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Designing E-Content for Teaching Basic Chemistry Concepts in Higher Education: A Needs Analysis

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ABSTRACT

The aim of this study is to develop an e-content including four topics and three experiments for SKU3013 Chemistry I that will be implemented using the blended learning mode. The ADDIE Model was followed in this design and development research. This paper will focus on the analysis phase only. Involved respondents were 52 students who registered for SKU3013 Chemistry I in semester 1 session 2016/2017 in one of the Malaysian higher education institutions (HEIs). The instrument involved in the study was the basic chemistry concept test. The results from the test showed that the students were weak in answering conversion factor problems. They were also weak in writing ionization energy equations, determining the limiting reactants, and calculating the percent yields. The results obtained from the basic chemistry test will be taken into consideration during the design phase to ensure that the e-content design can help students to overcome their weaknesses in learning basic chemistry concepts.

Keywords: e-content, basic chemistry concepts, blended learning, ADDIE model.

INTRODUCTION

The Malaysian National e-Learning Policy (*Dasar e-Pembelajaran Negara*, DePAN) was enacted in 2011 with the aim to develop an e-learning implementation framework. The policy was the roadmap for Malaysian higher education institutions (HEIs) for a period of five years starting from 2011 to 2015 (Ministry of Higher Education Malaysia, 2011). There are three phases involved in this policy which are the Initial Phase (2011-2012), Completion Phase (2013-2014) and Optimum Phase (2015). In the e-learning framework, five main pillars include infrastructure, organizational structure, professional development, curriculum and e-content, and acculturation. The policy was planned with the objective of cultivating the use of

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e-learning and teaching in all Malaysia HEIs to produce quality human capital with academic excellence in achievement, creativity, innovation, skills, and competition in all fields. The curriculum and e-content pillar roadmap are to ensure that all the HEIs in Malaysia use at least 5-10% of the blended mode of the course curriculum in the Initial Phase, 10-30% in the Completion Phase, and 30% in the Optimum Phase. All courses should blend its contents using both online and face-to-face delivery to achieve the blended mode status. A substantial proportion of the content is typically delivered online (30-79%) through online discussions, thus the number of face-to-face meetings was reduced (Allen & Seaman, 2010, p. 5).

DePAN 2.0 is an extension of the early versions of DePAN launched in 2011. This policy is expected to be completed in three phases. Phase 1 (2015), Phase 2 (2016-2020), and Phase 3 (2021-2025) are in line with the implementation of the Malaysia Education Blueprint 2015-2025 (Ministry of Higher Education, n.d.). DePAN 2.0 was developed to fulfil Shift 9 in the Malaysia Higher Education Blueprint: Globalized Online Learning (Figure 1).There are six major domains in DePAN 2.0: infrastructure and info-structure, governance, online pedagogy, e-content, professional development, and acculturation (Ministry of Higher Education, n.d.). One of the objectives of DePAN 2.0 is to develop quality, original and open e-content that based on standards and established to strengthen the teaching and learning process.

Figure 1. The 10 Shifts in Malaysia Education Blueprint (Higher Education) (Ministry of Education Malaysia, 2015)

e-Content

The e-content is a course material that is developed in digital form (such as graphic, audio, video, animation, simulation, etc.) and can be assessed online. The e-content domain in DePAN 2.0 focuses on original e-content, Open Course Ware (OCW) and e-content standards (Ministry of Higher Education, n.d.). In Phase 1 (2015) of DePAN 2.0, all HEIs need to develop original e-content for 10% of the offered courses. At the same time, 5% of the offered courses by each HEI need to be developed in OCW form and e-content standards need to be formulated by Ministry of Education (MOE). In Phase 2 (2016-2020), all HEIs should develop original e-content for 25% of the offered courses. At the same time, 10% of the offered courses by each HEI should be developed in OCW form. In this phase, the e-content standards also should be fully applied in all HEIs. Finally, all HEIs need to develop original e-content for 40% of the offered courses in Phase 3 (2021-2025). At the same time, each HEI needs to develop OCW for 15% of the offered courses. Besides that, the e-content standard must match the international standard in this final phase.

Due to the limited use of blended learning in Chemistry (Shibley, Amaral, Shank & Shibley, 2011), hence we decided to design some e-contents for chemistry topics to be delivered via blended mode. There is a need to study and select the topics to be delivered online to develop the e-contents for the SKU3013 Chemistry I course.

Basic Chemistry Concepts

The SKU3013 Chemistry I course is offered to semester I students who are majoring in chemistry in the related HEI. Besides that, students minoring in chemistry also need to take this course as their first course in the chemistry domain in the related HEI. The fundamental concepts of chemistry are discussed in this course. The topics discussed in the course are: 1) matters and measurements, 2) quantum theory and atomic structure, 3) periodic relationship among the elements, 4) stoichiometry, 5) chemical reactions, 6) gaseous and the kinetic-molecular theory, and 7) chemical bonding. At the end of the course, students should be able to:

a) apply fundamental chemistry concepts to solve chemistry problems,
b) demonstrate practical skills in conducting experiments,
c) practice noble values and scientific attitudes,
d) use problem-solving strategies and critical thinking in real life situations, and
e) communicate clearly during the presentation.

In addition to delivery of content, students need to perform practical sessions in the laboratory. There are seven experiments in this course:

a) basic laboratory technique,
b) dilution,
c) acid and base titration,
d) the hydrated salt formula,
e) Charles Law,
f) the dissimilarity between electrovalent and covalent bond, and
g) molecular geometry.

In accordance with DePAN 2.0, at least 10% of the offered courses should contain original e-content by 2015, 25% by 2020, and 40% by 2025. Hence, it was decided to design the e-content for some of the basic concepts taught in the SKU3013 Chemistry I course. The selected four topics are matters and measurements, the periodic relationship among elements, stoichiometry, and chemical reactions, while the three experiments selected are dilution, acid and base titration, and hydrated salt formula. The content delivery will be implemented in blended learning mode throughout the 14 weeks in the semester.

Blended Learning

The blended learning is a formal education programme in which a student partly learns at least through online delivery of content and instruction with some elements of student control over time, place, path, and/or pace and in part at a supervised brick-and-mortar location away from home (Staker & Horn, 2012). On the other hand, Friesen (2012) explained that "blended learning designates the range of possibilities presented by combining the Internet and digital media with established classroom forms that require the physical co-presence of teacher and students". At its simplest, blended learning is the thoughtful integration of classroom face-to-face learning experiences with online learning experiences (Garrison & Kanuka, 2004).

In this study, the definition of Staker and Horn (2012) was used to explain the blended learning approach. In the definition, the most important element that differentiates blended learning with technology-rich instruction is the phrase "with some elements of student control over time, place, path, and/or pace". According to Digital Learning Now! (2010), the four dimensions were explained as below:

a) Time: Learning is no longer restricted to the school day or the school year.
b) Place: Learning is no longer restricted within the walls of a classroom.
c) Path: Learning is no longer restricted to the pedagogy used by the teacher.
d) Pace: Learning is no longer restricted to the pace of an entire classroom of students.

Many researches had been conducted by implementing blended learning in different subjects and different levels of studies. Sarıtepeci and Çakır (2015) studied the effects of blended learning environment on engagement and academic achievement of middle school students. Results showed that students in blended learning environment showed meaningful increase in average academic achievement compared to students in face-to face learning environment. At the same time, the development of student engagement in the blended learning group were at higher level compared to control group. Besides that, students in blended learning environment were noticed as more confident, independent, engaged, and motivated, enhanced in student-student and student-teacher communication and collaboration, and improved higher order thinking skills and use of language (Parkes, Zaka & Davis, 2011).

To ensure that the e-content can be delivered via blended learning mode, e-content should be designed and delivered for SKU3013 Chemistry I course. There is a need to have a systematic instructional design (ID) model as a guideline. This ID model will enable to design and develop the e-content to be delivered in the Learning Management System (LMS) in the related HEI.

ADDIE Model

ADDIE model is an ID model consists of five phases: Analysis, Design, Development, Implementation, and Evaluation (Figure 2).

The analysis phase is the "Goal-Setting Stage." In this phase, the focus of designers is on the target audience. The designers need to make sure that the program matches the skill and intelligence level performed by each student/participant. This is to ensure that the designers will not duplicate the material which the designers already know and focus on the topics and lessons but the students have yet to explore and learn. During the analysis phase, the designers identify the goals and objectives, needs of the students, their existing knowledge, and other relevant characteristics such as learning style and interest. The analysis also includes the learning environment, delivery options, and timeline for the course.

Next, the design phase determines the goals, tools to be used to evaluate performance of students, assessment tests, subject matter analysis, course planning, and resources to be used. In this phase, the focus is on the learning objectives, course content, subject matter analysis, exercises, lesson planning, type of assessment instruments, and media selection. If multimedia resources will be produced, detailed storyboards and related prototypes are often made in this design phase. Besides that, graphic design, user-interface and content are determined in this phase too.

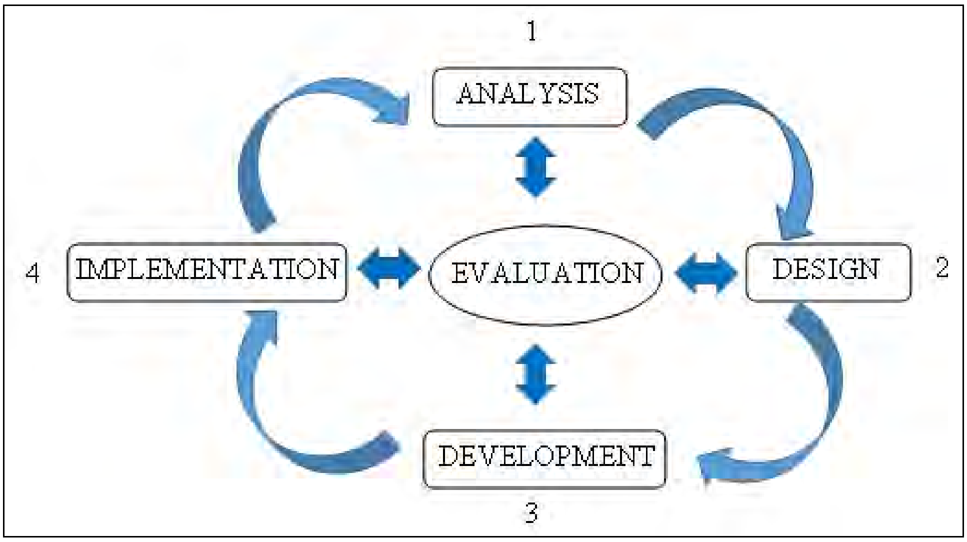

Figure 2. ADDIE Model

Then the development phase starts with the production and tests the methodology being used in the project. In this phase, designers will use the data collected from the analysis and design phase to create a program that will deliver the materials need to be taught to the students. The development phase is the phase that makes all ideas discovered in the analysis and design phase into concrete products. It is the production of the content and materials based on the information gathered in the design phase.

During the implementation phase, the developed program is installed in the real-world context. Briefing and training is performed for the related teachers and students. The program is implemented by delivering and distributing the material to the students. The effectiveness of the training materials will be evaluated after the program ends.

The last phase of the ADDIE model is evaluation. This is the phase in which the program is tested in terms of what, how, why, when of the things whether the entire program accomplished or not. The evaluation phase can be divided into two parts as the formative and summative. The formative evaluation can be executed in any phase of the model while the summative evaluation often occurs at the end of the program. The main goal of the evaluation is to determine whether the goals of the program have been met.

The ADDIE model had been used by some researchers to design instructional materials as it is the most common development process and almost all ID model were based on the generic ADDIE model (Chen, 2016; Farmer, 2011; Kruse, n.d.). This model provides a structured guideline for the instructional designers, a focus on the implementation and evaluation, and serves as a checklist to ensure the quality course design (Quinn, 2010). Shibley and his colleagues (2011) designed a General Chemistry course in blended learning environment by applying the ADDIE model. Results showed that both the student points in the course were increased and the failure rate was decreased. On the other hand, Laws, MacDonald and Mahfoud (2015) claimed that using the ADDIE model as the instructional model had made a tremendous impact on every aspect of the evidence-based medicine (EBM) course in WCMC-Q (a medical college in Qatar). Their students preferred both combination of online and in-class approaches. They enjoyed the blended learning environment compared to learning in-class. Besides that, average score and aggregate scores of students showed improvement after the blended course been implemented in the college.

Before starting the design phase, the target audience should be analyzed in terms of their needs. Hence, the understanding of students was studied for the selected basic chemistry concepts. The conceptual framework for the study is shown in Figure 3. This paper only focuses on the "needs analysis" based on the research questions below:

i. What is the students' level of understanding on the concept of Matter and Measurement?
ii. What is the students' level of understanding on the concept of Periodic Relationships among the Elements?
iii. What is the students' level of understanding on the concept of Stoichiometry?
iv. What is the students' level of understanding on the concept of Chemical Reactions?

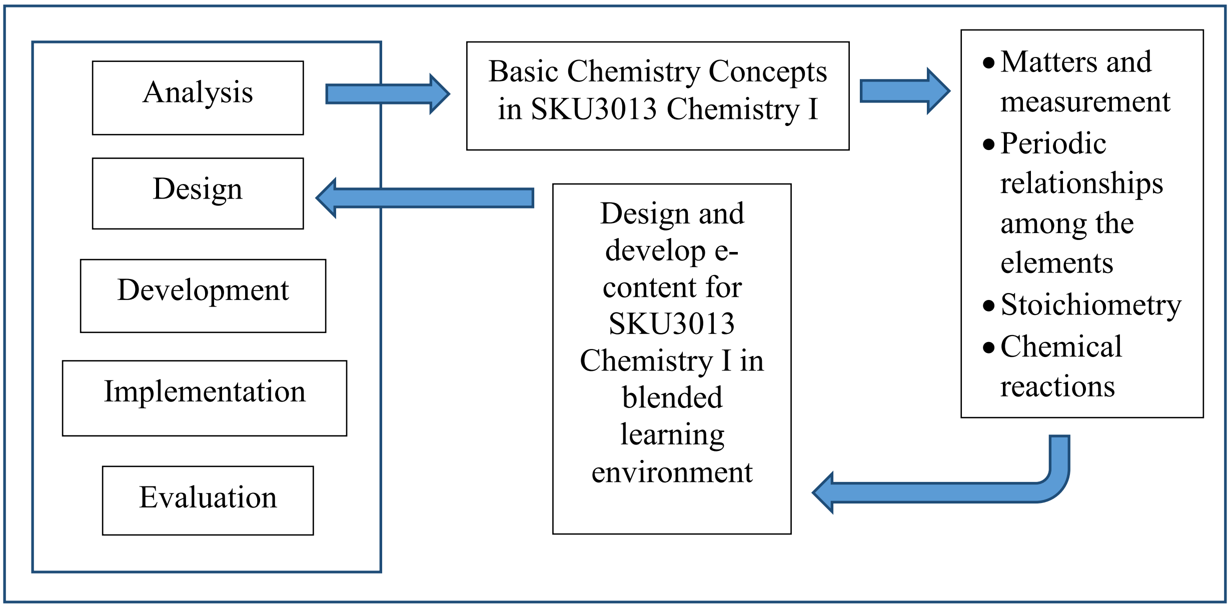

Figure 3. Conceptual framework of the study

METHODOLOGY

a) *Research Design*

This needs analysis study is a preliminary study conducted in order to design the e-content to be used for teaching basic chemistry concepts in higher education. This is the first phase in the ADDIE model (analysis, design, development, implementation, and evaluation). A simple survey study was performed with the aim to evaluate students' level of understanding on some basic chemistry concepts. The results of the needs analysis study will be used as a guideline in the design phase of the e-content for related topics and experiments.

b) *Respondents*

A total of 52 respondents were involved in the analysis phase of this study. They were students who registered for the SKU3013 Chemistry I course in Semester 1 at session 2016/2017 in one of the HEIs in Malaysia. Descriptive information of the respondents is shown in Table 1.

Table 1. *Descriptive information of respondents*

No.	Demographic information	Category	Frequency
1.	Age	19	31
		20	15
		21	2
		22	3
		23	1
2.	Gender	Male	5
		Female	47
3.	Ethnic	Malay	45
		Chinese	2
		Indian	2
		Others	3

c) Instrument

The instrument involved in this study is the basic chemistry concept test which developed by the researchers. It consists of five structured questions with a total of 12 items testing on various basic chemistry concepts aimed to evaluate existing knowledge of students related to the concepts taught in the course. The validity of the content was checked by three experts in chemistry domain. All Item Content Validity Indexes (I-CVIs) were reported as 1.00. The reliability (KR-20) of the test was 0.70. The distribution of items and some sample questions in the basic chemistry concept test is shown in Table 2.

Table 2. *Distribution of items and sample questions in basic chemistry concept test*

No.	Topic	Distribution of items	Total item	Sample questions
1.	Matter and measurement	1, 2a, 2b	3	The oceans of the earth have an average depth of 3800 m, a total surface area of 3.63 x 10^8 km^2, and an average concentration of dissolved gold of 5.8 x 10^{-9} g/L. How many grams of gold are in the oceans? Give the answer in the correct significant figures.
2.	Periodic relationships among the elements	3a, 3b, 3c	3	Explain the trend for the first ionization energy as down a group.
3.	Stoichiometry	4a, 4b, 4c	3	How many grams of nitrogen gas form when 1.00 x 10^2 g of N_2H_4 and 2.00 x 10^2 g of N_2O_4 are mixed? (apply limiting reactant process)
4.	Chemical reactions	5a, 5b, 5c	3	Calculate the concentration of the HCl solution used in the titration.

d) Procedure

This paper focuses on the "needs analysis", which is the analysis phase in the ADDIE model. The students' level of understanding related to basic chemistry concepts was obtained in the analysis phase. A basic chemistry concept test was distributed to the students who registered for SKU3013 Chemistry I course in semester 1 session 2016/2017. They were given one hour to answer the five structured questions on the concepts of matters and measurements, the periodic relationship among the elements, stoichiometry, and chemical reactions. After that, all the test papers were collected and marked by the researchers following the answer scheme. Marks were given for correct answers and no mark was given for wrong answers. The total marks obtained by the respondents reflected to their level of understanding on the basic chemistry concepts. The results obtained from the basic chemistry test were taken into consideration during the design phase (second phase in the ADDIE model) to ensure that the designed e-content could help students to overcome their weaknesses in learning chemistry concepts.

RESULTS and DISCUSSIONS

A total of 52 students answered to the basic chemistry concept test which consisted of five structured questions. Data collected from the basic chemistry concept test is shown in Table 3.

Table 3. Analysis of basic chemistry concept test

Chapter		Question	Wrong answer, n (%)	Partially correct, n (%)	Correct answer, n (%)	No response, n (%)
Matters and measurements	1.	The oceans of the earth have an average depth of 3800 m, a total surface area of 3.63 x 10^8 km^2, and an average concentration of dissolved gold of 5.8 x 10^{-9} g/L. How many grams of gold are in the oceans? Give the answer in the correct significant figures.	17 (32.7)	27 (51.9)	4 (7.7)	4 (7.7)
	2 (a)	Define the meaning of precision and accuracy.	9 (17.3)	6 (11.5)	36 (69.2)	1 (1.9)
	2 (b)	What is the best conclusion that can be drawn from Azman's data?	11 (21.2)	25 (48.1)	16 (30.8)	0 (0.0)
Periodic relationship among the elements	3 (a)	In your opinion, how would this account for the trend you discovered in atomic radius?	4 (7.7)	23 (44.2)	25 (48.1)	0 (0.0)
	3 (b)	Explain the trend for the first ionization energy as down a group.	7 (13.5)	10 (19.2)	34 (65.4)	1 (1.9)
	3 (c)	Write the chemical equation for the second ionization energy of Al.	30 (57.7)	2 (3.8)	19 (36.5)	1 (1.9)
Stoichiometry	4 (a)	Write the balanced chemical equation for the reaction.	6 (11.5)	5 (9.6)	41 (78.8)	0 (0.0)
	4 (b)	How many grams of nitrogen gas form when 1.00 x 10^2 g of N_2H_4 and 2.00 x 10^2 g of N_2O_4 are mixed? (apply limiting reactant process)	3 (5.8)	27 (51.9)	22 (42.3)	0 (0.0)
	4 (c)	Calculate the percentage yield of nitrogen gas from the process if the actual yield is 100 g.	20 (38.5)	16 (30.8)	14 (26.9)	0 (0.0)
Chemical reactions	5 (a)	Write the balanced equation for the titration above.	0 (0.0)	2 (3.8)	50 (96.2)	0 (0.0)
	5 (b)	From the titration above, name the analyte and titrant.	16 (30.8)	1 (1.9)	35 (67.3)	0 (0.0)
	5 (c)	Calculate the concentration of the HCl solution used in the titration.	2 (3.8)	5 (9.6)	44 (84.6)	1 (1.9)

Question 1 and 2 test the students on the concept of matters and measurement. The respondents were found weak in conversion factor involving calculations since resulting in only 7.7 % of them who managed to get full marks for Question 1. Students always forget to convert the unit when doing calculations or use the incorrect conversion which causing them to make errors in the calculations (Victorian Curriculum and Assessment Authority, 2011; 2013). To overcome this, taken steps to do conversion factor should be explained and worked on an example (Ayres, 2012; Sweller, 2006) of conversion factors should be given in designing the e-content later.

The majority of the students (69.2 %) could define precision and accuracy in Question 2a. These two terms are important in learning the concept of matters and measurement. The accuracy refers to the proximity of a measurement to the true value of a quantity while the precision refers to the proximity of several measurements to each other. Highly precise measurement does not necessarily guarantee accurate results.

Question 3 is about the concept of periodic relationship among the elements. Students were found weak in writing the ionization energy equations as about 60 % of them wrote the wrong equation for the second ionization energy of Aluminum. They tend to write the first ionization energy equation (Figure 4) or write the wrong imbalanced equation (Figure 5).

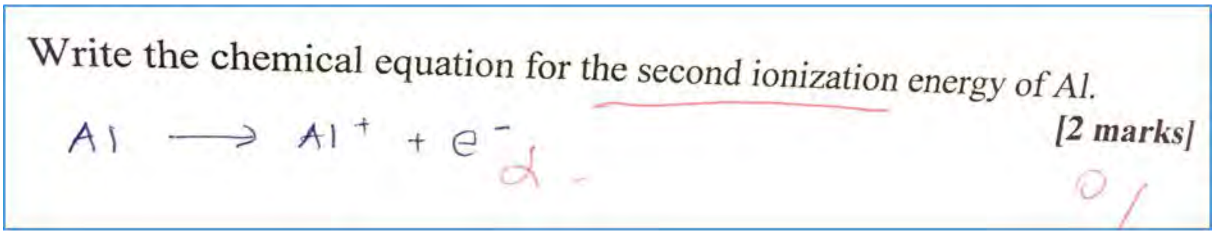

Figure 4. First ionization energy equation

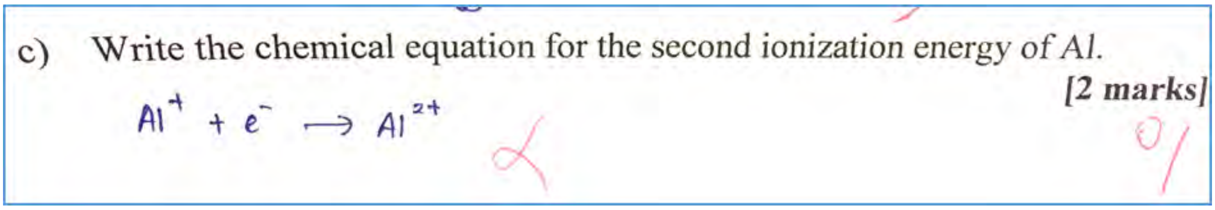

Figure 5. Wrong equations

Writing chemical formulas and equations are part of learning chemistry especially at symbolic level. One must transform chemical processes from the macroscopic level into the microscopic level and then represent them at the symbolic level to display the full understanding of chemistry concepts. However, Li and Arshad (2014) reported that teachers lacked practice of integration between these multiple levels of representation during the teaching and learning sessions. They always focus on macroscopic level (Boz & Boz, 2011) followed by symbolic level and the least were microscopic level. The most of the students have problems or misconceptions in understanding chemistry at the microscopic and symbolic levels (Al-Balushi, Ambusaidi, Al-Shuaili & Taylor, 2012; Aydeniz & Kotowski, 2012; Belge Can & Boz, 2011; Kamisah & Lee, 2014; Santos & Arroio, 2016). Belge Can and Boz (2011) concluded in their study that students' comprehension of the concepts in chemical formulas and equations, macroscopic versus atomic and molecular properties, solutions, chemical reactions, properties of atoms is lower than that of other general chemistry concepts included within the Chemistry Concept Inventory (CCI). Hence, the Periodic Table should be focused through explaining the characteristics of elements in terms of groups, periods, atomic radius, electronegativity, and ionization energy when designing the e-content for the periodic relationship among the elements.

The stoichiometry is the fourth topic in SKU3013 Chemistry I and it is tested in Question 4. It is one of the fundamental and universal concepts in general chemistry course and its connection to higher-level concepts such as limiting reagent (or limiting reactant) and reaction yields are unavoidable (da Silva, 2017). The results from the basic chemistry concept test showed that students were poor in determining limiting reactants (Question 4 b) and calculating the percent yields (Question 4 c). Only 42.3 % of them who could determine the correct limiting reactant managed to get full marks in the calculation of the mass of nitrogen gas. Almost half of them (51.9 %) got partially correct answers. Common errors made by the students were that they misinterpreted the limiting reactant due to the poor understanding and misconceptions in stoichiometry. This problem does not only happen among high school students (Gauchon & Méheut, 2007; Sidauruk, n.d.) but also among teacher trainees in university (Hanson, 2016). Students must write balanced chemical equations based on the chemical processes given and understand the stoichiometry concept to determine the limiting reactant correctly. When calculating percent yields, only 26.9 % of the students received full marks. Although students can get the correct answer for the mass of nitrogen gas, they misplaced the information in the formula for percent yield. The correct formula should be:

$$\text{Percent yield} = \frac{actual\ yield}{theoretical\ yield}\ x\ 100$$

However, the students misplaced the actual yield as the denominator (Figure 6) resulting in obtaining the wrong answer for the percent yield. To promote students' conceptual understanding and help students to overcome the problems in learning stoichiometry, simulation (Gupta, Ziolkowski, Albing & Mehta, 2017; Herrington, Sweeder & VandenPlas, 2017; Moore, Chamberlain, Parson, & Perkins, 2014; Sampath Kumar, 2016; Santos & Arroio, 2016) could be considered when designing the e-content in the LMS. The simulations can help students visualize chemical reactions and processes at the microscopic level and representation level that we cannot physically observe and are not easily represented in static textbooks (Herrington, Sweeder & VandenPlas, 2017). Besides that, analogy is another method which can help students to understand the content in an easier and more entertaining way. The analogy had been used in many studies (Harrison & De Jong, 2005; Marcelos & Nagem, 2012; Orgill & Bodner, 2004; Sevim, 2013) because it can help learners to understand a new concept by relating it to their existing knowledge or experience. The analogies are used when the target concepts are difficult or challenging and cannot be visualized (Orgill & Bodner, 2004). The researchers hope that students will engage in the learning process with the multiple format and multiple representation of learning materials provided in the blended learning environment (Gyamfi & Gyaase, 2015; Sankey, Birch & Gardiner, 2011).

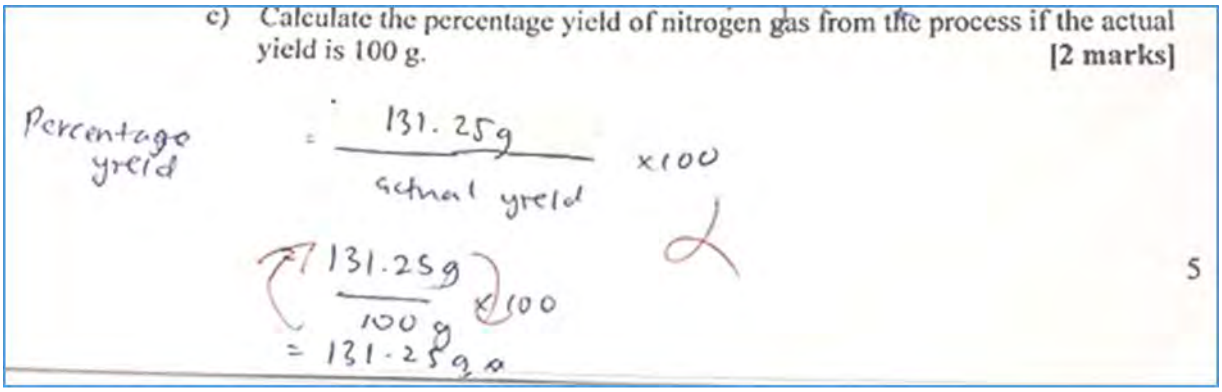

Figure 6. Students' wrong answers in calculating percent yield

Among the four topics, the students were good in answering questions related to the topic of chemical reactions. Almost all the students could write the correct balanced chemical equations (Question 5 a) on the titration process and calculate the concentration of the analyte (Question 5 c). However, some of the students (32.7 %) were confused between analyte and titrant (Figure 7). The analyte is the solution of unknown concentration normally placed in the Erlenmeyer flask during titration; while the titrant is the solution of known concentration normally placed in the burette. It is the standard solution added to the analyte during the titration until the endpoint is reached.

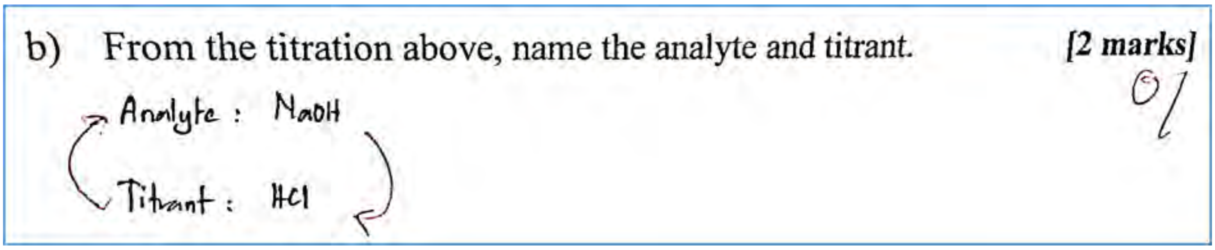

Figure 7. Student confused between the analyte and titrant

When designing the e-content for this topic, clear definitions should be given for the analyte and titrant to make sure that students will not be confused about these two terms anymore. Pictures or videos of the setup of the titration experiment can be used to strengthen students' memory in differentiating between the analyte and titrant. Chemistry is a visual science, hence using illustrations, diagrams, photographs, movies, or videos can enhance students' visualization on chemistry concepts (Pekdag & Le Maréchal, 2010; Williamson, 2011).

CONCLUSION

Students' understanding level on some basic chemistry concepts was analyzed using the analysis phase in the ADDIE model. From the results, students were found to have problems in changing the units involved in the conversion factor (matter and measurement concept), writing ionization energy equations (concept of periodic relationship among the elements), determining limiting reactants and calculating the percentage yields (concept of stoichiometry). Besides that, some of the students were confused between the analyte and titrant used in the titration process (concept of chemical reactions). Consequently, some ideas were suggested on helping students to overcome these problems. All the suggestions need to be taken into consideration when designing the e-content of the blended chemistry course in the design phase later.

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