Crafting Linear Motion Problems for Problem-Based Learning Physics Classes

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Abstract--- *Problem Based Learning (PBL) is an inquiry based learning where student begin with an ill structured problem and regulate themselves for knowledge construction. Unlike the traditional approach, PBL attention is directed to students' agency as knowledge constructor where it provides authentic experiences that promote active learning (to work cooperatively in a group), support knowledge construction (gather information across disciplines/subjects), and naturally integrate school learning with real life (to seek solution of real world). SMK SETA is one of the pioneer schools for implementing Problem-Based Learning (PBL) under STEM education initiative using low carbon as a theme. Crafting an ill structured problem of low carbon theme becomes a critical skill for the teachers where there is no formula on developing an effective problem. Teachers identify learning issues related to the low carbon theme, align them with the curriculum and comply in a lesson plan by principle of Constructive Alignment to adapt in PBL classes. Student of PBL are more likely to be active, creative, enthusiastic and work independently, while the teacher's role is only as a facilitator. In line with the Malaysia Education Blueprint, PBL promotes 21st century learning, higher order thinking skills (HOTS) and improves the quality of STEM education in Malaysia. Therefore, assigning an ill structured problem during physics lesson invites students' engagement to a real life experience because it helps to enhance students' critical thinking skills, problem solving skills, and promotes life-long learning. Implementing PBL into lessons however is challenging particularly at the stage of problem crafting. The challenge to construct an ill structured problem become a huge obstacle for teachers to adopt PBL as their teaching strategy. This paper describes the process on how an ill structured problem can be constructed for PBL Physics classes. The problem has to trigger the interest of students and related to the Physics curriculum learning outcomes. This paper will discuss the strategic ways that can be employed in developing an ill structured problem. The discussion is directed to the issues, challenges and ways to overcome the challenges when crafting the ill structured problem for secondary level.*

Keywords--- *Problem-based Learning, Physics, Linear Motion, Crafting, Problem.*

I. INTRODUCTION

SMK Sultanah Engku Tun Aminah is a pilot school for the implementation of Problem-Based Learning (PBL) in teaching and learning. This project was funded by the Japan International Cooperation Agency (JICA), headed by the Kyoto Environmental Activities Association (KEAA) in partnership with the Jabatan Pendidikan Negeri Johor (JPNJ) and Universiti Teknologi Malaysia (UTM). The PBL project is intendeds to integrate low carbon awareness among secondary school students in the Iskandar region to develop human capital that can accomplish the

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aspirations of Low Carbon Society Blueprint for Iskandar Malaysia 2025. Parallel with the Malaysia Education Blueprint (2015-2025) – Shift 1 (provide quality education of an international standards) the curriculum, examinations and assessments for all subjects especially STEM subjects (Science, Technology, Engineering and Mathematics) are revised as part of the broader KSSR, KSSM and higher-order thinking skills. The changes are meant to improve creative thinking, innovation, problem solving, and leadership among students. Adding to this, the teaching practices stress on student centred and have a greater emphasis on problem-based work. Therefore, practicing PBL can promote 21st century learning, higher order thinking skills (HOTS) and improve the quality of STEM education in Malaysia, especially in Johor. Given this, the practice of PBL is extended into Physics classes. This paper describes how the teachers crafted the PBL problems of linear motion for Physics classes.

PBL model originated from McMaster University and University of Maastrich medical schools. It was first developed by Barrows (1986) to find a more practical, hands-on approach to teach student doctors as opposed to listening to traditional lectures. Known for it success in the medical field, this pedagogical approach has been applied broadly in diverse discipline such as nursing (Wosinski et al., 2018),engineering (Jamaludin, Mohd.Yusof, Harun, & Hassan, 2012; Masek & Yamin, 2012; Hamiza, Zin, Williams, & Sher, 2013), science (Akçay, 2009; Khonchaiyaphum, Srikunlaya, & Rakrai, 2017), mathematics (Rustam E, Sidabutar, & Edy, 2017; Jacques, 2017; Suryani, Selvi, & Hasanah, 2018), and language (Mohd-ali et al., 2017; Ansarian & Mohammadi, 2018). These studies shared similar belief about the usefulness of PBL for knowledge construction. Nowadays, there are various types of PBL models, stemming from a variety of desired outcomes, implementation needs, as well as institutional systems, culture and constraints (Mohd.Yusof, Hassan, Jamaludin, & Harun, 2011). PBL is an inquiry based learning in which students begin with an ill structured problem and regulate themselves for knowledge construction. Unlike the traditional approach, PBL’s attention is directed to students agency as knowledge constructor where it provides authentic experiences that promote active learning (to work cooperatively in group)(Hamiza et al., 2013; (Shishigu Argaw et al., 2017), support knowledge construction (gather information across disciplines/subjects)(Poh Khoon, 2018), and naturally integrate school learning with real life (to seek solution of real world)(Shishigu Argaw et al., 2017). Students from PBL classes are more likely to be active, creative, enthusiastic and work independently, while teacher’s role is only as a facilitator. According to Nicholas and Judies (2009) cited in Phang et al. (2017), PBL promotes deep learning approach and improves students understanding and retention of knowledge, critical thinking and problem solving skills, motivation for learning, students ability to transfer skills and knowledge to new situations. Apart from that Mohd.Yusof et al., (2011) integrated the PBL with Cooperative Learning to guide students with the independent learning process. The cooperative learning requires students to develop good team working according to the, five principles of cooperative learning: positive interdependence, individual accountability, face to face interaction, appropriate interpersonal skills and regular group function assessment. This PBL model is known as Cooperative Problem Based Learning (CPBL) Model introduced by Mohd.Yusof et al., (2011). Cooperative Problem- Based Learning (CPBL) creates conducive environments for developing team working skills in students while they undergo their activities (Phang et al., 2017).

In line with Malaysia Education Blueprint (2015-2025) which is focusing on 21st Century Learning, the CPBL seems to be an adequate approach to cultivate communication, collaboration, critical thinking, creativity, as well as

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values and ethical applications (Mohd-nor, Suradi, Hajar, & Asidah, 2018). Jacques (2017) suggested that PBL can be known as a cornerstone pedagogy for STEM/STEAM approaches in the classroom since it requires the integration of several disciplines within one project. In this study, we used the CPBL model by Mohd.Yusof et al., (2011) to implement PBL in physics lessons. According to (Mohd.Yusof et al., 2011) there are three phases of CPBL as described in Figure 1.

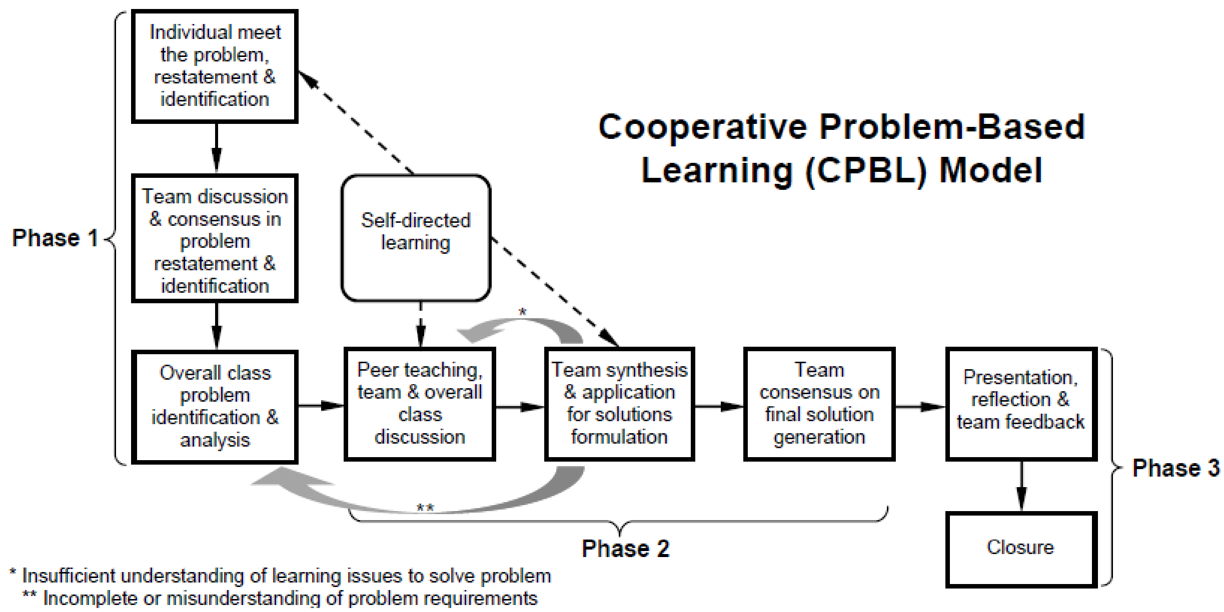

Figure 1: Cooperative Problem Based Learning (CPBL) Model

Each phase creates a number of issues for each discipline such as physics, science, mathematics and English. Issues are frequently associated with the question mark, the theoretical or practical difficulty, the cognitive gap, the barrier, the obstacle, which must be removed, surpassed or solved (Gorghiu, Drăghicescu, Cristea, Petrescu, & Gorghiu, 2015). Although it seems complicated to integrate the learning outcomes from different courses or disciplines, infusing only certain learning outcomes from different courses into a problem can be done (Jamaludin et al., 2012). Studies also state that science (biology, physics) and finance are also common second discipline for math PBL (Jacques, 2017). PBL begin with an ill structured problem and students regulate themselves for knowledge construction. Meant for an ill structured problems, one or more aspects of the problem are not provided, the description of the problem is unclear or not well defined, and the information needed to solve the problem is not contained in the problem statement (Chi, Feltovich, & Glaser, 1981 in Rodiawati, 2018). At phase 1, students are required to identify the problem statement and problem identification. The idea is to avoid students from immediately solving the problem. Instead they have to begin the problem solving by building understanding on the issues and analysing the given problems. Student have to restate the problem statement and problem identification in their own words to ensure their understanding of the problem given. Here student also identify their learning issues based on what they know and what they need to know by analysing the problem.

During the second phase, students begin to construct knowledge through peer teaching, synthesizing

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information, and solution formulation. The outcome of CPBL is to ensure learners are developing the skill to learn and apply new knowledge to formulate the solution (Mohd.Yusof et al., 2011). Studies show that students learn better by constructing solutions to open-ended, complex, and problematic activities with class-mates, rather than listening passively to lectures (Shishigu Argaw et al., 2017). Referring to the learning issues, individually students prepare for their peer teaching notes in the form of explanations, ideas and concepts that needs to be verified and questions on confusing points. All information and knowledge are shared and reviewed, before the relevant ones can be synthesized and applied to solve the problem. Other than promoting accountability, peer teaching is also essential for developing skills to learn. Students become engaged problem solver who seek to identify the root problem and the conditions needed for a good solution, during the process, they become self-directed learners (Sroufe & P.Ramos, 2015).

At phase 3, students make generalization, closure and reflection to what they learnt. The outcome is to evaluate the final solution from each team and summarize the concepts, formulas and skills learned. Misconception, difficulties and mistakes are continuously reviewed and debated with peers and teacher. Good practices in process skills or team working are highlighted to motivate students (Mohd.Yusof et al., 2011).

Adding to this, students are guided to internalize what they have learned and develop metacognitive skills during individual reflections. These are what make the model of CPBL stand in contrast with other models of PBL. The emphasize on team working promote cooperation among students resulting in improved learning quality and skills such as academic achievement, interpersonal skills and self-esteem.

II. METHOD

Despite the many benefits of using PBL, crafting PBL problem is challenging since problems need to be carefully designed and crafted to achieve the learning objectives (Mohd-ali et al., 2017). Problem crafting for PBL is challenging and often becomes a huge struggle for educators. This is often experienced by novice practitioners of PBL since there is no clear formula on developing effective problems. This paper describes the process on how an ill structured problem can be constructed for PBL Physics classes.

The problem has to trigger the interest of students and related to the Physics curriculum learning outcomes. As this is a paper for sharing experience, it does not require method of analysis. However, the data analysis does follow the Miles and Huberman analysis techniques. Data were selected from lesson plan reflections and interview transcript (data condensation), data were group into selected themes (data display) and, analysis and synthesis during writing (conclusion drawing).

In our previous studies (Mohd-nor et al., 2018), we have discussed on the five principles of effective problem and seven steps of problem crafting. The discussion focused on crafting STEM problem for low carbon society.

Referring to this, the five principles requires authentic and realistic, constructive and integrated, suitable complexity, promote self-directed learning and lifelong learning, and stimulate critical thinking and metacognitive skills to be promoted from the problems. This principle is used as the guideline during the problem crafting. There are seven steps in problem crafting.

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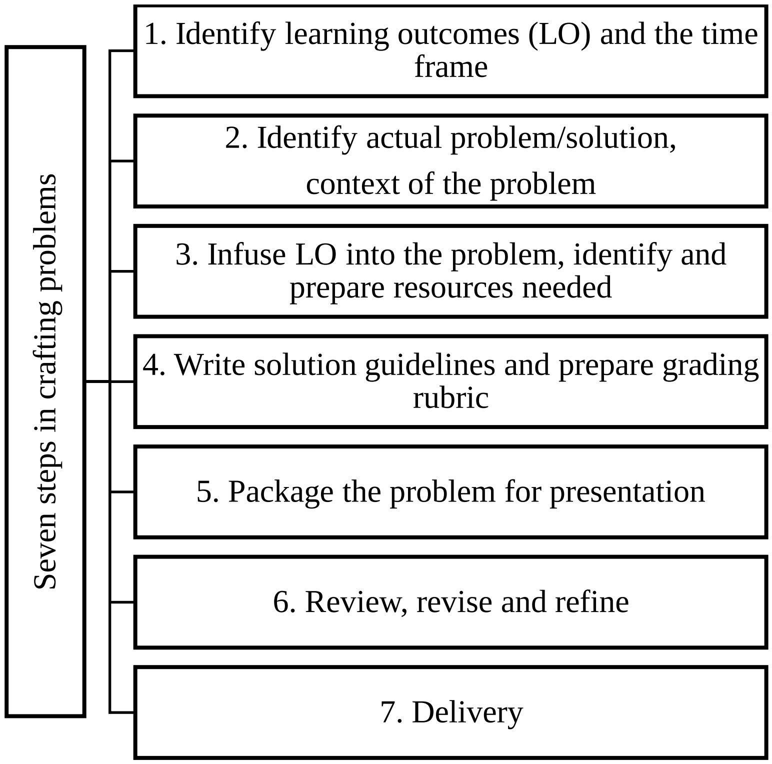

Figure 2: Seven Steps in Crafting Problem

III. CRAFTING LINEAR MOTION PROBLEM

The experience of PBL classes give an overview of how PBL can be conducted in Physics classes. The idea sparks when a teacher come across Physics exercises of linear motion using Angry Bird as a character in a question. Angry Bird game is familiar to all and the story have lots to do with motion, momentum and inertia. That is when we decided to implement PBL for Physics classes and start to craft the problem. Linear motion is a topic from Form 4 Physics syllabus. This chapter requires experimentation and hands on activities. The topic explained about distance, displacement, speed, velocity, acceleration, deceleration, inertia, momentum, collision, explosion, force, impulse, impulsive force, and gravitational force, equilibrium of forces, work, energy, power, efficiency, and elasticity. However, because of overlapping school programmes and syllabus demand we only manage to cover distance, displacement, speed, velocity, acceleration, deceleration, inertia, momentum, collision and explosion by PBL approach.

Referring to Figure 2, first step is to identify the learning outcomes and time frame. The learning outcome chosen from the Form 4 Physics syllabus are student is able to (1) define the momentum of an object, (2) define momentum (p) as the product of mass (m) and velocity (v) (p = mv), (3) state the principle of conservation of momentum, (4) describe applications of conservation of momentum and solve problems involving momentum. Referring to these, the teachers list down the possible learning issues based on what student had known and what they need to know more by using the KNL table. This step is important for students to identify their knowledge gaps. According to Jamaludin et al., (2012) knowledge gap created in the problems is essential to avoid students

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from being easily frustrated by the given problem. Each week, only 6 periods of lesson are allocated for physics classes. Therefore, we divided this time frame into 4 days of PBL lessons. For this stage, the time frame allocated is 8 periods.

The next step is to identify the actual problem and the context of the problem. The lesson plans were developed based on the principle of Constructive Alignment (CA). Table 1 shows the example of lesson plan for a Physics PBL class based on Constructive Alignment (CA).

Table 1: Example of Lesson Plan for Physics PBL Class based on Constructive Alignment (CA)

Stage	Learning Outcome	Teaching & Learning Activities	Assessment	Form 4 Physics Curriculum
STAGE 1 (8 periods) Momentum	To identify what we know, what we need to know and the learning issues from the bulletin given. To form KNL table To enhance students in soft skills development (team work, problem solving, Communication and etc.)	PHASE 1 Teacher shows slide of sample problem and how to do PR, PI and KNL table Students read and prepare individual PR and PI based on the main problem given.(bulletin) Student propose PR and PI individually and share with other members Each team present their PR and PI	Individually, in team and in class (notes, presentation)	A student is able to: -define the momentum of an object. -define momentum (p) as the product of mass (m) and velocity (v) i.e. $p = mv$. -state the principle of conservation of momentum. - describe applications of conservation of momentum. -solve problems involving momentum.

Following this, we began to infuse learning outcomes into the problem and develop the necessary resources for teaching and learning. The first draft of the problem is built from the Angry Bird game. The game is known by the students and is easy to play. Student have experiences playing with the game which make the problem sound interesting. The game's objective is to break the wall and release the birds, thus it involves physics concepts such as speed, distance, velocity, time taken, explosion and momentum. An ideal problem to stimulate learning is described by the characteristics, such as authentic, complex, open-ended, thematic, and it must always fall within students' capability to solve (Sim, Wee, & Kek, 2001). Following the principles of effective PBL problem, the objective of the game is changed and a new story is created in order to make it authentic and real. The story is changed to a story about the Bird Island being attack by pigs who planned to steal the Angry Bird tribe eggs. Hence, the objective is to design a new Angry Bird character to be recruited in the Angry Bird Game defeating the pigs. The story and the problem are designed to stimulate students' prior knowledge, connect multiple subjects, construct deep understanding, and harness students' metacognitive skills. At this phase, teachers are required to write solution guidelines and prepare the grading rubric for formative assessment. Possible answers and learning issues are listed from the draft problem to make sure that the students are on track. The grading rubric is adapted from the low carbon society PBL classes (Mohd-nor et al., 2018). When finalizing, the problem is packaged as a competition poster that need to be delivered by students by the end of the PBL classes. The problems are reviewed, revised and refined by other Physics teachers, PBL teachers and UTM lecturers (facilitators of PBL program). The discussion and process were executed back to back for the next problems. Few amendments were made on the terminologies, sentences and arrangement of the competition poster. Figure 3 shows an example of a problem for Physics PBL classes.

Figure 3: Example of Problem for Physics PBL Classes (Cycle 1)

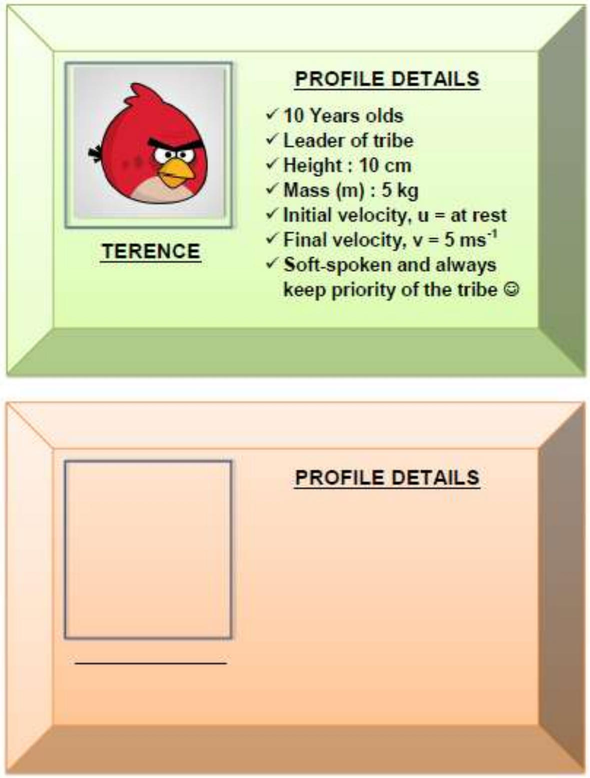

Figure 3: Example of Problem for Physics PBL Classes (Cycle 1)

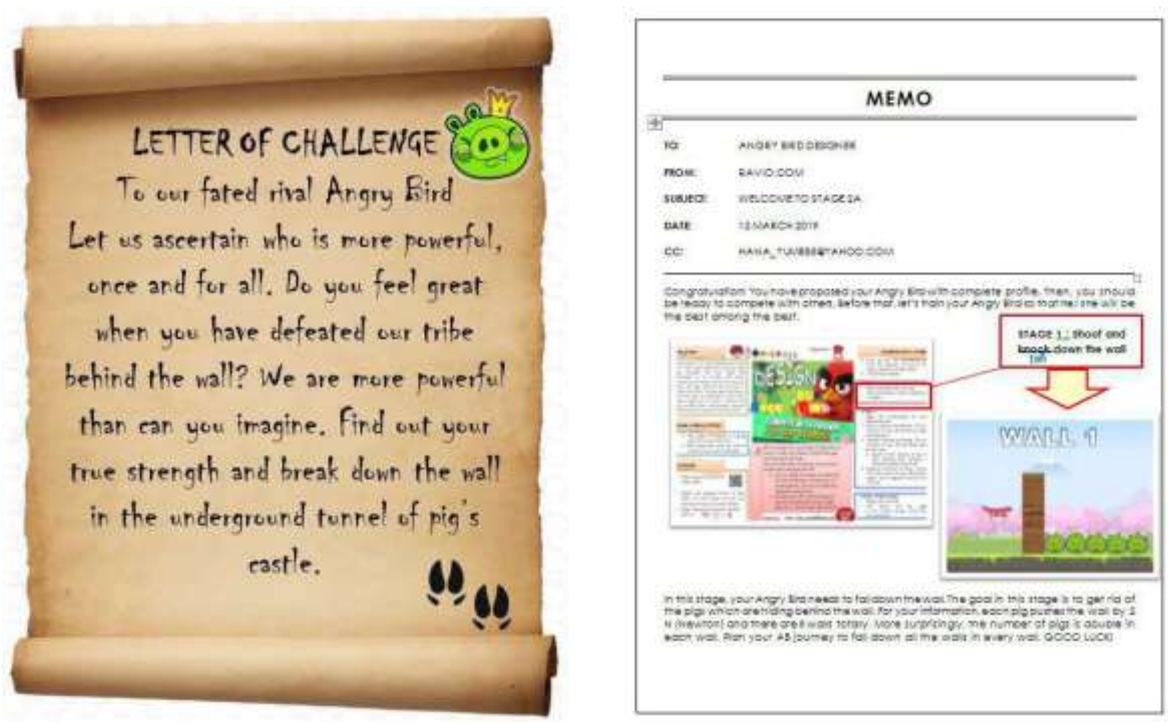

Figure 4: Example of Problem for Physics PBL Classes (Cycle 2 and Cycle 3)

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IV. FINDING

The idea of using PBL as a teaching strategy in classroom has long been taught. However, lack of confidence and ideas are the biggest constraint. After 3 years of conducting lessons using PBL for low carbon society, the teachers begin to feel comfortable to change their existing pedagogical practices into open inquiry pedagogy. A study of Shishigu Argaw et al., (2017) shows that students' achievement in physics can be improved by using the PBL. Physics subject is known as the most difficult subject for science student of SMK SETA. When comparing the result of biology and chemistry, physics has always been left behind. The students have been experiencing difficulty to understand the physics concepts and applications. In PBL lessons, the teachers outlined various creative packages to help students with the inquiry process and to engage student with the learning process. In comparison to the PBL program for low carbon society, PBL for physics classes have specific content to be delivered. All students must be able to achieve the learning outcomes. Thus, the problems must explicitly outline the learning outcomes. However, often the problems are either too complex to be solved cooperatively in small groups, or too simple so the learning outcomes can be achieved in one cycle. Apart from that, the creative package is not appealing to student`s interest. Using the informal learning as our source of inspiration, we choose Linear Motion topic by Angry Bird poster competition. In this study, we collect teachers' reflection in daily lesson plan as part of the evaluation process in the implementation of PBL. Along with the reflections, teachers were interviewed after the PBL classes have completed for more justification and elaboration in the written reflections.

Reflections by Teacher Suhaila :

"In order to create effective PBL problem, I need to plan well. My biggest problem is the use of English. I'm worried that using the wrong language will result in less effective PBL problem. Therefore, I did refer to English teacher on the sentence structure and sometimes I did explain in Bahasa Malaysia. To make sure everyone is on track and play their roles, I did check on each group for all activities. Meanwhile, the learning outcomes in Physics curriculum must be achieved during the class. Because of that, I got helps and opinions from other teachers and PBL community related to Physics content, language terms, PBL scope and more. The topics choose is momentum and the creative packaged use is competition poster, Angry Bird. The idea sparked by current student interest in comics and online games. The students are interest with the Angry Bird theme because they are familiar with the game."

Meanwhile, the time frame and the language have become some of the challenges in conducting PBL for physics classes. As the English language is not the mother tongue language of teacher and students, terminologies and sentence structure are the concern for teacher in having effective PBL classes. The instruction has to be crystal clear for all student, otherwise the student will be demotivated, less interested and left behind.

Reflections by Teacher Suhaila :

"I use my daily and weekly lesson plan to schedule my activities for PBL Physics classes focusing on time allocation. However, the activities usually exceeded the time allocate. The students are not well prepared for the class. They afraid to present, afraid to give and share idea, afraid to ask for help and do not know where to find the information. Therefore, I did give them few sources such as books, website links, and videos. During the planning, I also realize that mathematics and languages merged in the problem. They use mathematics when conducting and reporting experiments, and they used languages during presentation."

Since this is the first time of having PBL physics classes, the time frame for each activity does not follow the given hours. Students are afraid to try and always wait for instructions. As these are expected by the teachers, students are grouped with ex-PBL students. Throughout the 3 cycles of PBL for Physics classes, teachers find that it is possible to craft physics problem following the curriculum and PBL principles. Hence, PBL can integrate a few topics across subjects especially mathematics and languages. For example, student have to tabulate data, draw graph, state the relationship of variables, and know the basic mathematical calculation for unit conversion and formula.

Reflections Teacher Suhaila:

"Most of the students are very excited and engage with problems and classes. They feel unique and encouraging during group discussion. The presentations from other groups are very helpful while the explanation form the teacher is minimal. However, there are still students being sleeping partner, might be because of the students are still confused and still want the usual method of teaching. They are used to be spoon feed, and now they have to do their own learning. The students look stress and worried. I believe this is because they are not ready to take the challenge. React to this situation, I give some times for the student to observe and adapt to the changes. I also assign specific simple task for them to build their confidence."

From the reflection above, Teacher Suhaila, stated that students are excited and able to engage with the content. They are very cooperative and helpful in guiding their group member to do problem restatement (PR) and problem identification (PI). Besides that, they volunteer to start the peer teaching and group discussions. They also encourage and guide their friends to explore the content knowledge deeper. On the other hand, there are some students who are still doubtful of the activities and have no confidence on their selves. Here comes the role of a teacher. Teachers are not only scaffolding the content and knowledge development, but also on the communication skills, motivation and self-directed learning.

Reflections Teacher Suhaila :

"Apart from this experience, I have to keep in mind not to give the answer to the student. As I`m rooted to traditional teaching, this has become a challenge to me. However, 4 years of conducting PBL program for low carbon society, I slowly have shifted my teaching paradigm from teacher centred to student centred. The positive changes on student communication skills, skills to learn, self-esteem and confidence level are a big bonus in conducting PBL. PBL is an interesting method to practice with training, motivation and cooperation from others. Therefore, I will continue my efforts to implement PBL in physics class in the future as I learned its effectiveness in building 21st century students' skills."

The reflection above proved that teaching and learning through PBL method has impacted both teacher and student in several ways. With proper training, planning and collaboration, PBL can be practiced by integrating subjects. Students developed cognitive skills apart from getting high achievement in their grades.

V. CONCLUSION

Problems stimulate learning in a PBL class. Hence, it is fundamental that problems map out learning outcomes

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of the curriculum. Problems should be generated in a holistic manner crossing the boundaries of many subjects rather than as a silo subject problem. An effective problem of PBL must consider the goals of the classes (curriculum) following the five principles of authentic and realistic, constructive and integrated, suitable complexity, promoting self-directed learning and lifelong learning, and stimulating critical thinking and metacognitive skills.

Undoubtedly problem crafting is not an easy process. Without training, experience, motivation and cooperation from other teachers, crafting PBL problems for Physics classes can be confusing, stressful and overwhelming. However, PBL can be a powerful teaching method with great impact to prepare students with 21st century skills. PBL is a good alternative teaching method to improve the academic achievement and develop social skills of students (Shishigu Argaw et al., 2017). This is parallel to MEB (2015-2025) which emphasises on problem based learning and project based work to provide quality education for an international standards.

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