Innovative organic synthesis course for sustainable development in chemistry education to enhance students’ critical thinking skills

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Abstract. This study focused on innovative learning using the framework of sustainability development in organic chemistry. A retrosynthetic analysis was used in this study in learning organic synthesis integrated with the principle of the Green Chemistry (GC) and the Critical Thinking skill (CTs). The results indicated that the sustainable developing framework can be assimilated with the learning in different disciplines. It was also found that a big impact for student’ mind set was their ability to analyse the sustainability development. It was clear that the students can improve their critical thinking skills by doing some tasks. It means that the framework of sustainability development in learning can increase the students’ critical thinking and awareness to keep the balance of the nature and their ability to deal with the global challenges in order to develop sustainability.

1. Introduction
Organic synthesis is one complex subject in organic chemistry that concerned with the intentional construction of organic [1]. In learning organic chemistry, students need the comprehended understanding about the basic organic concepts [2]. Students should be learn the basic organic concepts like all type reaction of addition, elimination and substitution in the previous learning before they are starting to learn about organic synthesis [3]. It is because all the basic concepts have to integrate by the students in order to answer the organic synthesis problems [4]. Moreover in learning organic synthesis if students want to find the good achievement in their learning, they are not only learning about how to integrate the concepts but also learn about how they can implemented the synthesis of organic compound in laboratory activities. It can give them the experience to be the researcher in the real world and give them the authentic problems [5]. It means that they must have the synthesis techniques in doing their laboratory tasks.

Meanwhile, the organic synthesis learning was developing because the need of human being to have the better life [6]. The rapidly of increasing need of medicine from pharmacies and materials to make the cosmetics, textiles, and other industries, become the major reasons in build organic synthesis studies. It make the purpose of organic synthesis was driven to generate all the useful compounds for people use in all fields of life such as pharmacies, cosmetics and textiles. Surprisingly, the developing of organic synthesis was rapidly and quickly. It has a good impact to produce a lot of medicine
compounds. Even though, the effect will cause the wastes of organic chemicals compounds and bring the pollution into the land, air and water [7].

Therefore, the Green Chemistry concepts were introduced in order to reduce the bad effect of organic synthesis process [8]. The scientist recommended the 12th principles of Green Chemistry to be applied in organic synthesis [9]. The Green Chemistry directing the synthesis of compounds to reduce the toxicity of the materials and the reagent that can polluted the surrounding environment. It make them use the eco-friendly material and compound. The preservations of the organic resources become consent to the Green Chemistry concepts. According to the some literatures, stated that the Green Chemistry make the sustainability of the natural resources and avoid the extinction of some vegetation because of the exploitation [10]. The Green Chemistry requires give the efficiency of the time and process in synthesis of secondary metabolites. It means that we do not need to spend a lot of time to produce the compound or through a long process to make it. The Green Chemistry concepts was more efficient and effective process in synthesis the compound of secondary metabolite compare with the process in nature [11]. It is because in isolation process we can use a lot of materials from natural resources that just produces not significant yields as the results.

There were several researches, that show the application that combine of organic synthesis subject by using the Green Chemistry principle as a new framework [12, 13, 14]. It can lead students to open their mind to understand about the important of sustainability of the surrounding environmental in their life [15]. Similarly, the sustainability development can be transfer to the students by doing and learning in organic synthesis by using the Green Chemistry concepts [16].

Therefore, in order to be able to synthesize organic compounds, the students need the clearly understanding about the basic organic concepts. These will help the students to combine and relate the concepts with their ability to synthesis organic compound in the laboratory [17]. Students laboratory skills recognize can help them to support their ability in synthesis organic compounds [16].

Currently, the students’ ability to synthesize organic compounds by integrate the basic organic concepts and by using the techniques show the students skills. Their skills include the high order thinking skills. The skills was classify as transferable skills of the students [18]. The recently study found that Green Chemistry in laboratory activities make students challenged to think critically in integrate their basic concepts to complete the tasks [19, 20]. Therefore, the objective of this studies is to develop the innovation of organic synthesis course that can be the applied the sustainable education in chemistry.

2. Method
This study was using a descriptive method that describe the students’ conceptual knowledge in learning organic synthesis by using retrosynthetic analysis as an innovative learning in organic chemistry. The participant of this research were 16 students that come from one state university in Papua and 28 students come from one state university in Bandung. All of them are in the third semester. The participants already finish all the prerequisite courses such as basic organic chemistry 1 and basic organic 2 courses, and the 1st laboratory experiment course.

The retrosynthetic test that given to the students according to the retrosynthetic stage that explore the students’ conceptual knowledge and their ability in doing the synthesis process relate to their ability to think critically about the Green Chemistry principal. The results of the students’ performance were analyzed by using the retrosynthetic analysis criteria test. The data obtained came from the students' answers when they were given the retrosynthetic analysis about the target molecule. The particular task that the students must complete related to their understanding about the conceptual knowledge in organic synthesis based on retrosynthetic analysis and the indicators of critical thinking. The conceptual knowledge will be integrating with the 12th Green Chemistry principal.

3. Result and Discussion
Commonly, the step of synthesis organic compound can through two (2) ways: 1) The synthesis pathways: The straight pathways of synthesis (directing from connection and transformation) of
starting materials into the target molecule; 2) The retrosynthetic analysis: The backwards ways that show the possibilities of disconnection and change that it can happen in target molecules that will guide us to the current starting materials [21].

Furthermore, this study focused on the synthesis of organic compounds using retrosynthetic analysis to find out the conceptual knowledge of students and how students think when doing retrosynthetic analysis. In this case, the study inserting the principal of Green Chemistry (GC) with the conceptual knowledge about organic synthesis, make the students faced with the sustainability challenge and the indicators of Critical Thinking skills (CTs). It improve their thinking to engage with the reality in the world where they lived in. The Green Chemistry can reconceptualize students to the reflective thinking about the sustainability development in their daily life [10]. Therefore, this study make the integrating between the conceptual knowledge using retrosynthetic analysis with the principal in GC and indicators of CTs in Table 1.

**Table 1. Integration of the conceptual knowledge in the retrosynthetic analysis with principal in Green Chemistry with the Critical Thinking indicators.**

| Code | Conceptual Knowledge by Using Retrosynthetic Analysis | Principal in Green Chemistry (GC) as Sustainability Development | Indicators of Critical Thinking Skills (CTs) |
|------|------------------------------------------------------|------------------------------------------------------------------|-------------------------------------------|
| a    | Identify characteristic of target molecule (C1)      | Prevention (GC1)                                                  | Provide further explanation to identify assumptions (CT1) |
|      |                                                      | Inherently safer Chemistry for accident prevention (GC2)         |                                           |
| b    | Determine the position of the disconnection and transformation of the molecule target (C2) | Reduce derivatives (GC3)                                          | Inference to deduce and consider the results of deduction (CT2) |
|      |                                                      | Catalysis (GC4)                                                  |                                           |
| c    | Determine the current starting materials (C3)         | Designing safer chemicals (GC5)                                  | Inference to deduce and consider the results of deduction (CT2) |
|      |                                                      | Safer solvents and auxiliaries (GC6)                             |                                           |
| d    | Describing the characteristic of the starting materials (C4) | Real-time analysis for pollution prevention (GC7)                 | Provide further explanation to identify assumptions (CT3) |
|      |                                                      | Design for energy efficiency atom economy (GC8)                  |                                           |
| e    | Finding the correct reaction’s type, reagen and condition to convert the starting materials into the target molecule (C5) | Less hazardous chemical synthesis (GC9)                          | Inference to deduce and consider the results of deduction (CT2) |
|      |                                                      | Use of renewable feedstocks design for degradation (GC10)       |                                           |

Table 1 show us the integration of the conceptual knowledge with principal in GC and also make the connection with the indicator of CTs. From Table 1 we found that there are integration between all the concept knowledge with GC and CTs but it different by every code. We found in code a the integrate of Conceptual Knowledge 1 (C1) with GC1 and GC2, while it also have integrate with CT1. Eventually in code b, we found that the integration between C2, GC3, GC4 and CT2. We found the integration between C3 with GC54, GC6 and also CT2 in code c. In code d, we found the connection between C4 with GC7, GC8 and CT3. Eventhough for code e, we have integrate C5 with GC9, GC10 and CT2. According to the results of scores from students’ answer that have then we divide into three classes as: (1) The upper classes; (2) The middle classes; and (3) The lower classes.

According to Table 1, it well known that students answers by using retrosynthetic analysis as conceptual knowledge always link with the GC Principle and also combine with the indicators of the CTs. From the results of implementation of the tasks we can make a graphic of the achievement of every class per codes as in Figure 1.
In Figure 1 shows the students' achievement from every code in three level class. Based on the figure, it can be seen that the average percentage of students’ achievements in each group for each code of has the same pattern in three level class that has a high score in the code a and decreases until code e. Based on graphics, the students in upper class have the highest percentage achievement in code a (40%), the medium percentage achievement in codes b, c, and d (30%) and have low percentage achievements in code e (20%). Currently, students' in the middle class have the highest percentage achievement in code a, and b (30%), the medium percentage achievement in codes c and d (20%), and the lowest percentage achievement in code e (10%). While the students in the lower class achievement have the highest percentage achievement in code a and b (20%), the lowest percentage achievement in codes c, d and e (20%). It shown that students’ in upper class have the highest percentage achievement compares with the other class. According to the result, we found that 16 students from Papua are in the lower class, while 28 students from Bandung divided into 14 students are in the middle class and 14 students are in upper class.

Therefore, the result shows that student's percentage achievement is connected with the level of tasks in retrosynthetic analysis that is given to them. It means that in students' achievement about the characteristics of molecular targets, student must develop their thinking about prevention and in-depth safer chemistry for accident prevention. Students have no difficulties in finding information related to the target molecule. They can use a variety of offline and online media. In this case, the lecture give a chemAxon as a media offline to help students in all groups because the target molecules are given to them to be raw materials for making drugs, raw material for coloring, and ingredients for cosmetics. This makes them interest in the characteristics of the target molecules. It will improve their enthusiasm because the target molecule is related to their life [12].

Student in upper class analysis and characterization maximally by using the Marvinsketch ChemAxon that shows the analysis of elemental for the physical and chemical properties of molecule targets, which is to predict the stereoisomers of the target molecule, conformers to identify minimize energy and stabilization and geometry of the target molecule. Otherwise, students in the middle class, just shows two critical elemental analysis, isomers, and geometry descriptors, and the lower group just two criteria is elemental analysis and geometry descriptor. Based on students answers, we found that students develop the CT1 because their think critically to use Marvinsketch ChemAxon for help them characterize molecules. Eventhough, from students answers we found that students in middle and lower class did not try to collect all the significant data that they need. They just choosed the information that familiar to them. Differently, the students in the upper class have thinking critically to answers the question. It because when they have been told identify the characteristics of molecule targets (code a) they used all the criteria in Marvinsketch to help them to characterize the molecule target (Figure 2).
Based on student’s answers, it was found students in upper class can connect the characteristics of the target molecule with the properties of target molecule structure, the stereoisomer of target molecule, the energy minimizes of target molecule and the geometry of the target molecule. Therefore, they can predict the proper disconnection for the target molecule and they can have the prevention of the minor product. It make the design prevention the of target molecule process synthesis through a more simple step. When the students found a lot of information from the Marvinsketch ChemAxon software about identify the characteristic of target molecule, they must think critically provide further explanation to identify assumptions that include with the characteristic of the target molecule compound.

Based on the findings obtained, it is known that solving the problem of synthesis of organic compounds through the stages of retrosynthetic analysis can be used to apply the principles of Green Chemistry and increase students’ critical thinking skill [10]. In addition, it can be used as a new reference for learning that leads to sustainable development in organic synthesis. In addition, through this task, student learning can improve the ability to completing the stages of synthesis of organic compounds. In this case, the indicator of critical thinking skill (inference to deduce and consider the
results of deduction) in accordance with this stage is finding the correct reaction’s type, reagen and condition to convert the starting materials into the target molecule.

Thus learning the synthesis of organic compounds by using the retrosynthetic analysis as an approach to the principles of Green Chemistry. This is in line with the goal of developing sustainability in chemistry learning. Later, it is expected that all chemistry students can be more aware of the importance of keeping lives around and can deal with global challenges.

4. Conclusion
The finding of this study shows that there are connections between conceptual knowledge with the Green Chemistry concept about sustainability development. It indicated by students’ answer that show the conceptual knowledge of students. It is known that students’ conceptual knowledge was highest in identifying characteristic of target molecule and starting materials, and lowest score in finding the correct reactions type, reagen and condition, to convert the starting materials into the target molecule of the retrosynthetic approach. It is suggest to carried out learning using retrosynthetic analysis in organic synthesis and therefore that they will develop all their abilities in synthetic organic compounds by using Green Chemistry principal. It can lead to develop the innovative sustainable development in learning synthesis organic chemistry. The study found that students critical thinking also can improve by learning with the retrosynthetic analysis.

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