Exploring 10th Grade Students' Self-directed Learning in a Mathematics Problem-based Learning Classroom

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This study aimed to explore the self-directed learning (SDL) of 10th grade students in a mathematics problem-based learning (PBL) classroom (n = 36). The data were collected during January-February 2019 using students' self-assessment of SDL behaviour, students' SDL observation forms, students' interview schedules students' reflection forms, and the teacher's notes. Descriptive statistics (mean and standard derivation) and descriptive analysis were used to analysis the data. The findings indicated that in a mathematics PBL classroom, the students' mean scores in all three aspects of SDL (i.e., ownership of learning, self-management and self-monitoring, and extension of learning) had increased. In addition, students' SDL in the ownership of learning aspect was observable in the second and fifth steps of the PBL process, and students' SDL in self-management and self-monitoring and extension of learning aspects were observable in the second, third, fourth and fifth steps of the PBL process.

In recent years, self-directed learning (SDL) has become one of the keys for a range of 21st century skills (The Partnership for 21st Century Skills, 2011). Initially, SDL was studied in the field of adult learning. Later, Hanson (1996) conducted a study that found that SDL seems to be dependent on the readiness of the learner, content and the context of learning rather than on the age of the learner. Thus, SDL has been recommended as an important life skill to be fostered through K-12 education. Gibbons (2002) stated that for formal education, SDL is "any increase in knowledge, skill, accomplishment, or personal development that an individual selects and brings about by their own efforts using any method in any circumstances at any time" (p. 2). This definition implies that SDL occurs where students have a degree of control over the timing, pace, and place of their learning. Students are able to feel ownership of their learning, can self-evaluate, reflect on their progress and set goals for learning more (Shulman, 2017). In this study, the researchers explored the SDL of 10th grade students based on the work of Tan, Divaharan, Tan, and Cheah (2011). Their study defined the features of students' SDL in K-12 education, involving the following three aspects: (a) ownership of learning, (b) self-management and self-monitoring, and (c) extension of learning.

In the first aspect, the *ownership of learning* refers to personal responsibility in identifying learning gaps and setting learning goals. This aspect has four behavioural indicators for observation: (1) the students identify, determine and articulate their own learning goals (setting goals); (2) the students identify the gaps in their learning (identifying learning gaps); (3) the students plan to achieve their goals (self-plan); and (4) the students challenge themselves and set the standards for the achievement of their learning goals (challenging learning abilities). In the second aspect, s*elf-management and self-monitoring* refers to the process of managing tasks, time and resources, as well as the ongoing efforts of making improvements or taking action to meet the learning goals. There are four behavioural indicators for observation as follows: (1) the students formulate questions and generate relevant inquiries (formulating questions); (2) the students explore a range of possibilities and make sound decisions (exploring to make a decision); (3) the students self-manage their time (managing time); and (4) the students critically reflect on their learning and initiate the gathering of feedback from teachers and peers to achieve their learning goals (reflecting learning abilities). In the third aspect, the *extension of learning* refers to making links across

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disciplines, connections between formal and informal learning as well as interests in and out of school. Two behavioural indicators of this aspect are: (1) the students apply what they have learned to new contexts (applying prior knowledge), and (2) the students apply the skills that they have acquired to learn beyond the contents (connecting knowledge to the real-world).

Mathematics is globally considered as the basis of all science and technology. It is one of the core and compulsory subjects of primary, junior and senior secondary schools' curriculum. It is also a fact that most careers depend on mathematical skills (Dada & Dada, 2014). Kleden (2015) suggested that the important aspects in learning mathematics are that students must initiate self-learning, schedule the learning time, identify their learning necessities, formulate learning goals, identify resources and materials for learning, select and employ appropriate learning strategies, and evaluate the learning outcomes. It could be claimed that SDL is a behaviour required for students in learning mathematics. In addition, Dada and Dada (2014) stated that SDL behaviour could enhance achievement in mathematics.

However, Thai students lack SDL behaviour. For example, in the *ownership of learning* aspect, Thai students could not clearly identify which part of the mathematics lesson that they did not understand. They neither set learning goals nor planned learning tasks to achieve the goals. Instead, students would rather wait to receive directions from their teachers. (Angsuwotai, 2007). In the *self-management and self-monitoring* aspect, the students could not manage time appropriately for a mathematics assignment, including formulating the questions to recheck on their peers or themselves as well as to reflect on their tasks. They could not choose appropriate strategies for their own learning. Rather, students looked for the correct answers from their teachers than try to find out by themselves (Anuphap, 2017). In the *extension of learning* aspect, the students could not construct personal meaning through integrating new ideas and concepts with previous knowledge (Chanprasert, 2011). Consequently, many Thai students are still acquiring information in teacher-centred classes. In such a learning environment, students become passive and dependent learners. A transition from passive learning to actively engage in their own learning is the first step towards the development of students to be SDL learners (Buaraphan, 2015; Promsawan & Katwibun, 2017).

Many studies have reported that SDL was fostered by problem-based learning (PBL) (e.g., Loyens, Magda, & Rikers, 2008). PBL is a student-centred approach where students determine the key issues of learning and solve real-world problems through working collaboratively. Students are responsible for their own learning, while the instructor's role is to facilitate the students' learning process without imparting any direct answers or knowledge (Abubakar & Arshad, 2015). Therefore, the researchers were interested in exploring 10th grade Thai students' SDL in a mathematics PBL classroom. In this study, the researchers used the PBL process adapted from Othman, Salleh, and Sulaiman's study (2013). Their study used a PBL process that was not complicated for secondary school students. They proposed five steps in the PBL process: (1) an introduction to the problem, (2) self-directed learning, (3) group meeting, (4) presentation and discussion, and (5) exercises.

Method

This mixed methods research was conducted by collecting, analysing and integrating quantitative and qualitative data in a single study. This is the preferred method in social research (Mwaniki & Mue, 2015). The participants were 36 10th grade students from a high school in Chiang Mai, Thailand. The data were gathered using the following instruments:

(1) Six PBL lesson plans (100 minutes per lesson for six weeks in the second semester of the academic year 2018 during January - February 2019). The lesson plans were created by the researchers and verified by three mathematics PBL experts. (2) Students' self-assessment of SDL behaviour, which had 10 items consisting of 10 kinds of behaviour under three sub-scales: The ownership of learning, self-management and self-monitoring and the extension of learning. These were rated on a 6-point Likert scale (1 = not at all to 6 = all the time). Before using this instrument, the researchers examined the reliability of students' self-assessment of SDL behaviour by testing it in a parallel PBL classroom (n = 36) (Cronbach's alpha co-efficient, r = 0.83). (3) The students' SDL observation form had 10 items rated on a 6-point Likert scale. Before using this instrument, the researchers also tested the students' SDL observation form in a parallel PBL classroom (n = 36) (Cronbach's alpha co-efficient, r = 0.87). (4) Students' reflection forms: Students reflected on their SDL behaviour during the PBL classroom. (5) The students' interview schedule, focusing on students' SDL behaviour, consisted of 10 main questions; for example, "How do you challenge your learning abilities?" and "How do you evaluate the learning outcome?". It took approximately 20 minutes per person to complete each interview. (6) Teacher's notes: The teacher recorded students' learning behaviour, problems in the classroom, and offered suggestions for those problems.

The participants took the students' self-assessment of SDL behaviour (Pre-test) (Cronbach's alpha co-efficient, r = 0.95) before starting the lessons in their free time. In the classroom, data were collected by one of the researchers who taught the six lesson plans. The second researcher acted as the supervisor/adviser (Corresponding author). During the intervening time, other sources of data were students' SDL observation forms, students' reflection forms and the teacher's notes (video recordings were used to provide backup data). At the end of the six lessons, the students' self-assessment of the SDL behaviour was used to verify the students' SDL (Post-test) (Cronbach's alpha co-efficient, r = 0.96). Moreover, the researchers selected six students with mixed mathematics performance (two high, two average, and two low) by sorting the scores of the mathematical test from the previous semester and the recommendations of the class teacher, to interview them in order to obtain in-depth information on the students' SDL. The researchers transcribed the interview data from a voice recorder, which was used during the interviews. The collected data were analysed using both quantitative and qualitative methods. The data from students' self-assessments of SDL behaviour and students' SDL observation forms were analysed by using descriptive statistics, including mean and standard derivation. The data from students' reflection forms, students' interview schedule, and the teacher's notes were analysed by descriptive analysis.

Results

The results were reported according to students' self-assessment of SDL behaviour, students' SDL observation form, students' reflection form, students' interview form, and teacher's notes. With regards to the students' self-assessment of SDL behaviour, the mean scores of all three aspects of SDL were increased from the pre-test to post-test after intervention (refer to Table 1). Out of the four forms of behaviour of the ownership of learning aspects, only three forms of behaviour had mean scores with an increased tendency. For gauging the *self-management and self-monitoring* aspect, the mean scores of all four forms of behaviour were improved. Focusing on the *extension of learning* aspect, the students' behaviour of applying prior knowledge remained increased while connecting knowledge to real-world behaviour remained stable.

Focusing on the analysis of the students' SDL observation form in the PBL classroom, it could be clearly seen that the mean scores of all aspects (i.e., ownership of learning, self-management and self-monitoring, and extension of learning) had an increased tendency in all six PBL lessons. In examining the *ownership of learning* aspect more closely, the mean score was the highest for the behaviour of identifying learning gaps followed by the behaviour of challenging learning abilities, setting goals and making a self-plan, respectively (refer to Figure 1). In the *self-management and self-monitoring* aspect, the behaviour of formulating questions had the highest mean score followed by the behaviour of reflecting the learning abilities, managing time and exploring to make decisions, respectively (refer to Figure 2). In the extension of learning aspect, the mean scores of connecting knowledge to real-world behaviour was higher than the mean scores of applying prior knowledge behaviour (refer to Figure 3).

Table 1
Means and standard deviations of the scores on students' self-assessment of SDL behaviour.

SDL Behavioural Indicators	Pre-test		Post-test	
	Mean	S.D.	Mean	S.D.
Ownership of Learning				
Identifying learning gaps	5.00	1.1	5.00	0.9
Setting goals	4.58	1.1	4.75	0.9
Self-plan	2.97	1.8	3.86	1.2
Challenging learning abilities	3.69	1.5	4.81	1.1
Self-management & Self-monitoring				
Formulating questions	4.14	2.0	4.83	1.5
Exploring to make decisions	3.92	1.6	4.08	1.2
Managing time	4.33	1.7	4.61	1.3
Reflecting learning abilities	4.06	1.4	4.67	0.8
Extension of learning				
Applying prior knowledge	4.08	1.5	4.69	1.0
Connecting knowledge to the real world	4.72	1.3	4.72	0.9
Overall	4.15	1.8	4.60	1.2

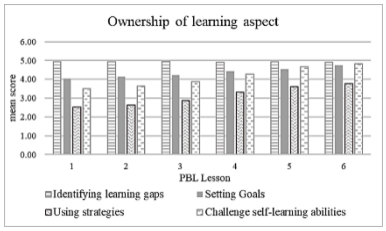

Figure 1. Mean score of students' self-assessment of SDL behaviour in the ownership of learning aspect.

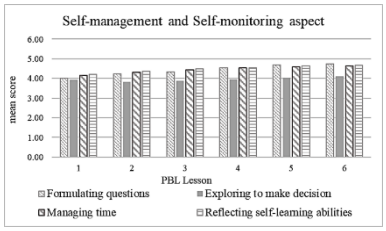

Figure 2. Mean score of students' self-assessment of SDL behaviour in the self-management and self-monitoring aspect.

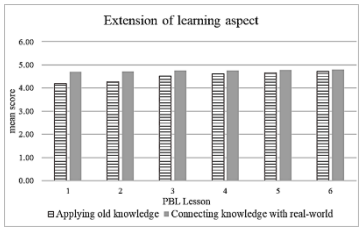

Figure 3. Mean score of students' self-assessment of SDL behaviour in the extension of learning aspect.

In addition, the data from the interviews of the six selected students with different mathematics achievement levels provided more details on the students' SDL in all aspects (ownership of learning, self-management and self-monitoring, and extension of learning), which are presented in Tables 2, 3 and 4, respectively.

Table 2
SDL in the ownership of learning aspect from the students' interview form.

Mathematics Achievement Level	Behavioural Indicators
High	The students specifically identified which parts of the assignment that they did not understand (identifying the learning gap). They set very clear goals and corresponded to their learning gaps (setting a goal). They explicitly knew what they needed to do to achieve their goals by themselves (self-plan). Moreover, they needed more challenging problems (challenging their learning abilities).
Average	The students broadly identified which parts of the assignment that they did not understand (identifying the learning gap). They set rather clear goals and corresponded to the topics learned in that lesson (setting a goal). They knew what they needed to do to achieve their goals, but at first, they needed suggestions from the teacher (self-plan). Moreover, they preferred additional exercises (challenging their learning abilities).
Low	The students vaguely identified which parts of the assignment that they did not understand (identifying the learning gap). They set unclear goals and corresponded very little to the topics learned in that lesson (setting a goal). They needed the teacher's direction to achieve their goals. (self-plan). In addition, they neither wanted additional exercises, nor any challenging problems (challenging their learning abilities).

Firstly, Table 2 showed the data focusing on the students' SDL in the *ownership of learning* aspect. The students with high mathematics achievement were able to articulate their learning gaps and learning goals better than the other student groups. In addition, the students with a high and average mathematics achievement preferred more exercises to supplement their learning abilities. In contrast, the students with low mathematics achievement were not able to clearly articulate their learning gaps and learning goals. Furthermore, they preferred to do only assignments in the classroom rather than do more exercises in their free time.

Secondly, Table 3 showed the data focusing on SDL in the *self-management and self-monitoring* aspect. The high and average achievers often asked questions. They recognised that the consequences of some decisions were more important than others and these decisions required more scrutiny. In addition, they automatically monitored their learning abilities. Moreover, the high achievers managed time better than the other groups. Furthermore, the low achievers had the ability to manage and monitor their learning, but this seemed to be inferior to the high and average achievers.

Finally, Table 4 showed the data focusing on the SDL in the extension of learning aspect. The students with a high and average mathematics achievement recognised that their prior knowledge was the best tool, which would help them to learn new things easier. Moreover, the students of all achievement levels could connect with what they had already learned with real-world situations. However, the students with an average and low achievement could connect less diversely and complicated than the students with a high achievement.

Table 3
SDL in the self-management and self-monitoring aspect from the students' interview form

Mathematics Achievement Level	Behavioural Indicators
High	The students often asked questions to find out what was behind the data (formulating a question). They did their assignment solely without seeking solutions from their teacher or peers (exploring making a decision). They could usually complete their assignment on time (managing time). They usually reflected on their work (reflecting learning abilities).
Average	The students always asked questions to check their understanding (formulating question). They were able to complete their assignment by discussing solutions with their peers and the teacher (exploring making a decision). They often completed their assignment on time (managing time). They often reflected on their work. If there were any mistakes, they would adjust or correct their work by discussion with their peers (reflecting learning abilities).
Low	The students asked questions to get the solutions (formulating questions). They were barely able to complete their assignment by exploring to make discussion. Instead, they needed help from their peers (exploring making a decision). They could occasionally complete on time (managing time). They rarely reflected on their work. If there were any, they would adjust or correct their work according to the teacher's suggestions (reflecting learning abilities).

Table 4
SDL in the extension of learning aspect from the students' interview form

Mathematics Achievement Level	Behavioural Indicators
High	The students usually brought their prior knowledge to learn new things (applying prior knowledge). They also usually connected with what had already been learned with the real world or other subject areas (connecting to the real world).
Average	The students often brought their prior knowledge to learn new things (applying prior knowledge). They often connected with what had already been learned with the real world (connecting to the real world).
Low	The students occasionally brought their prior knowledge to learn new things (applying prior knowledge). They seldom connected with what had already been learned with the real world (connecting to the real world).

Furthermore, the data from students' reflection forms and teacher's notes showed the students' SDL in the PBL classroom as follows. In the *ownership of learning* aspect, most of the students showed improvement in their ability to identify learning gaps, goal setting and making a self-plan in the second step of the PBL process, self-directed learning. In this step, the students assessed their learning abilities from the individual worksheets (identifying learning gaps). For example, some students stated: "I cannot write the linear inequalities graph system." Then, the students created their learning goal and planned what they had to do to achieve their goals (setting a goal and self-plan). For example, some students stated: "I wish I could write the linear inequalities graph system" and "I can do that by seeking the

solutions using prior knowledge." The students showed improvement in challenging learning abilities in the fifth step of the PBL process, exercises. They tried to do additional exercises or tried to solve the problems using productive methods. For example, some students stated: "I did more mathematics exercises and tried to solve more complex problems than I had ever learned" and "I tried to solve the problems in an effective way."

In the *self-management and self-monitoring* aspect, most students showed improvement in formulating questions, exploring to making a decision, managing time, and reflecting on the learning abilities in the second, third, fourth and fifth steps of the PBL process, self-directed learning, group meeting, presentation and discussion, and exercises. For example, in the second step of the PBL process, the students formulated and generated inquiries relevant to the topic in that lesson (formulating questions), in the third step of the PBL process, they explored a range of possible answers with their group members and discussed to make a group decision (making a decision), in the fourth and fifth steps of the PBL process, they tried to understand mistakes in their work. (reflecting on learning abilities). In the second, third, fourth, and fifth steps of the PBL process, they tried to finish the assignment on time (managing time).

In the *extension of learning* aspect, many students showed improvement in applying prior knowledge and connecting their knowledge to real-world situations in the second, third, fourth, and fifth steps of the PBL process: self-directed learning, group meeting, presentation and discussion, and exercises. For example, in the second and third steps of the PBL process, the students applied what they had learned to new contexts, and in the fourth and fifth steps of the PBL process, they tried to find out more connections to the real-world problems by themselves (connecting their knowledge with the real world).

Discussion and Conclusion

There were two key findings from this research. First, the students' mean scores in all three aspects of SDL (i.e., ownership of learning, self-management and self-monitoring, and extension of learning) had increased in a mathematics PBL classroom. These findings supported the existing literature that SDL was fostered by PBL (Evensen, Hmelo, & Hmelo-Silver, 2000; Loyens, Magda, & Rikers, 2008).

Second, students' SDL in the *ownership of learning* aspect was observable in the second (self-directed learning) and fifth (exercise) steps of the PBL process. These findings corresponded with Loyens, Magda, and Rikers (2008). To gain a better understanding of the problem, students had to independently decide how detailed and extensive their self-study should be. Students' SDL in the *self-management and self-monitoring* and *extension of learning* aspects were observable in the second (self-directed learning), third (group meeting), fourth (presentation and discussion) and fifth (exercise) steps of the PBL process. These findings suggest that PBL activities require students to discuss and plan approaches to resolve their gaps in knowledge while reflecting on their progress. This makes them aware of their prior knowledge and motivates them to take charge of their learning. In sum, the ownership of learning, self-management and self-monitoring, and extension of learning, hence, clearly play a role in the PBL learning process. Especially, this finding provided more insight into how and what students' SDL aspects are immersed in each step of the PBL process.

However, the data collection of this study was limited by the time constraint to investigate the students' SDL. Future research should employ a longitudinal design, which could examine SDL changes over time. The findings of this study could benefit mathematics teachers to focus on how to foster different aspects of students' SDL in the PBL process in appropriate ways.

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