regarding acid-base, students state that pure ethanoic acid is more acidic than liquid ethanoic acid because pure ethanoic acid produces more hydrogen ions. This moderate alternative conception may also be another linguistic problem as the term 'pure' may have the connotation of 'no impurities,' and thus, naturally, 'more acidic' is present to indicate the hydrogen ions produced (Hoe & Ramanathan, 2015). Alternative conception is also defined with different terms such as s misconceptions. Factors that cause misconceptions can be students, teachers, language used, teaching methods, characteristics of teaching materials, and reference books, by including everyday experiences into the student area (Resbiantoro et al., 2022).

Various efforts to reduce the abstract and complex nature of chemistry have been carried out by using models (Chittleborough & Treagust, 2007; Kermen & Méheut, 2009; Bilginer & Uzun, 2022; Demirçalı & Selvi, 2022), analogy (Clement & Ramirez, 2008) and metaphors (Reese, 2008). However, the difficulties faced by the learners in understanding the chemical concept have not yet been fully resolved. Simplifying the concept through analogies, models and metaphors in the learning process is often not followed by explanations of the scope and limitations so that the concept the learners build differs from scientists (Adbo & Taber, 2009). For example, when teachers use an analogy in learning the concept of electron configuration, they do not complete it with an explanation of the behaviour of significant matters that are very different from small matters. It is possible that the use of analogy causes a variety of learners' alternative conceptions.

Teachers should consider that every learner has various preconceptions or initial mental models. A mental model is a form of knowledge organization that represents objects, conditions, sequences of events, how the world works, and social and psychological actions in daily life. The forms of organization do not mean the one at a time of static representation from the outside but a dynamic abstract used to interpret experience and share meaning (Khan, 2007). Mansyur et al. (2022) stated that in general learner' mental models are still initial and are very dependent on context. Modelling-based teaching is an effective method for creating scientifically more accurate mental models for learners during the science concept learning phase (Bilginer & Uzun, 2022). Research by Halloun (2007) shows that mediated modelling learning could elevate learners' achievement reflected in more meaningful subject-matter understanding, better learning style, higher chance of success, lower school dropout rate, and smaller social gap between students with different backgrounds. So, the orientation of prospective chemistry teachers is influenced by chemistry teaching models in courses (Gencer & Akkus, 2022).

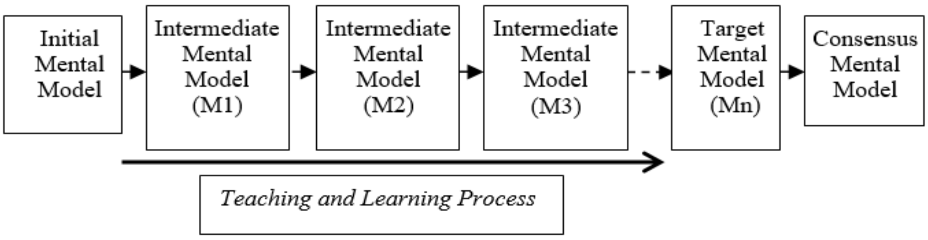
Schwichow et al. (2021) state that it is crucial for teachers to know pupils' preconceptions in science education so that teaching and learning can be effective. Teachers' understanding will be directly related to the teaching methods they choose in addressing students' preconceptions when teaching science (Kambouri, 2016). Lin and Chiu (2010) clearly state the failure of teachers to make clean preparations for the learner because they do not understand the preconceptions of learners and resources, which would potentially cause mismatches in anticipating the learning process. Teachers should teach by considering pupils' mental processes and the variables influencing their thoughts and behaviour (Dindar & Geban, 2016). Teachers can help learners construct new concepts based on an existing conceptual framework. Understanding learners' initial mental models is helpful in designing instructional methods to be applied. That means identifying students' models and inferences about their mental models must be identified before the teacher designs the learning design (Redhana et al., 2020). Learners' mental models must be used as a reference for teachers in designing learning approaches, learning models, learning strategies, learning media, and choice of textbooks (Fratiwi et al., 2020).

Although each individual has a different initial mental model, teachers can group the individual mental models based on similar characteristics and specific patterns. According to Bofferding (2014), mental models are divided into initial mental models, transition 1, synthetic mental models, transition 2, and formal mental models. Lin and Chiu (2010) divide them into scientific, phenomenon, symbolic character, and inference models. Jansoon et al. (2009) classify mental models into macroscopic, sub-microscopic, and symbolic models. In comparison, Adbo and Taber (2009) group them into teaching models, scientific models, and alternative models. Grouping learner mental models will be beneficial for designing strategies and methods selected in the learning process. Thus, the learning process based on initial mental models of learners does not mean to be done individually.

A learning process based on mental models is building the target or consensus mental models that start from the initial mental models. The target model is achieved through the construction process of the intermediate mental models repeatedly and continuously. The theoretical framework-based learning models of Clement (2000) can be used as a framework for the learning process based on mental models. Clement describes the learning process as the sustainable construction and revision of learners' models. Figure 1 illustrates the learning process based on mental models by constructing an intermediate mental model based on Clement's framework.

Figure 1

Theoretical framework of learning based on mental models



The design of the learning model can integrate learning resources, learning activities, learning strategies, and assessments. The mental models based on students' prior knowledge are expected to be able to believe in theory and practice (Stains & Sevian, 2015). Initial mental models are a source of meaning and help learners understand concepts through a teacher's guidance. It can be obtained through a series of tests, while the expression of the model is through verbal descriptions, images, tables, concept maps, sign models, and concrete models. Students' initial mental model can be seen from the information stored in long-term memory before they are exposed to a new concept (Utami et al., 2019). The mental model construction process includes the creation, elaboration, use, evaluation, and revision. In order to develop a target mental model, the learner can take steps of reflection, such as modification or integration into the intermediate mental model. Studies based on mental models can provide qualitative data, compensating for some lack of quantitative data.

Mental model exploration is complicated. Different researchers did many forces in exploring mental model, some of them through questions in the form of multiple choices, paragraphs, interviews, and class observation (Lin & Chiu, 2007; Coll, 2008; Park & Light, 2009; Jansoon et al., 2009; Adbo & Taber, 2009; Strickland et al., 2010; Wang & Barrow, 2010; Lin & Chiu, 2010). Soeharto (2021) used a two-level test that was developed as a diagnostic instrument because students' conceptions and reasoning were linked to understanding scientific misconceptions. At all times, mental model exploration is restricted to the evaluation instrument and consistency of students' conception, identifying threshold concepts, and analyzing troublesomeness in one concept. There has not been any research that intertwines the student model exploration result with the lecture process. Therefore, a lecture model must be developed based on a preliminary mental model. This study analyzes the changes in PCT school chemistry models after applying mental model-based lectures.

The research question: (1) How are school chemistry models of PCT before incorporating mental model-based chemistry school lectures? (2) How do school chemistry models of PCT develop during the mental model-based chemistry school lecture?

Methods

This research used a mixed methods approach, employing an embedded experimental model to collect quantitative and qualitative data. This research started with a quantitative data collection process to analyze PCT's preliminary mental models on the school chemistry topics to be taught. Subsequently, qualitative data were collected through observation during group discussions, and quantitative data were gathered to analyze the PCTs' mental models after the lecture.

Context

This lecture covered the applicable curriculum of content-based schools in Indonesia. Lecture topics included stoichiometry, thermochemistry, chemical kinetics, equilibrium, and acid-base. Previously, PCT already had an alternative conception of these essential chemistry concepts. Through this mental model-based lecture, it was expected that these alternative conceptions would transform into target conceptions, enabling the PCTs to formulate school chemistry topics in a clear and straightforward way for students. This lecture program was carried out for one semester with 15 meetings. Each meeting lasted 150 minutes face-to-face in class, 180 minutes for independent study, and 180 minutes for structured assignments. The syllabi and lecture units are shown in Appendix 1. In this lecture, PCT's analyzed school chemistry topics, determined essential concepts, and presented them at three levels of representation (macroscopic, sub-microscopic, and symbolic) through various activities. In chemistry teaching, PCT's are trained to present essential concepts and their multiple representations simultaneously in front of the class. Each group received questions and feedback from other groups and lecturers on these occasions.

Participants

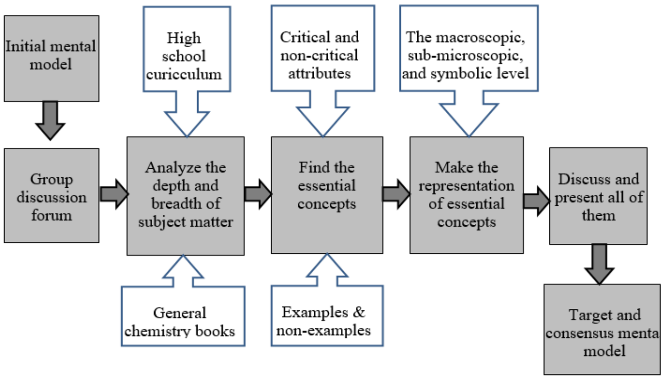
The study participants were a total of 35 PCT who were third-grade undergraduate students in the department of chemistry education at a university in Bandung, Indonesia. PCT were enrolled in a school chemistry course. Responsible lecturers are the instructors for the school chemistry course. This lecture aims to elevate PCT's understanding and guide them to present well-defined and straightforward materials for students.

Intervention

Regulations demand that student teachers master the chemistry topics they will teach and have the skills to convey these topics effectively. However, in reality, teaching has been predominantly teacher-centered, with little emphasis on teaching practice and limited experience in assembling teaching materials. Therefore, this research aimed to make learning more student-centered and active. The mental model-based lecture intervention begins with a group discussion. In the group discussions, an analysis of the depth and breadth of the chemistry subject matter is carried out, and essential concepts are determined. In group discussions, PCT's initial mental models develop into intermediate models (M1, M2, M3). After finding essential concepts, they are strengthened by presenting chemistry topics in three levels of representation. Further, PCT go through presentations and discussions in class involving the lecturer. The role of the lecturer in class discussions is to develop intermediate models into target mental models. The intervention can be seen in Figure 2 for better clarity. This course was carried out for one semester with 15 meetings.

Figure 2

Overview of the school chemistry mental model-based lecture



Instruments

The PCT's mental model was developed through the Diagnostic Test of School Chemistry Mental Models (DTSCM) instrument and observations during lectures. DTSCM was used to collect mental model data at the beginning and end of the lecture, and observation guides were used to collect data on the development of the PCT's mental models during the lecture. The test consists of ten questions in the form of a two-tier test, which includes four choices of answers and six choices of reasons. The reasons are presented in the symbolic model of the phenomenon at sub-microscopic and macroscopic level. Topics tested cover the concept of chemical reactions and limiting reactants for stoichiometry, the concept of activation energy and reaction enthalpy for thermochemistry, the concept of collision theory and reaction rate for chemical kinetics, the concept of dynamic equilibrium and the equilibrium constant for chemical equilibrium, and the concept of titration and acidity of solutions for acid and base.

The DTSCM question number 8 can be seen in Figure 3. Question number 8 provides a question in determining the potential energy profile of the NO and N_2O reactions. Then, there are options A, B, C, and D in the form of a graph showing the relationship between time and potential energy. Then, the PCT's must also choose the reason for the answer by choosing options 1, 2, 3, 4, 5, or write the reason themselves in the empty area in option 6. Each question has an answer option and a reason option that must be chosen. If the answer and reason are correct, then a score of 1 will be given. However, if either the answer or the reason is correct, the score will be 0.5. If both are wrong, then a score of 0 will be given. This DTSCM test consists of 10 questions, so the total score for all correct answers is 10. The DTSCM instrument was validated by expert chemistry and science education lecturers and tested for reliability. Cronbach's alpha reliability of DTSCM is 0.798, as shown in Table 1.

Table 1

Cronbach alpha coefficients of the DTSCM

Variables	Number of item	Cronbach Alpha
Stoichiometry	2	0.779
Thermochemistry	2	0.771
Chemical Kinetics	2	0.699
Equilibrium	2	0.726
Acid and Base	2	0.676
Overall	10	0.798

The lowest reliability is on acid-base topics and the highest is in stoichiometry with Cronbach's alpha coefficient of 0.676 and 0.779, respectively.

Figure 3

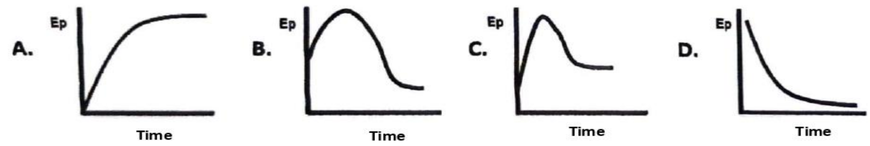
Sample questions in DTSCM instrument

Question 8

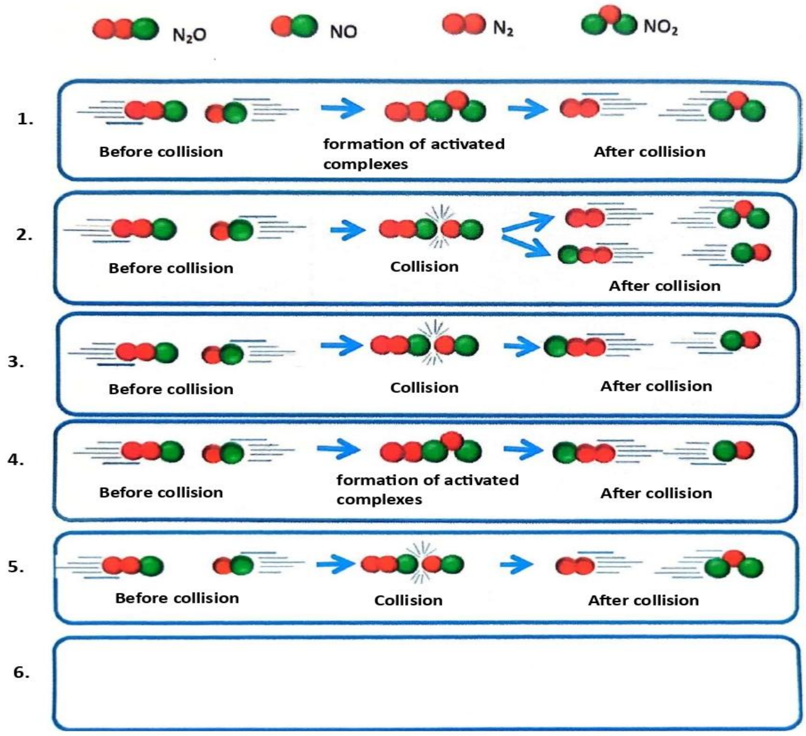
The following reaction can be explained using collision theory:

$NO + N_2O \rightarrow NO_2 + N_2$

Based on the results of observations during the reaction, it shows that the reaction is exothermic and the potential energy level profile during the reaction process is constantly changing. In your opinion, which potential energy profile is correct?



Which of the models below could be the reason for your answer above?



Analysis

Qualitative data were obtained from classroom observations. Two trained observers carried out classroom observations. PCT-lecturer interactions during lectures were recorded by observers as notes using the open narrative method. Observations were then coded in a classroom observation rubric (Appendix 2). The class observation rubric is designed to record the development of PCT mental models during lectures through PCT-lecturer activities. The development of mental models from observations is then processed by grouping intermediate model achievements. The codes of M1, M2, and M3 were found in student expressions categorized as intermediate mental models. It was still initial and then changed after discussion.

Quantitative data was obtained from the PCT pretest-posttest results using DTSCM. Qualitative data were analyzed descriptively to find trends and patterns of change emerging during the research. Meanwhile, quantitative data, both descriptive and inferential, were analyzed statistically. The level of the mental model is categorized based on the dominant answer type, namely "type 11" (complete, can draw conclusions and find reasons), "type 10" (partial, can draw conclusions but has difficulty finding reasons), "type 01" (partial, cannot draw conclusions even though they know the reasons, and "type 00" (incomplete, unable to draw conclusions and find reasons).

The Statistical Package for the Social Sciences (SPSS) was used for quantitative data processing analysis. Wilcoxon's test was performed to evaluate whether there was a significant difference in the medium mental model of school chemistry before and after the lecture. Besides being used to compare the overall mean, Wilcoxon's test was also used to compare the mean of each part of the mental model of school chemistry. Qualitative analysis was conducted on three examples of intermediate mental models: the molecular formula, standard enthalpy of formation, and practical collision. The representations of these concepts at the macroscopic, sub-microscopic, and symbolic levels were then described.

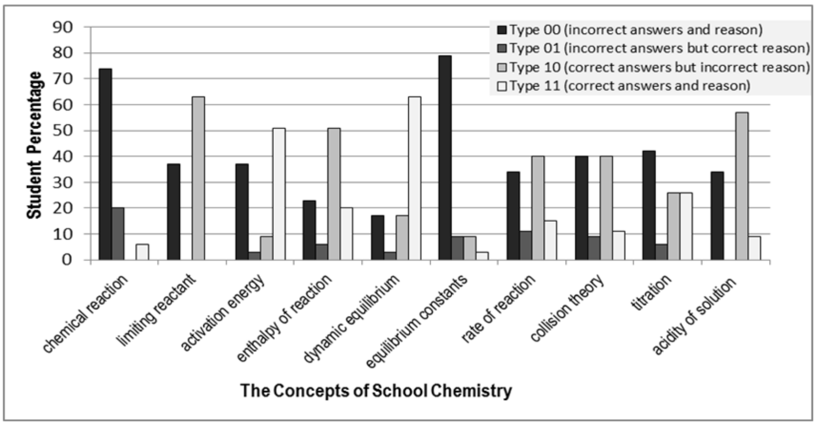
Findings

Initial School Chemistry Mental Models of PCT

PCT's initial school chemistry mental models are shown in Figure 4. Based on the dominant types of answers, they are divided into three groups: scientifically more accurate (type 11), moderate (type 10 and type 01), and incomplete (type 00). Most PCT have a scientifically more accurate mental model in the concept of activation energy and dynamic equilibrium; a moderate mental model in the concept of limiting reagents, reaction enthalpy, reaction rate, collision theory, and acidity of solution; and an incomplete mental model in the concept of chemical reaction, the equilibrium constant, and titration.

Figure 4

Description of PCT's initial mental models



Development of School Chemistry Models of PCT

The essential concept labels on school chemistry that PCT found are summarized in Table 2.

Table 2

Essential concept labels on school chemistry topics

Topics of School Chemistry	Essential Concept Label
Stoichiometry	Molecular formula, empirical formula, relative atomic masses, relative molecule masses, mole, chemical reactions, limiting reactant, percentage

Topics of School Chemistry	Essential Concept Label
	composition, and percentage yield.
Thermochemistry	Exothermic reactions, endothermic reactions, thermochemical equations, enthalpy change, standard enthalpies change, standard enthalpies of formation, standard enthalpies of burning, standard enthalpies of neutralization, and calorimetry.
Chemical kinetics	Reaction rate, rate constant, reaction orders, effective collision, transition state, activation energy, catalyst.
Chemical equilibrium	Equilibrium reaction, dynamic equilibrium, equilibrium constant, reaction quotient, equilibrium shift, heterogeneous equilibrium.
Acids and bases	Arrhenius acid-base, Bronsted-Lowry acid-base, Lewis acid-base, neutralization, monoprotic acid, polyprotic acid, autoionization of water, pH, salts, strength of acid and base, buffer solution, hydration, hydrolysis, titration, indicator.

The definition of such essential concepts developed during the lecture in intermediate mental model 1 (M1) towards the next intermediate mental model (Mn). The development example of PCT's School Chemistry Models relied on labeling the concepts of chemical formulas, standard enthalpy formation changes, and effective collisions. Models between M1 and M2 in the molecular formula concept label develop on the types of compounds and their constituent particles. Through group discussions, learners could find a more precise classification of matter. Compounds were divided into molecular compounds and ionic compounds. The molecular formula states the type of molecule and the number of atoms that make up the molecular compound. In the intermediate model M3, PCT's found that elements are not only composed of atoms. Some elements are also composed of molecules such as H_2, O_2, and S_8, called element molecules. Finally, PCT reached the target mental model stating that the molecular formula shows the type and number of atoms in a molecule, including element and compound molecules.

The development of an intermediate mental model on the concept label of standard enthalpy of formation change occurs at the critical attribute of the standard state. Most students perceive the standard state of a substance to be the same, regardless of its form. The definition "standard state is the state of a substance at a temperature of 25°C and a pressure of 1 atm" dominates students' initial mental models. They do not yet realize that this definition is for substances in the form of gas. Through lecturer facilitation in the form of providing a general chemistry resource book, students discovered that the standard state of a substance depends on its phase. The standard state of a gas is at a pressure of 1 atm, whether pure gas or a mixture. The standard state of solids and liquids is the pure state, while the standard state of a solution is defined as having a concentration of 1 M.

The development of an intermediate mental model on the concept label of effective collision began with the emergence of various statements about collisions. Among the statements that developed were "collisions can reduce activation energy," "every collision is always effective," and "effective collisions cause reactions to react quickly." Through group discussions, students found the target model that effective collisions produce reactions when they have the proper orientation and sufficient energy.

The essential concepts are shaped into three levels of representation. An example of the representation at the macroscopic, symbolic, and sub-microscopic levels on the concepts of molecular formula, standard enthalpy of formation, and effective collision can be seen in Table 3, 4, and 5.

Table 3

Development of the representation of the molecular formula concept

Essential Concept	Representation	
	Level	Development
Molecular formula is a formula that states the type and number of atoms in a molecule	Macroscopic	We are familiar with water, vinegar (acetic acid), and oxygen gas in everyday life. Each has unique characteristics in terms of shape, smell, taste, and many others.
	Sub-microscopic	The typical properties of each compound depend on the constituent particles. Water, vinegar (acetic acid), and oxygen gas comprise molecules. The molecular formula depends on the type and number of atoms present. A water molecule contains two types of atoms: H and O, with numbers 2 and 1, respectively, and the molecular formula H_2O, as well as the other compounds.
	Symbolic	The molecular formulas of water, acetic acid, and oxygen gas are H_2O, CH_3COOH, and O_2.

Table 4

Development of the representation of standard formation enthalpy

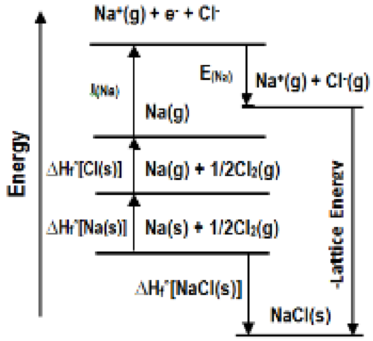
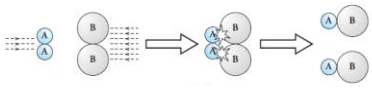
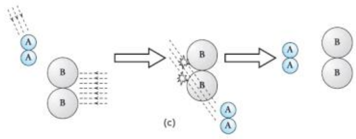
Essential Concept	Representation	
	Level	Development
Standard enthalpy of formation is the number of heats absorbed or released in the formation of one mole of a compound from its elements at standard state	Macroscopic	We often found many reactions forming compounds from the elements in the laboratory. One popular example is sodium chloride formation from sodium metal and chlorine gas. Every production of 1 mol of compound sodium chloride releases heat as much as 401.9 KJ
	Sub-microscopic	The process of formation of sodium chloride compounds through several stages. • Solid metal sodium (sodium standard state) undergoes a sublimation process by absorbing energy of 108.7 KJ mol^{-1}. Chlorine gas (chlorine standard state) dissociates by absorbing energy of 120.9 KJ mol^{-1} • Sodium in the gas phase is ionized by absorbing energy of 493.8 KJ mol^{-1}. Chlorine atoms in the gas phase capture electrons that release sodium by releasing energy of 379.5 KJ mol^{-1}. • Sodium and chlorine ions bond to form sodium chloride, releasing energy of 654.8 KJ mol^{-1}. So the whole process of formation of sodium chloride releases heat as much as 401.9 KJ mol^{-1}
	Symbolic	

Table 5

Development of the representation of effective collision

Essential concept	Representation	
	Level	Development
Effective collisions are collisions with proper orientation and sufficient energy to produce a reaction	Macroscopic	The effect of temperature is one of the factors that influences the reaction rate. Generally, as temperature increases, reactions occur more quickly. The reaction between hydrochloric acid and sodium thiosulphate forms a yellow precipitate. The yellow precipitate formed at high temperatures is higher than that at lower temperatures.
	Sub-microscopic	The reaction between sodium thiosulphate with hydrochloric acid to produce sodium chloride, sulfur dioxide, water, and precipitate sulfur yellow. At low temperatures, reactant molecules have low kinetic energy. This lowers the frequency of collisions with the proper orientation. As a result, fewer products are produced. In contrast, at high temperatures, the collisions are more frequent. Hence, the effective collisions of reactant molecules also increase the products.
	Symbolic	Effective collision  Ineffective collision 

Representation at the macroscopic level of the molecular formula concept begins with familiar molecular compounds in everyday life, such as water, vinegar, and oxygen gas. Furthermore, it is described that the distinctive properties of each of these compounds are different from one another. At the sub-microscopic level, it is stated that each molecular compound comprises smaller particles in the form of molecules. The molecular formula determines the type and number of atoms that make up the molecule. The molecular formulas of water, acetic acid and oxygen gas are shown at the symbolic level.

The macroscopic level representation of the concept of standard enthalpy of formation presents the formation of compounds from their elements, such as the formation of sodium chloride from sodium and chlorine. At the sub-microscopic level, students describe the stages of formation and the energy involved in each stage. The stages of the reaction scheme are presented at the symbolic level.

The macroscopic level representation of effective collisions presents a reaction between sodium thiosulphate and hydrochloric acid. This reaction produces a yellow precipitate of sulfur. Precipitation intensity depends on the reaction temperature. At the sub-microscopic level, the effect of temperature on the effective collision is described. The collision scheme is presented at the symbolic level.

Improvement of PCT School Chemistry Mental Models

Table 6 provides mental model score recapitulation and N-Gain of the students attending the mental model-based school chemistry lectures.

Table 6

Average Score of N-Gain

No	Student Code	Preliminary Score	Final Score	*N-Gain* (%)	Category
1	Stdnt 3	4.0	8.5	75.00	High
2	Stdnt 10	3.5	8.5	76.92	High
3	Stdnt 11	6.0	9.5	87.50	High
4	Stdnt 12	4.0	9.0	83.33	High
5	Stdnt 14	3.0	8.0	71.43	High
6	Stdnt 19	3.0	9.5	92.86	High
7	Stdnt 33	4.0	8.5	75.00	High
8	Stdnt 2	2.5	7.0	60.00	Medium
9	Stdnt 1	3.0	7.0	57.14	Medium
10	Stdnt 4	5.0	8.0	60.00	Medium
11	Stdnt 5	1.0	4.0	33.33	Medium
12	Stdnt 18	5.0	7.0	40.00	Medium
13	Stdnt 7	5.0	7.5	50.00	Medium
14	Stdnt 8	4.0	8.0	66.67	Medium
15	Stdnt 9	5.0	7.0	40.00	Medium
16	Stdnt 16	2.0	6.0	50.00	Medium
17	Stdnt 20	4.0	7.5	58.33	Medium
18	Stdnt 21	5.5	8.5	66.67	Medium
19	Stdnt 22	5.5	7.0	33.33	Medium
20	Stdnt 23	6.0	8.0	50.00	Medium
21	Stdnt 24	4.5	7.5	54.55	Medium
22	Stdnt 25	3.5	7.5	61.54	Medium
23	Stdnt 26	3.5	5.5	30.77	Medium
24	Stdnt 27	3.0	5.5	35.71	Medium
25	Stdnt 28	3.5	7.5	61.54	Medium
26	Stdnt 29	2.5	5.5	40.00	Medium
27	Stdnt 32	2.0	4.5	31.25	Medium
28	Stdnt 35	2.5	5.5	40.00	Medium
29	Stdnt 6	4.5	5.5	18.18	Low
30	Stdnt 13	3.0	4.0	14.29	Low
31	Stdnt 15	3.0	4.0	14.29	Low
32	Stdnt 17	5.5	6.0	11.11	Low
33	Stdnt 30	3.5	4.0	7.69	Low
34	Stdnt 31	3.0	5.0	28.57	Low
35	Stdnt 34	2.0	4.5	3.25	Low
	Total	130.5	236.0	1708.25	-
	Average Score	3.73	6.74	48.81	-

N-Gain can be used to comprehend the improvement of PCT's school chemistry mental models after attending a mental model-based lecture. Based on the 35 students, most experienced an increase in their school chemistry mental model scores, categorized as low (7 PCT), medium (21 PCT), and high (7 PCT). The average score was in the medium category with an N-Gain value of 48.81%. The quantitative analysis results showing the difference in median of school chemistry models before and after the lectures are presented in Table 7.

Table 7

The results of Wilcoxon signed-rank test

Sub-scales	Pre-lecture			K-S Test	Post-lecture			K-S Test (p)	Wilcoxon Signed-rank Test	
	N	M	SD	(p)	N	M	SD		Z	p
Stoichiometry	35	4.71	4.191	0.000	35	12.71	6.680	0.001	-4.507	0.000
Thermo chemistry	35	10.57	5.392	0.000	35	13.29	4.012	0.000	-1.998	0.046
Chemical kinetics	35	7.50	4.647	0.000	35	13.29	6.056	0.000	-3.811	0.000
Chemical equilibrium	35	8.43	4.661	0.000	35	13.86	4.216	0.000	-4.251	0.000
Acids and bases	35	7.86	4.894	0.002	35	10.86	4.615	0.000	-2.859	0.004
Overall	35	39.14	12.514	0.200	35	64.00	17.184	0.012	-4.898	0.000

Kolmogorov-Smirnov test (K-S test) shows that the data are not normal distribution ($p < \alpha = 0.05$), except in pre-course overall. Wilcoxon signed-rank test with the significance level $\alpha = 0.05$ shows a significant difference between the median initial and final mental models. The differences occur in each topic's overall score and median score. The highest development of mean score of mental models is in the stoichiometry concept is 4.71 to 12.71, and the lowest on the thermochemistry concept is 10.57 to 13.29. Overall, the mean score of PCT mental models develops from 39.14 to 64.00.

Discussion

The mental model-based learning is a discovery in this research. PCT's mental models in school chemistry topics experience development with average scores ranging from 39.14 to 64.00. PCT are trained to discover essential concepts in school chemistry topics and define concepts in group discussions. Further, PCT formulate each concept in three representation levels: macroscopic, sub-microscopic, and symbolic. It is expected to make the teaching and comprehension process easier. It also aims to explain chemistry phenomena based on underlying molecular processes. PCT are expected to intertwine the three representation levels. If the intertwining fails, their knowledge will be fragmented and incomplete. This task can only be accomplished when PCTs have a complete mental model for the essential school chemistry topics. This is in line with Santos and Arroio (2016), who state that if students can comprehend the role of each level in the chemistry representation, they will be able to connect the knowledge from one level to the other and develop relational understanding. According to Murni et al. (2022) learning modules that integrate three levels of chemical representation can build mental models of chemical concepts. The mental models developed help students to understand chemistry concepts better.

The development of definitions and representations of essential concepts is shown to be more optimally carried out through group discussion than individually. Individual mental models that are formed and developed in a social context will be different even if they observe the same event or carry out the same task. Group discussion forums will help members communicate with each other to explore their mental models, create shared mental models, and learn new mental models. Students are also able to embed mental models of other concepts within their own mental models in relevant domains when working in groups. Students can refine their mental models to closely resemble the physical models by using shared ideas during discussions and problem-solving (Newman et al., 2018). The formulation of school chemistry topics into a form that is easy for teachers to teach and easy for students to understand can be completed through various methods employed by each group member. Some of the ways that have developed to solve these problems include using formulas and sequences of certain steps, using mechanical and procedural strategies, and conceptualizing thinking. This agrees with the opinion of Henderson and Tallman (2006), who state that mental models can be built socially through interactions with more capable or knowledgeable people. The sharing of information between groups increases the "broadness" of the group's mental model through the interpretation and dissemination of information and, at the same time, increases the "suitability" of individual mental models.

PCT's mental model profiles of essential concepts in school chemistry material were found to have various types. This aligns with individual mental models formed based on previous experiences, beliefs, and the socio-cultural environment (Henderson & Tallman, 2006). PCT's initial mental model on the concepts of chemical reactions, equilibrium constants, and collision theory are dominated by type 00, meaning that most students do not have a scientifically more accurate mental model. The chemical reaction concept is a very basic concept and serves as a prerequisite for many other concepts. Equilibrium constants are related to chemical reactions, especially when determining the direction of chemical reactions. Collision theory is also a fundamental concept in the topic of reaction rates, especially in explaining the factors that affect reaction rates.

Meanwhile, the concept dominated by the scientifically more accurate type (type 11) includes activation energy and dynamic equilibrium. Research by Chiu (2002) shows that students in the experimental group could build a mental model of chemical equilibrium, including dynamic and disordered molecule activation and interaction between molecules on a microscopic scale. In contrast, the control group failed to build the correct mental model in the concept of chemical equilibrium. Compared to collision theory, PCT tends to use the activation energy approach in explaining reaction rates. This is less favorable because the activation energy is only tied to the temperature factor in explaining the reaction rate. In contrast, other factors are not directly related to the activation energy. Understanding the concept of dynamic equilibrium is very useful for explaining equilibrium shifts, but difficulties will still be encountered if understanding the equilibrium constant is weak. This causes very few essential concepts to be dominated by mental model type 11, but most are dominated by type 00. Mental model type 01 is less common than type 10, which means that very few students know the reasons but are unable to draw conclusions. On the other hand, it is still relatively common for students to be able to draw conclusions even though they do not know the reasons. This is in accordance with the statement that mental models are generative, dynamic, sustainable, and can be updated based on the information obtained (Franco & Colinvaux, 2000).

Conclusion and Implications

The results of the quantitative analysis show a significant difference between the median mental model of school chemistry before and after the lecture. This shows an increased understanding of chemical concepts before and after mental model-based learning. Students' understanding of chemistry lesson material in implementing the mental model-based learning develops the essential concepts of school chemistry from intermediate models (M1) through subsequent models toward the target or consensus model. The mental target or consensus model represents each essential concept at three levels: macroscopic, sub-microscopic, and symbolic. Mental model-based lectures have facilitated the change of intermediate mental models of PCT to achieve the target models and the consensus model.

This research implies that the management of school chemistry lectures must use the Student-Centered Learning (SCL) approach rather than Teacher-Centered Learning (TCL). The SCL approach is a continuous learning process of transformation focusing on enhancing and empowering PCT to develop their critical capabilities. In SCL, learning centers focus more on PCT, while lecturers' roles include motivators, facilitators, and evaluators. PCT has the opportunity to take a more active role in learning activities so that they are not just passive recipients of knowledge. In addition, PCT also have the opportunity to develop their analytical skills in exploring individually and in groups when faced with problems or phenomena, with lecturer facilitation. To support this, lecturers must provide complete learning resources, including general chemistry books from various authors, so that PCT can use them as inspiration for school chemistry topics. PCT are given as many opportunities as possible to discuss and build their mental models with each other. PCT are continually encouraged to find essential concepts from each school chemistry topic and present them in three levels of representation.

Based on research findings, it is highly recommended that lecturers know the initial mental model of PCT before conducting school chemistry lectures. Each PCT comes to the classroom, with various knowledge, skills, beliefs, and attitudes acquired from previous experiences. These differences in background will have implications for how PCT interpret and manage information. PCT will be able to learn when they are able to connect new concepts with the knowledge or concepts they already have or know. PCT's initial mental model can be used to design, develop, and implement lecture programs. Furthermore, in order to build knowledge, PCT should be given the opportunity to do this in groups. Group work creates a more interactive and participatory learning situation, allowing PCT to discuss, debate, and exchange ideas. In a group, each member has the opportunity to express their opinions and contribute to solving complex problems. Through intense interaction in groups, PCT learn to communicate better, work together, respect differences of opinion, and build trust in each other. Studying in groups creates a more dynamic and fun atmosphere. PCT have the opportunity to help and inspire each other. They can share different ideas and viewpoints, encouraging critical and creative thinking. In groups, PCT can leverage their strengths to achieve better results collectively. In addition, the group work learning method also creates a conducive environment for experimentation and experience-based learning. PCT can explore new problem-solving, hone analytical skills, and test their knowledge. This gives students a more holistic learning experience and deepens their understanding.

The findings of this research suggest that it is important for PCT and teachers to formulate school chemistry topics in a way that is easy to teach and understand. Presenting essential chemical concepts in multiple representations will provide many benefits. Students will practice correlating scientific phenomena with the molecular behavior they have experienced. Students can also present in simpler forms at a symbolic level. The linkage of the three levels of representation contributes to the construction of understanding and meaningfulness of chemical concepts so that students will have mental models that are more scientifically accurate.

Researchers need to conduct further research to develop mental model-based lectures in basic chemistry courses and groups of advanced chemistry courses to increase continuity with school chemistry course groups. Therefore, PCT have mental models that are more scientifically accurate. It is also necessary to conduct studies to uncover other factors that correlate with the mental model of school chemistry to improve the integrity of the PCT mental model.

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Appendix

Appendix 1: Syllabi and Lecture Units

SYLLABUS
SCHOOL CHEMISTRY II (KI508)

Course Description

This course aims to provide provisions for prospective chemistry teacher students to be able to study the breadth and depth of high school chemistry subject matter based on the 2006 National Curriculum content standards; to discover essential concepts of high school chemistry subject matter based on the National Curriculum; and develop essential concepts into three levels of chemical representation, namely macroscopic, sub-microscopic and symbolic. This ability is trained through a guided inquiry approach with group discussions as the main method, so that student participants are accustomed to finding answers to the learning problems they will face on their own. Evaluation of learning outcomes is carried out through assessing the lecture process, assignments, and the ability to link the three levels of representation in the explanation of a concept.

1. Course Identity

Course name	:	School Chemistry II
Code number	:	KI 508
Number of credits	:	3 credits
Semester	:	6 (six)
Course group	:	Skills Courses (MKK)
Study Program / Program	:	Chemistry Education / Bachelor Degree (S1)
Course status	:	Compulsory
Prerequisites	:	Have passed the General Chemistry course and Basics of Chemistry
Lecturer		Team Teaching

Objective

After completing one semester of lectures, students are expetected to participate in the lecture will be able to: (i) study the breadth and depth of high school chemistry subject matter based on the 2006 National Curriculum content standards. (ii) discover the essential concepts of high school chemistry subject material based on the National Curriculum. (iii) develop essential concepts into 3 levels of chemical representation, namely macroscopic, sub-microscopic and symbolic.

2. Content Description

The lecture process provides learning experiences for prospective chemistry teacher students in analyzing learning resources for school chemistry subject matter in the form of general chemistry books as well as various animations and related experiments, reviewing chemistry subject content standards in the National Curriculum, analyzing the depth and breadth of school chemistry subject material, discovering concepts -essential concepts of school chemistry subject matter, developing 3 levels of representation for each essential concept, and linking the 3 levels of representation when explaining essential concepts of school chemistry subject matter.

3. Learning approaches

Learning approach : constructivism
Learning methods : discussions, lectures, assignments, exercises
Learning media : LCD

4. Evaluation

Evaluation of learning outcomes is carried out through assessment of the lecture process, assignments, unit 1 tests and unit 2 tests. Process evaluation takes the form of activities in group discussions and class discussions. Assignment evaluation is the result of agreement from group discussions. Unit test evaluation in the form of the ability to link 3 levels of representation in the explanation of essential concepts.

5. Details of Lecture Material for Each Meeting

Meeting 1 : Plan and scope of lectures
Meeting 2 : Stoichiometry
Meeting 3 : Stoichiometry
Meeting 4 : Thermochemistry
Meeting 5 : Thermochemistry
Meeting 6 : Reaction rate
Meeting 7 : Reaction rate
Meeting 8 : Unit Test 1
Meeting 9 : Equilibrium
Meeting 10 : Equilibrium
Meeting 11 : Acids and bases
Meeting 12 : Acids and bases
Meeting 13 : Electrochemistry
Meeting 14 : Electrochemistry
Meeting 15 : Unit Test 2

6. Reference

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LECTURE EVENT UNIT
SCHOOL CHEMISTRY II (KI 508)

Discussion topic : Stoichiometry
Approach : Constructivism
Methods : Lectures, discussions, assignments, exercises
Objectives : 1. Students are able to study the breadth and depth of high school chemistry subject material on stoichiometry based on the National Curriculum.

2. Students are able to discover the essential concepts of high school chemistry subject matter on the subject of stoichiometry based on the National Curriculum.
3. Students are able to develop essential concepts on the subject of stoichiometry into three levels of chemical representation, namely macroscopic, sub-microscopic and symbolic.

Meeting : 2 and 3
Time : 6 x 50 minutes face to face

No	Learning Description		Evaluation
	Lecturer Activities	Student Activities	
1	Analysing stoichiometry learning resources		Task
	• Providing content standards for the 2006 National Curriculum in chemistry subject. • Providing *General Chemistry books.* • Providing animated examples related to stoichiometry, such as chemical reactions, limiting reagents, molecular formulas, and empirical formulas.	• Examining competency standards related to the subject of stoichiometry in chemistry subject content standards of the 2006 National Curriculum. • Examining the presentation of stoichiometry concepts from experts. • Integrating and summarizing stoichiometric concepts.	
2	Analysing the depth and breadth of the subject of stoichiometry		Participation in discussions and tasks
	• Dividing students into several discussion groups based on similarities in diagnostic test results on mental models, learning motivation, learning styles and logical thinking abilities. • Explaining the scope of analysis of the depth and breadth of school chemistry subject matter. • Taking turns taking part in student group discussions.	• Sitting in each group • Getting an idea of the scope of analysis of the depth and breadth of school chemistry subject matter. • *Brainstorming* each group member's initial mental model. • Conducting discussions to discover the depth and breadth of school chemistry subject matter on the subject of stoichiometry. • Generating group agreement.	
3	Discovering essential concepts on the subject of stoichiometry		Presentation
	• Explaining the scope of essential concepts on the subject of stoichiometry. • Taking turns in group discussions and informing other groups of interesting developments. • Leading class discussions	• Getting an overview of the label's scope and definition of essential concepts. • Discussing labels of essential concepts. • Discussing the definition of each essential concept label. • Presenting the results of the discussions regarding labels and definitions of essential concepts in class discussions.	
4	Developing 3 levels of representation of each essential concept		Task
	• Explaining the scope of developing representations on the subject of stoichiometry. • Taking turns in taking part in the group discussions.	• Getting an overview of the scope of representation development on the subject of stoichiometry. • Discussing the macroscopic representation of each essential	

No	Learning Description		Evaluation
	Lecturer Activities	Student Activities	
	• Informing about interesting developments from other groups.	concept on the subject of stoichiometry. • Discussing sub the microscopic representations of each essential concept. • Discussing the symbolic representation of each essential concept on the subject of stoichiometry.	
5	Linking 3 levels of representation		
	• Asking representatives of each group to explain one of the essential concepts on the subject of stoichiometry by linking 3 levels of representation in class discussions. • Leading class discussions.	• Comparing the results of other groups with the work of their group. • Engaging in the class discussions to gain consensus.	

Appendix 2: Lecture Observation Sheet

LEMBAR OBSERVASI

PERKULIAHAN KIMIA SEKOLAH BERBASIS MODEL MENTAL

Tujuan : Mengetahui proses perkuliahan Kimia Sekolah berbasis model mental

Pokok Bahasan : Stoikiometri

Pertemuan ke- : 1 dan 2

Hari/Tanggal :

No	Dimensi	Kegiatan Dosen		Kegiatan Mahasiswa	
		Indikator	Ya/Tidak	Indikator	Ya/Tidak
1	Analisis sumber belajar	• Menyediakan buku *General Chemistry* dari berbagai pengarang • Menyediakan beberapa contoh animasi yang terkait • Menyediakan standar isi mata pelajaran kimia KTSP 2006	Ya Ya Ya	• Menelaah penyajian konsep-konsep yang terkait dengan materi subyek kimia sekolah dari berbagai pengarang *General Chemistry* • Menelaah standar isi mata pelajaran kimia KTSP 2006 • Mengintegrasikan dan membuat rangkuman konsep-konsep yang disajikan oleh berbagai pengarang dalam buku	Ya Ya Ya

No	Dimensi	Kegiatan Dosen		Kegiatan Mahasiswa	
		Indikator	Ya/Tidak	Indikator	Ya/Tidak
2	Analisis kedalaman dan keluasan materi subyek kimia sekolah	• Membagi mahasiswa kedalam beberapa kelompok diskusi berdasarkan kemiripan hasil tes diagnostik model mental • Menjelaskan ruang lingkup analisis kedalaman dan keluasan materi subyek kimia sekolah • Melibatkan diri dalam diskusi kelompok mahasiswa secara bergiliran	Ya Ya Ya	• Duduk dalam kelompok masing-masing • Mendapatkan gambaran ruang lingkup analisis kedalaman dan keluasan materi subyek kimia sekolah • *Brainstorming* model mental awal setiap anggota kelompok • Melakukan diskusi untuk menemukan kedalaman dan keluasan materi subyek kimia sekolah • Menghasilkan kesepakatan kelompok	Ya Ya Ya Ya Ya
3	Menemukan konsep-konsep esensial	• Menjelaskan ruang lingkup konsep-konsep esensial • Melibatkan diri dalam diskusi kelompok secara bergiliran		• Mendapatkan gambaran ruang lingkup label dan definisi konsep esensial • Mendiskusikan label konsep-konsep esensial	

No	Dimensi	Kegiatan Dosen		Kegiatan Mahasiswa	
		Indikator	Ya/Tidak	Indikator	Ya/Tidak
		• Menginformasikan perkembangan yang menarik dari kelompok lain • Memimpin diskusi kelas untuk menyepakati label dan definisi konsep esensial materi subyek kimia sekolah	Ya Ya	• Mendiskusikan definisi setiap label konsep esensial • Menyampaikan hasil diskusi mengenai label dan definisi konsep esensial dalam diskusi kelas	Ya Ya
4	Mengembangkan 3 level representasi dari setiap konsep esensial	• Menjelaskan ruang lingkup pengembangan representasi • Melibatkan diri dalam diskusi kelompok secara bergiliran • Menginformasikan perkembangan menarik dari kelompok lain	Ya Ya Ya	• Mendapatkan gambaran ruang lingkup pengembangan representasi • Mendiskusikan representasi makroskopis dari setiap konsep esensial • Mendiskusikan representasi sub mikroskopis dari setiap konsep esensial • Mendiskusikan representasi simbolis dari setiap konsep esensial	Ya Ya Ya Ya

No	Dimensi	Kegiatan Dosen		Kegiatan Mahasiswa	
		Indikator	Ya/Tidak	Indikator	Ya/Tidak
5	Mempertautkan 3 level representasi	• Meminta perwakilan setiap kelompok untuk melakukan eksplanasi salah satu konsep esensial dengan cara mempertautkan 3 level representasi dalam diskusi kelas • Memimpin diskusi kelas	Ya Ya	• Membandingkan hasil kelompok lain dengan pekerjaan kelompoknya • Melibatkan diri dalam diskusi kelas untuk mendapatkan berbagai kesepakatan	Ya Ya

Catatan :

- Secara umum mahasiswa masih kebingungan terhadap proses perkuliahan karena baru pertama kali membuat representasi
- Diskusi berjalan sangat meriah tetapi tidak setiap anggota berpartisipasi secara aktif
- Diskusi kelas cukup alot pada definisi dan label konsep rumus molekul, massa atom relatif dan mol
- Pada pembuatan representasi, sebagian besar mahasiswa masih bingung membedakan level makroskopis, sub mikroskopis dan simbolis