Cooperative Problem Based Learning: How does it foster metacognitive skills?

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***Abstract*---Metacognitive skills are a crucial set of skills that forms the basis of professional skills for future engineers. The skills help in planning, monitoring, and evaluating, which are required to solve global, challenging and audacious problems typical in complex real-world issues. These skills do not naturally occur and cannot be taught. Instead, they need to be trained through appropriate learning activities. Constructivist learning approaches have been shown to be effective in fostering metacognitive skills development, such as Cooperative Problem Based Learning (CPBL) which integrates the principles of cooperative learning (CL) into problem-based learning (PBL). This single case study research investigates an engineering student's metacognitive skills development as he went through CPBL to identify crucial elements during implementation. In-depth interviews were analyzed using an interpretative phenomenology approach to study how metacognitive skills were developed. Each phase of CPBL helps develop metacognitive skills of the student. Therefore, it is important to follow closely the phases in CPBL so that students can develop metacognitive skills that will make them better learners and future engineers.**

Keywords—problem based learning, cooperative learning, problem solving, metacognition

I. BACKGROUND

The 21st century presents various challenges for future engineers such as rapid technological development, an avalanche of information, issues of sustainable development and more. The demands from stakeholders for engineers to possess professional skills and high technical expertise cannot be ignored. Pressing issues on sustainable development commands the need for engineers who can tackle complex problems such as those on poverty and hunger, to make the best use of technology for promoting peace for the betterment of the world. So, it is a necessity for future engineers to understand issues on humanity and diversity involved, to help them handle conflict and harness differences for advancement. These skills and knowledge can be developed continuously with strong metacognition. Thus, there is an urgent need to develop metacognitive skills among engineering students.

Metacognition plays an important role in all learning and life experiences, especially to support in enhancing the skills needed to be relevant future engineers. Metacognitive skills help in planning, monitoring, evaluating and revising required for complex problem solving [1, 2]. Metacognitive skills can be used to improve learning: content knowledge and understanding, and the ability to handle both routine and unfamiliar problems. These skills also enable individuals to monitor their current knowledge and skill levels, plan and allocate limited learning resources with optimal efficiency, and evaluate their current learning state [3, 4].

Although not easy to develop, metacognitive skills can be trained through appropriate learning activities. It takes time to develop metacognitive skills. Poh et al. [5] recommended that engineering students should cultivate and master metacognitive skills as early as possible to ensure that they have the skills by graduation. The importance of developing metacognitive skills among engineering students were stated in various research [6-9]. Prince and Felder [10] stated that constructivist approaches are best implemented to achieve metacognition, such as cooperative learning (CL) and problem-based learning (PBL) [11-13]. CL focus on the development of learning teams, where students support each member in learning and produce high quality works [14, 15].

Cooperative Problem Based Learning (CPBL) is the integration of CL into PBL [16, 17]. CPBL supports teaching and learning of small-groups in a class of up to 60 students with floating facilitators [16, 18, 19]. As in PBL, CPBL requires the problems to be realistic and ill-structured. The CPBL learning environment is underpinned by constructive alignment [20, 21], How People Learn framework [22], PBL and CL [14]. Previous research showed that undergoing CPBL enhanced students' team-based problem-solving skills [20], which confirmed the development of metacognitive skills. As shown in Figure 1, the implementation of CPBL is divided into three phases:

1. Phase 1: problem restatement and identification (PR & PI),
2. Phase 2: peer teaching (individual, team peer teaching, and overall class discussions), synthesis, and solution formulation.
3. Phase 3: closure, reflection and internalization.

The issue now is to investigate how metacognitive skills were developed when students undergo CPBL in a typical classroom setting, because this will lead to a deeper understanding of which elements and activities develop the different metacognitive skills that can be used to guide educators in facilitating the different phases in CPBL. The research question for this study is “How are metacognitive skills developed when undergoing CPBL?” The answer will help educators to facilitate better for metacognitive skills development among students.

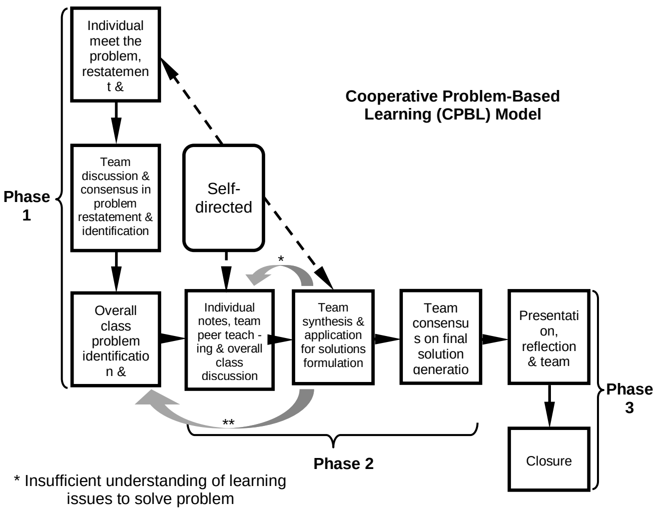

Fig. 1. Cooperative Problem-Based Learning (CPBL) Model [17].

II. Research Methodology

This is a single case study [23] carried out through the lenses of phenomenology [24]. Phenomenology focuses on understanding and interpreting profound human experience [24], in this case, to explain in-depth how metacognitive skills were developed as a student undergoes CPBL. Since this study was conducted among first-year students taking the Introduction to Engineering (ITE) course, the results represent the entry level metacognition for engineering students.

ITE is a three-credit hour course for first year chemical engineering students in a Malaysian university. The objective is to bridge students’ learning experience in school to learning to be an engineer in the university. Students undergo CPBL to learn about engineering processes through sustainable development themed problems. In semester 1, year 2015/2016 session, students were given a nine-week problem on Zero Waste Challenge. Students were divided into teams of three or four across genders, ethnicity and academic achievements.

To support students in reaching the required depth in learning, the problem was divided into three stages, each consisting of one CPBL cycle. The overall problem was given in Stage 1, with problems given in subsequent stages providing details about further requirements. Since students were new to CPBL, the problem was designed to gradually challenge students with increasing difficulty. Details on the course can be seen in Mohd-Yusof et al. [17, 18]. The overall three main stages of the problem were:

Stage 1*:* Familiarization of Sustainability, Zero Waste and Benchmarking

Stage 2*:* Audit of Solid Waste

Stage 3: Propose Engineering Solution and Economic Analysis

A respondent who went through each CPBL cycle conscientiously was interviewed throughout the semester. The data was transcribed and analyzed using thematic analysis [25]. This method is used to analyze, identify and report patterns within data to describe the experience across the data. This paper presents the result from the respondent that underwent each activity in all the phases of CPBL. Since this is a qualitative study that seeks to understand the phenomena in detail, focusing on one student that fits the criteria is sufficient. The engineering student, named Timothy, was selected as the respondent based on the following criteria:

1. First year student taking ITE course
2. Went through all the three CPBL phases without fail

III. Findings

This section elaborates in detail how Timothy developed his metacognitive skills as he underwent CPBL. All quotes have been corrected for grammar.

A. Monitoring Skill

To understand the problem given, Timothy read it many times and tried to get the main point. He was really immersed in the problem and kept thinking until he found the main objective of the problem. He knew he needed to do the problem restatement and problem identification (PR&PI). The first thing he did was identify the gist of the problem. He realized that the brochure for the problem contained a lot of information. Extracting the important information can help solve the problem. He could explain the gist of the problem very well. By following the steps in PR&PI, Timothy managed to identify the actual objective of the problem and successfully described the objective of Stage 1 when he said, “Because I actually reread several times. I keep thinking to find the main problem. I know the concept is zero waste, but I keep thinking what is the main problem? Maybe if I look for a few times, I will get something new.”

The act of **rereading** the text many times, showed that the process of **monitoring** happened. To fill in his knowledge and information gap before solving the problem, Timothy needed to find information, make comparison, do the checking, and monitor his understanding. This process enforced the process of monitoring. By following the steps in PR&PI, Timothy managed to identify the actual objective in this problem. He successfully described the objective of Stage 1 as follows:

“*Stage 1 problem is about familiarization of sustainable development, zero waste, waste management, and also bench marking… benchmarking is something new for me. For SD, actually we do this study. I think Stage 1 is important because it helped us to link SD, benchmarking and zero waste together. Like we need to create zero waste environment, but we must to understand what zero waste concept is. Problem arise when there is solid waste management problem. Then the problem in development become unsustainable. Then how do we solve this problem by benchmarking? Benchmarking with other countries. This is how these three things link together. Then after solving, it became a cycle that can come back to zero waste concept”.*

The **monitoring** skill in Stage 2 was enhanced when Timothy underwent the same activities and became more familiar with the CPBL process. From experience gained in Stage 1, the process of doing PR&PI was easier than before. To determine the problem and objective in stage 2, he used his experience, knowledge and information from Stage 1 and related it with Stage 2. He said,

"*In my understanding, for Stage 1, we already know zero waste, sustainable development and benchmarking. These are important things for Stage 2, because from Stage 1 we are certain that if we want to create zero waste environment and achieve sustainable development, we need to have very good waste management system. In Stage 2 we are starting to look at our waste management system. What do we do with waste disposal and waste management? So I can find the problem and try to solve the PR&PI. We need to perform waste audit, to collect the data in order to gain more understanding. And then understand the current community practices. So these are what I understand about the Stage 2 problem. So, the important points for Stage 2 is for us to collect data to look deeper on how we do waste disposal and waste management."*

In Stage 2, while searching for information, Timothy was confused how to justify the benchmarking. He knew that he needed to provide justification for the benchmarking. He kept monitoring his understanding while coming up with the criteria for benchmarking. Finally, he decided to compare the data he gained with other countries' data. In the middle of this interview, he monitored his confusion, generate his own question and finally came up with a solid answer. He said, "*I wonder how to justify my benchmarking. So, meaning to say in this stage I need to discover what I need to benchmark on. I need to do benchmarking in terms of what. Meaning to say I need to compare my data with other countries? Ooohh..ok"*

The same process of monitoring occurred in the Phase 3. Timothy shared that listening to other teams' presentations helped them in monitoring and evaluating whether their process and output was on the right track. Also, presentation helped in monitoring, so he can achieve a better understanding. Timothy discovered the data was different among each team even though he knew that during the data collection process, there were three or four teams working together. He assumed that there were differences in the data collection method. Some of the teams went from door to door to collect the waste from students in residential colleges. He was able to identify the cause of differences in the results for data collection. By comparing the presentations, Timothy was able to give justifications on the differences of the results. He saw the different perspectives and solutions for the same problem. He said, "*In our section 3, we combined data. My group and three other groups combined the data. So, our data is the same. The combined group of course should have the same data. But our data is different from other groups. I think because other groups were doing door to door if I'm not mistaken."*

B. Planning Skill

Planning skill became more obvious in Stage 2 after Timothy experienced Stage 1 and as he became more familiar with CPBL. In Stage 2, the first thing Timothy did was set the objective to start this phase related to zero waste, sustainable development and benchmarking. He understood the concept of zero waste and sustainable development. He was aware about taking care of the environment and knew the objective, which was to compare the waste management between Malaysia and other countries for benchmarking. Looking for information for literature review and extract the gist associated to the topic was not an easy task. He had to find information from various sources. From his reading, he started planning to get the correct information by drawing out the problems in Malaysia and doing a comparison. He listed common problems related to zero waste in Malaysia. As he looked for information, he kept asking himself why there was no focus in giving awareness about zero waste and why developed countries excelled. Timothy showed his ability in doing analysis. He kept monitoring his knowledge and understanding by doing comparison from the sources that he obtained. He said,

"I don't understand till now why Malaysia don't have public awareness about the importance of 3R. So, I wonder how other countries can excel in 3R. So, I start to study and discover that Japan is one of the modern countries that successfully used 3R. There is something different from public awareness campaign between Japan and Malaysia. Public awareness in Japan on 3R is conducted face to face between city official and public. Which means public can give their comment. They can give feedback to the city official. However, in Malaysia, we rarely have this chance. I think this is the difference. I need to take note on this difference and come out with better solution."

At first, he planned to collect data from residential college, department office and café where students were always present to get accurate data. Timothy also considered the time and the people who collect the data. He said,

"*Actually, I did some literature review on the internet. Basically, people will just categorize first. I would have some boxes or dustbin, then we will label this box for papers, so you only can drop paper; this box for metal like aluminum can, and then the other boxes for plastic, food waste and then the last one is others. Others mean maybe glass or any other waste. First is the date and time we did the data collection, the place we did the data collection and the people who will be doing the data collection. These 3 are very important elements in data collection."*

Working together with people from various backgrounds gave Timothy new experience. He felt happy with his work in Stage 1. He gained skills and knowledge, and appreciated being guided through CPBL because he felt as if he was being trained as an engineer, especially in team working and communication. He emphasized the benefits of doing discussions. He learnt about managing his tasks properly, noting on the need to be more organized to face the Stage 2 problem. He said,

"*The most important thing that I gained from the overall Stage 1 is about the CPBL. Before this I don't know about CPBL. But after this I think it is a process. This process helped me to increase the efficiency of my work especially in* *team work. If you follow the CPBL, everyone is sharing their knowledge. Because there are discussion part and sharing session, we actually share our knowledge and we gain a lot of new knowledge from the others. Not only share our knowledge we also gained something new. We gained something new from the others especially during the class peer teaching."*

Timothy and his team prepared for their presentation. This showed that his team planned well to make sure the presentation was smooth. They learned from their mistake during the previous presentation on engineering overview, where they were a little bit rushed during the presentation. In the Stage 1 presentation, he and his team were prepared in terms of time management, script, and elaboration. This time, his team made sure everyone had enough time to deliver their part. He remarked, "*This time we are very well prepared. Because last time during engineering overview, we were a bit rushed with the presentation and we didn't rehearse. But this time, we managed to finish the presentation slide."*

C. Evaluating

Evaluating skill was developed mostly in Phase 3 of all stages. This skill was also developed in Phase 2 during Stage 3 of the problem. In Phase 2, the outcome is for learners to take responsibility for their own learning as CPBL encourages students to identify their learning needs and determine the resources they will need to use to accomplish their tasks. During this phase, students learn together, evaluate different approaches to solve the problem and justify the choices made. Peer teaching activities in Phase 2 was a platform for discussion, where the students learn from each other. There were interactions among team members, brainstorming for better answer, giving and accepting information, opinions and justifications. During peer teaching, the students checked what they had to do to make sure they were on the right track. In addition, they had to make sure everything was verified. All these were experienced by Timothy. He had to convince his teammates about his selected country as the benchmark. He provided them with the information and justifications. He knew that his ideas need to be discussed with his team. He wanted to correct his ideas by communicating with his team, and gain acceptance from everyone in his team. This was a kind of verification and checking whether his ideas were good. In his team, monitoring process about his understanding occurred. He explained,

"We need to correct and communicate our findings with teammates. Of course, when doing peer teaching notes, we come out with a lot of different kinds of findings. So, I need to communicate with my teammates on the findings to gain acceptance from everyone. I need to confirm their opinion because I don't have a Japanese member in my team. So, I need some verification because we are engineering students. I prefer to confirm everything if they are right"

In Phase 3 of Stage 2, monitoring and evaluation skills were used to identify which kind of waste the students should focus on. The information and knowledge from the previous stages helped Timothy in making the decision. In addition, he had to propose a plan for their campus to move towards zero waste, detailing the process for implementation that is realistic. Timothy said,

"*I analyzed the data, of course, paper and plastic are the waste most generated, however we discovered a trend that food waste is actually rising. It was rising fast. Why does this happen? Because the recycling initiative currently only focus on paper, plastic and aluminum can. Look at the recycling bin. There are only paper, plastic and aluminum can. This is only the small picture. If you see the big picture in the whole of Malaysia, the recycling campaign also only focus paper, plastic and aluminum can. But food waste is the most generated pollution in our environment. When disposed in landfill, it will release gases that cause bad smell and methane. This is very powerful greenhouse gas and carbon dioxide. I think we should handle and set up a food waste reduction campaign to reduce the food waste generated."*

In Stage 3, generating PR&PI was easier. He was able to identify the objective for Stage 3. However, Stage 3 is the most challenging stage, since the teams had to be creative in coming up with a suitable engineering solution. Proper studies must be done. The solution must be practical, with the proper process and mechanism, and suitable for the community. To overcome the challenge, Timothy discussed with his teammates. The process included interaction within himself, and with peers. By doing this, he created the opportunity to revise his knowledge and clear areas of confusion. he said, "To overcome this challenge, we did a lot of discussion. Because other than that we don't have any way to overcome the challenges except to do more research, do more literature review, and then we also ask some opinion."

When proposing the solution, he needed to justify his choice based on the three pillars of sustainability: economic, societal, and environmental requirements. He did a lot of literature review, economic analysis, justified the finding and proved that his team's engineering solution was practical to be implemented on campus. He explained,

"*We just think about the anaerobic digestion plant. The simple one and more general. Because everyone thinks this is very practical. So, we look at other research and other universities at other country. At universities in other countries they own anaerobic digestion plants. But then, we think that the cost is too high. But then we found a problem, if we develop anaerobic digestion plant, we cannot promote sustainability to the students. Because students have less chance to be in contact with anaerobic digestion plant. So, we plan to have one in every residential college. We start in a college using simple material like rubber, we called it a rubber balloon like a collector. And then we transfer into generator to supply electricity. This is very simple and involved students. Students have more chance to get more in contact with the anaerobic digestor. So, they can learn the process, and then they can involve themselves in the reduction of the food waste."*

One of the important things that the students did was checking their solution. When students check their work, it means that the students paused for a moment and reflected. Reflection is an opportunity to make sure everything was in the right track. Timothy and his team checked their solution for economic analysis, the effectiveness of the solution and the scientific validity of processes involved. The process was back and forth in monitoring and evaluating to gain understanding. He said,

"*Yes, we do the checking for the solution and economic analysis. What type of material we need to use, what is the cost and the most important is the cost must be done to generate income. So, we need to do investigate what is the output, what is the outcome of this, what can I get from this solution. How can I balance my economic analysis. And then for the scientific part, for the critical part, we also study about the scientific process. A lot of biological processes, about how the microorganisms decompose the waste, and then for the chemical process like how the biogas is converted to electricity, to use as combustion fuel to use in generator.*"

In Phase 3 of Stage 3, the presentation served as a discussion point on the possible ways found by the different teams. The facilitator probed students during the discussions to determine acceptable solutions and to justify their choice of the best solution. A thorough discussion of the solution is important to gauge students' level of learning, whether deep understanding was attained. During the overall class presentation, students learned to acknowledge others' ideas from the presentations. At the same time, they compared ideas with others and adjusted their understanding. In Phase 3, overall class presentation was the best place for students to monitor and evaluate their understanding to integrate their understanding with others.

IV. DISCUSSION

Table 1 summarizes metacognitive skills developed in each phase and stage based on Timothy's experiences as he conscientiously underwent CPBL. To see how his metacognitive skills were developed, specific elements that supported the development are discussed to help educators identify actions needed while facilitating learning.

Table 1: Metacognitive Skills Developed in Each Phases

PHASE	Monitoring	Planning	Evaluating
1	Reading and restating problem in PR & PI	Setting objectives in PR	Identifying learning needs in PI
2	Search new information for peer teaching	Data collection in solution generation	Peer teaching
3	Listening & understanding presentations, reflection	Preparing team presentation	Solution presentations; propose, check & discuss solutions, reflection

CPBL starts with a problem. It is important for the problem to stimulate students' thinking, engage students' motivation and interest and be open-ended [26]. The design of the problem should permit free enquiry so that students identify and obtain the information needed to solve the problem [26]. A problem that is authentic and provocative create interest and motivate students to use their metacognitive skills. For instance, Timothy was clearly interested and immersed in the zero-waste problem that pushed him to learn and think at a deep level to find the solution. They think critically to interpret the problem from different perspectives, identify existing and new knowledge, seek and learn new knowledge cooperatively to reach deep understanding, identify and evaluate possible solution, making decision and apply the correct concept to synthesise the solution. When students solve an open-ended problem that is of interest to them, they may find their own solution to be inadequate. This occurred in Stage 3, where Timothy felt motivated by the problem, but at the end felt unsatisfied with their solution, driving him to evaluate the process that he went through to improve himself. The problem was purposely designed to gradually challenge students in three stages with increasing difficulty, with systematic scaffolding to support learning as they developed the necessary skills in each of the CPBL cycle [17]. Starting with Stage 1, Timothy gradually developed his metacognitive skills until he was able use it to the fullest in the last stage. Students internalize the experience by reflecting their process of learning and applying the skills in a new situation.

Restating and identifying the problem in Phase 1 of the CPBL cycle led students to discover the objective, goal and purpose to learn. This was significant in guiding Timothy in his learning journey. Helping students to identify what and why they learn and how they will benefit can trigger students' awareness of their own thinking process. Prompting students with procedural questions may help foster greater self-awareness and metacognition [27]. Timothy said that CPBL helped him to develop skills to be an engineer. As he progressed through CPBL, he discovered that if he was going to achieve the long-range goal, he must develop and accomplish mini goals along the way [28]. Thus, making learning objectives explicit is important to help students plan strategies and ways to monitor their progress towards attaining the objectives. Identifying objectives through Phase 1 activities, which was repeated each time in Stages 1, 2 and 3, helped foster monitoring and planning skills.

Synthesizing and applying the knowledge to come up with the solution, class solution presentations and reflection instilled evaluation skills. These activities took place at the end of Phase 2 and in Phase 3. To come up with the solution, students had to evaluate ideas from team members, while the class presentations allow students to evaluate solutions from difference teams. Team reflections guide students to evaluate how the team process, while individual reflection encourage students to evaluate their own learning process.

The CL principles in CPBL guides students to learn in teams, enhancing all the metacognitive skills. Undergoing CPBL drove Timothy to develop traits through the CL pillars: positive interdependence, individual accountability and face to face interaction. In CPBL, students work individually first, then discuss in team and finally with the whole class, a pattern which originated from CL. This process, which is present in Phases 1 and 2, helped students to develop the ability to evaluate their capabilities, skills and own understanding. The tasks in team and whole class led students to monitor and evaluate the initial knowledge gained while working alone. In Timothy's case, he was guided to participate in discussions, or dialogue with peers, lecturers and stakeholders connected to the problem to get deeper understanding. As he became immersed in the problem, the whole class became a learning community which he looked forward to exchanging ideas and receiving feedback especially during the peer teaching sessions and class presentations. Through discussion among team members, overall peer teaching and class presentations, he recognized the importance of peer support as he developed his capabilities to accomplish his goal. CPBL encourages cooperation; students must be guided to discuss their understanding, evaluate their work and the work of the team, and reflect on their learning. Justifying a decision to peers and skeptically examining the explanations from peers provide valuable opportunities for students to develop communicative and metacognitive skills. Therefore, educators need to make sure to motivate, support and maintain the students' self-confident so that they can discuss in a safe atmosphere.

V. CONCLUSION

Metacognitive skills can be developed if students undergo each phase in the CPBL cycle. Educator should guide and motivate students to follow all the steps, especially for students who are new to CPBL. The important elements for developing metacognitive skills are suitable problems that engage students, proper implementation of cooperative learning principles and closely following the CPBL cycle. As students undergo CPBL, educators should guide student teams to identify learning objectives, which they can translate into learning goals for self-monitoring and planning. Critical discussion and peer feedback in all CPBL phases are identified as the contributing factors in developing metacognitive skills and should thus be encouraged by educators in facilitating students learning. Most importantly, to foster metacognitive skills among students effectively, educators need to ensure that students closely follow the CPBL cycle.

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