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A Study on Cognitive Load and Related Factors at e-PBL

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The focus of this research is on identifying the problems that learners experience during online problem-based learning (e-PBL) from a cognitive perspective. The study is concentrated on learners' cognitive load level at each stage of e-PBL. The research questions are specifically as follows: What is the level of cognitive load at each stage of e-PBL and what is the relationship between cognitive load and group performance? What cognitive difficulties are experienced by learners in e-PBL and what causes cognitive difficulties? In this study, we found that cognitive load was the highest in stage 1 and there was negative relationship between cognitive load at stage 1 and group performance. In addition, learners experienced difficulties during e-PBL such as the complexity of task, the difficulty in collaboration, and the lack of appropriate references. For further study, we will investigate some strategies regarding adjusting learners' cognitive load in the early stages of e-PBL.

Keywords : PBL, e-PBL, Cognitive load, Cognitive difficulties

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Introduction

Problem Based Learning (PBL) is a learner centered method that enhances learning performance with authentic and ill-structured problems (Barrows, 1985; Thomas, 1997). Traditionally, PBL advocates enhancing knowledge acquisition and deepening students' understanding by means of social knowledge construction (Zumbach, Hillers, & Reimann, 2004). Recently, the PBL using online learning environment has been increased in most educational sectors because online learning environment can provide more realistic tasks using multimedia, various learning resources, and information. In addition, these online based tasks allow learners to engage in rich interaction with other learners, instructors, experts, and various learning resources. Furthermore, online environment allows learners to store all records of discussion and questions digitally. In this activity, instructors are able to monitor and to support learners' learning processes appropriately in e-PBL.

However, novice learners' working memory can be overloaded from the e-PBL environment because they have to search for a problem solution based on weak prior knowledge, which makes them spend more time and energy in online verbalization. Moreover, it is not easy for novice learners to solve ill-structured problems online because they experience some difficulties during e-PBL such as the low level of self-directed learners' cognitive presence and flow[1] problems. It may result in high cognitive load, and thus, we need to optimize strategies for cognitive load reduction and learning motivation in e-PBL environment.

In this context, recent discussions on instructional support strategies regarding cognitive efficiency have been actively conducted, especially in learner-centered teaching and learning circumstances such as e-PBL. Kirschner and his associates have mentioned that appropriate support needs to be planned and provided by teachers in learner-centered learning circumstances (Kirschner, Sweller, & Clark,

1 The notion is defined as a framework for facilitating learners' optimal experience. When learners are fully engaged in learning, they experience flow that maximizes learners' positive outcomes. In this study, flow is a state or situation where learners are engaged in optimal experiences during a

2006) and Schmidt, Loyens, Van Gog, and Pass (2007) have proposed methods to support appropriate instructions for optimizing learners' cognitive load in PBL. However, providing proper instructions for supporting learners during e-PBL must be preceded by empirical analysis of learners' cognitive status and the cognitive difficulties they experience. Therefore, the purpose of the study is to identify the problems that learners experience during online problem based learning (e-PBL) from a cognitive perspective and to optimize cognitive load to enhance learning performance in e-PBL environment.

The research questions are specifically as follows:

1. What is the level of cognitive load[2] at each stage of e-PBL and what is the relationship between cognitive load[3] and performance?

2. What cognitive difficulties[4] are experienced by learners in e-PBL and what causes cognitive difficulties?

Literature Review

The effectiveness of PBL

Currently problem-solving is considered one of the important skills that learners should have (Jonassen, 2002) and PBL can be a representative learning method to

learning process.

2 The notion is defined as the amount of cognitive load that learners experience due to the limited-capacity information processing system when they perform special tasks.

3 The notion is defined as the load related to the executive control of working memory. In order to acquire knowledge, the information should be processed in working memory, and cognitive load means the relationship between the amount of information that can be handled in working memory and the information that should be handled in working memory. Cognitive load is classified into intrinsic cognitive load, extraneous cognitive load, and germane cognitive load. Extraneous cognitive load is the load that can be improved by instructional strategies such as learning materials and the way of presenting learning resources. Germane cognitive load is the mental effort that is directly related to the learning in the range of working memory.

4 The notion is defined as the difficulties that learners experience in the process of PBL. In this study, cognitive difficulties were classified into intrinsic cognitive difficulties, extraneous cognitive difficulties, and germane cognitive difficulties based on learners' responses.

enhance problem-solving skills.

PBL is a learner-centered pedagogy in which learners acquire knowledge through the process of problem solving using realistic, complex, and ill-structured tasks. Krajcik and his associates have mentioned that PBL is a methodology characterized by solving the problem through asking a problem, discussing, predicting, planning, experimenting, collecting information, analyzing data, and drawing a conclusion (Krajcik, Blumenfeld, Marx, & Soloway, 1994). The role of the instructor who provides scaffolding to help learners is to facilitate learning. The instructor promotes class discussion and enhances appropriate resources to promote learning performance.

PBL is a learner-centered environment and it promotes learner's critical thinking and collaborative learning by the learning process of problem-solving with authentic tasks. Thus, PBL is an instruction model in which learner-centered learning takes place with focus on problems, cases, and tasks. Therefore, PBL makes learner-centered learning possible by the process of presenting authentic problems and learner's problem-solving.

PBL certainly seems to be a more challenging, motivating, and enjoyable way to learn compared with other traditional teaching methods. Through the process of problem-solving, learners can enhance collaborative and self-directed learning. In addition, working in groups makes learners develop collaborative problem-solving skills and acquire problem-solving and meta-cognitive skills as well as special domain knowledge.

The research on the effectiveness of PBL has been conducted mainly in the field of medicine. Berkson's study (1993) does not show any evidence that a PBL approach is better than the traditional approach. However, the results indicate that learners like PBL and it helps learners understand their problems and solve them during the learning process.

Strobel and Barneveld's study (2009) indicates that PBL is an effective strategy for achieving learning of ill-structured and complex problems and is also more effective than the traditional instruction to promote long-term retention of

knowledge.

To promote the effectiveness of PBL, it is necessary to provide a learner-centered learning environment and authentic problems. Also, instructors provide learners with appropriate resources as facilitators. In PBL, instructors need to support switching from their traditional roles in conventional teaching methods to new roles as facilitators and tutors who help learners understand tasks and utilize various learning resources (Hawkins, 1995). To increase the effectiveness of PBL, instructors should know when learners feel difficulties and what they need to be supported in PBL.

The difficulties in e-PBL

E-PBL is a leaner-centered learning environment in which learners solve problems themselves using various resources provided by web. E-PBL leads to self-directed learning and collaborative learning. In addition, e-PBL is to implement PBL in a web-based learning environment. In other words, e-PBL is a teaching method combining web-based learning and PBL and it enables learners to implement the main processes of PBL based on web because there are some spatial and temporal limits on PBL in face-to-face learning environment (Malopinsky, Kirkley, Stein & Duffy, 2000).

E-PBL was proposed to conduct PBL more effectively for utilizing various resources and overcoming spatial and temporal limits (Hoffman & Ritchie, 1997). Hoffman and Richie (1997) recommended the use of technology in order to deliver problem scenarios to help learners with the comprehension of the task. Lui (2005) has mentioned that "Cognitive tools can enhance PBL delivery and provide necessary support to learners." (p.3) Thus, e-PBL has been suggested to overcome the restrictions on the traditional PBL learning environment and the e-PBL environment is evolving with the development of technology. In the e-PBL environment, all records of discussion and questions are saved online and instructors can monitor the process of learners' problem solving frequently;

therefore, effective PBL can be possible if used online.

The most important nature of e-PBL includes the quality of problems and ill-structured problems based on real-life situations should be used. If the task is not authentic or situated, it is not possible to get knowledge effectively in e-PBL. During e-PBL, learners experience collaborative learning based on the web going through the process of solving the real problems. Therefore, the teamwork is not balanced, and it is expected that learners will show low quality learning performance. Besides the quality of problems, ill-structured problems, and collaboration, there are some other difficulties. First, there are low participation and motivation problems during the learning process. Learners don't meet an instructor and other learners face to face because they acquire knowledge in cyber-space. Second, there is a low level of learners' self-directed cognitive presence and flow problems.

In addition, it may cause negative learning performances. In a conventional environment, instructors can support learners in improving cognitive presence or focusing on learning but it is difficult to help learners enhance cognitive presence and flow online because physical contact is restricted in e-PBL. Therefore, if cognitive presence cannot be strengthened and learners cannot focus on learning process during e-PBL, they probably quit the learning or represent negative results like low learning performances or low satisfaction with learning even though they accomplish the learning.

Cognitive load theory

According to Sweller, van Merriënboer, and Paas (1998), the cognitive load theory assumes a limited working memory. It can store about seven elements and information was almost lost after twenty minutes.

To retain information even after twenty minutes, it is refreshed by practice or rehearsal. Because the amount of information that can be processed in working memory at a time is limited, cognitive load can happen (Chandler & Sweller, 1991; Kalyuga, Chandler, & Sweller, 1998). The level of cognitive load depends on the

number of elements and the complexity among elements, and cognitive load happens if the elements that must be processed exceed the processing capacity of the working memory.

Cognitive load can be classified into three parts depending on factors that cause cognitive load; Intrinsic cognitive load, Extraneous cognitive load, and germane cognitive load.

Intrinsic load is related to the complexity of the learning task itself, and the level of intrinsic load depends on the number of elements that are included in the learning task and the relationships among elements in the interaction. Therefore, the level of complexity of a learning task and the level of intrinsic load become high if the number of elements that should be processed and the interaction among elements are high.

Contrary to intrinsic load that occurs depending on the difficulty of the learning material or the learning task itself, extraneous load occurs due to ineffective learning environments, types of presenting learning tasks, inappropriate presenting time of learning contents, and irrelevant learning strategies.

Extraneous load can be a major factor that causes cognitive overload because it is cognitive load that interferes with learning causing unnecessary mental activities that are not directly related to learning. Therefore, extraneous load should be minimized by removing mental activities that is not related to learning in an appropriate instructional design (Mayer & Moreno, 2003).

Contrary to intrinsic load and extraneous load, germane load is positive load that has influence on the promotion leaning performance and a mental effort that directly affects learning. Germane load occurs in a learning process, which forms schemata in learners' cognitive structure through cognitive activities such as elaboration, contraction, and assumption (Moreno & Park, 2010). To lead learning successfully, the space for germane load should be maximized because it can help learners' cognitive processes.

Method

The descriptive methodology used in this study involves an open-ended survey that allows describing learners' difficulties that they experience during the learning process of e-PBL.

We have tried to collect diverse ranges of responses to find learners' cognitive load at each stage of e-PBL during their activities in a web-based PBL learning environment.

Participants

The subjects were sixty-three undergraduate students in a college of education. They were female students who took the course titled 'Methodology and Technology of Education.' This is a required course for pre-service teachers' training. Most students were in junior year at the college and had prior knowledge related to learning theories such as behaviorism, cognitivism, and constructivism and instructional design models.

Procedures

E-PBL was conducted over a four week period. We designed e-PBL environment based on main activities of a general model of PBL. Exemplary features of the e-PBL environment are presented in Figure 1, and the menus and their functions used in the e-PBL environment are explained in Table 1.

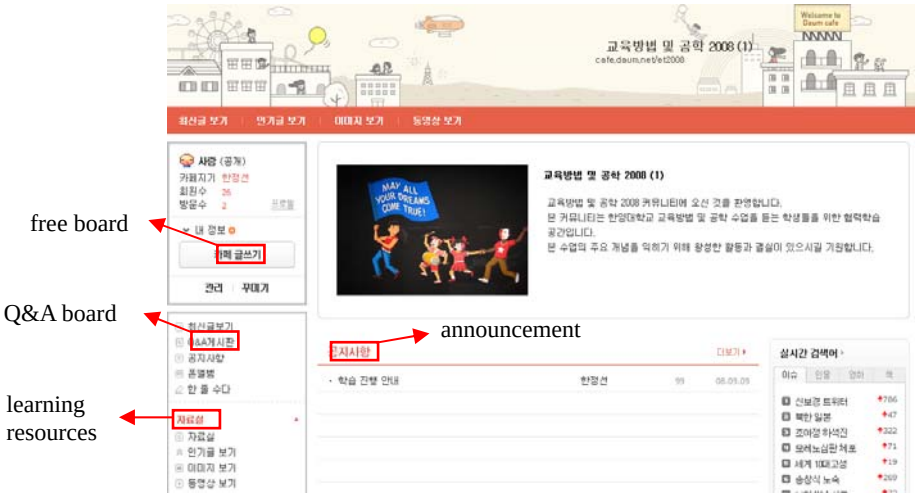

Figure 1. Intro screen for the e-PBL online environment to give problems, announcement, and learners' writing on the board

Table 1. Menus and their functions used in the e-PBL environment

Menu	Description of functions
Announcement	To guide PBL process
Free board	To present learners' writings
Q&A board	To ask an instructor questions about given tasks and to offer learners answers to help e-PBL
Learning Resources	To provide supportive learning materials to help learners' activities

The general process of PBL can be summarized as follows (Zumbach, Hillers & Reimann, 2004):

In this study, all the students participated in a four-stage e-PBL course in an online environment. In the first stage, the problem for the collaborative task was presented first. It was about solving the given educational problematic situation using ASSURE model that was one of the instructional design models. The learners had an opportunity to identify the problem and learning issues. Then they set a goal, made a plan, and distributed roles. For these activities, an instructor provided supporting materials such as guidance for structuring the PBL process.

Table 2. Problem-Based Learning Process

Stages		Activities for each stage	
1st	1-1	Give the problem	C
	1-2	Define the problem and learning objectives	C
	1-3	Organize each individual's tasks and problem solving stages	C
2nd	2-1	Self-regulated learning (gather problem-relevant information to solve the problem)	I
	2-2	Collaborative learning (discuss collected data and individual solutions in a follow-up meeting)	C
3rd	3-1	Provide feedback	C
	3-2	Have a final discussion to solve the problem	C
4th	4-1	Reflect on their own and others' contributions, the process, other possible solutions, and what they learned	I· C

I: Individual learning, C: Collaborative learning

In the second stage, the learners shared and applied knowledge by gathering problem- relevant information and discussing collected data. For these activities, the instructor provided supporting materials based on the group's collaboration level. In the third stage, the instructor provided each group with feedbacks and learners had a final discussion. In the last stage, the learners submitted, evaluated, and reflected the solutions of the problem. For obtaining the participants' reception of e-PBL, data were collected through reflection papers and questionnaires at each stage. Questionnaires consisted of a closed question related to cognitive load and an open question with three main headings related to the difficulties of e-PBL, online community, and the instructor's support. Those questionnaires regarding the factors that made you feel cognitive difficulties in the process of learning were for investigating the factors that caused cognitive load. Based on the answers of the questionnaires, factors that caused cognitive load were found and they were classified into intrinsic factors, extraneous factors, and germane factors. In addition, based on the reflection paper submitted at each stage, we have investigated the

change of cognitive load at each stage, the type of difficulties in the learning process, and the correlation among the collected data. Regarding the measurement of cognitive load, self-report measurement was used which was measured by learners' recognition and report about the state of their own cognitive processes by themselves. The question of self-reported measurement was made on the basis of the 9-point mental effort rating scale developed by Paas (1992) and the incidence of learners' cognitive load was measured individually after finishing activities at each stage. Concretely, the 5-point Likert scale was used with '1' (very less) and '5' (very much) in self-report measurement and the question is "Did you make a lot of cognitive load in the learning process?"

We used SPSS 19.0 for data analysis, ANOVA for the change of cognitive load frequency to analyze significant difference among stages, and Correlation Analysis among related influencing factors, cognitive load, group coherence[5], and group performance[6]. We extracted participants' problems through collected data in this study. All data were classified, analyzed, and interpreted by thick description and encoding.

Results

What is the level of cognitive load at each stage of e-PBL and what is the relationship between cognitive load and group performance?

The results of the analysis of the level of cognitive load at each stage of e-PBL were statistically significant. The level of cognitive load was significantly higher at

5 The notion is defined as the state or situation in which all learners' ideas or opinions coordinate together well so that they form a united whole. In this study, group coherence means the coordination of group discussion and the collaborative work.

6 The notion is defined as the product made by learners having a diversity of skills and ideas within a group. In this study, group performance was measured by the learners and the instructors based on the collaborative final product that group members made together through discussing and coordinating different opinions, and collaborating work.

the first stage (M=1.61, SD=1.21) than at the second (M=4.15, SD=1.08), the third (M=3.80, SD=1.33), and the fourth stages (M=3.91, SD=1.61). As a remarkable result, cognitive load was the highest at stage 1 and it reduced slightly as the work progressed.

Also, it indicated that learners had difficulties in understanding the task, setting a goal, and distributing roles in the early stage and it caused higher cognitive load at this stage than at other stages. Table 3 showed the level of cognitive load at each stage of e-PBL.

Table 3. Descriptive statistics of the level of cognitive load at each stage

	M	SD
Stage 1	4.61	1.21
Stage 2	4.15	1.08
Stage 3	3.80	1.33
Stage 4	3.92	1.61

From the results of T-tests of the levels of cognitive load, there were statistically significant differences between stage 1 and stage 3, and between stage 1 and stage 4. The post comparative analysis of the level of cognitive load at each stage is shown in Table 4. Based on this result, it can be concluded that instructional support should be required much more in early stages in e-PBL in order to manage learners' cognitive load and enhance their performance.

In addition, the relationship between cognitive load at each stage and group performance was analyzed to investigate how the level of cognitive load at each stage influences learning performance.

The results of the analysis showed that there was a positive relationship between cognitive load and performance at stage 1 and it was statistically significant. However, there existed no relationship between the other stages. Correlation coefficients between cognitive load at each stage and performance are shown in Table 5.

Table 4. Post comparative analysis of the level of cognitive load at each stage

Stage		Mean Difference	Std. Error	Sig.
Stage 1	Stage 2	.46	.24	.21
	Stage 3	.81**	.24	.00
	Stage 4	.69*	.24	.02
Stage 2	Stage 1	-.46	.24	.21
	Stage 3	.35	.24	.44
	Stage 4	.23	.24	.76
Stage 3	Stage 1	-.81*	.24	.00
	Stage 2	-.35	.24	.44
	Stage 4	-.12	.24	.96
Stage 4	Stage 1	-.69*	.24	.02
	Stage 2	-.23	.24	.76
	Stage 3	.12	.24	.96

*p<.05, **p<.01

Table 5. Correlation Coefficients between cognitive load at each stage and performance

	Stage 1	Stage 2	Stage 3	Stage 4	Group performance
Stage 1	1	.57**	.06	.12	.35*
Stage 2	.57**	1	.50**	.51**	.06
Stage 3	.06	.50**	1	.86**	-.28
Stage 4	.12	.51**	.86**	1	-.22
Group performance	.35*	.06	-.28	-.22	1

*p<.05, **p<.01

What cognitive difficulties were experienced by learners in e-PBL and what causes cognitive load?

The results of the study showed the cognitive difficulties that the learners

experienced during e-PBL based on their responses. In this study, these cognitive difficulties were classified into three types of cognitive load, intrinsic load, extrinsic load, and germane load.

The first cognitive difficulty is related to intrinsic load and it is about the lack of prior knowledge, the difficulty of the task, and the complexity of the task itself. The second cognitive difficulty is related to extraneous load and it is about conflicts arising from differences in opinion, uncertainty, and limitations on online communication. The third cognitive difficulty is related to germane load and it is about cognitive efforts to solve the problems, difficulties in the process of finding helpful learning resources for troubleshooting, and difficulties during the reflection process.

Based on the learners' answers, we found what caused the learner's cognitive difficulties. The learners' responses indicated that the lack of prior knowledge and the difficult task made them spend much time understanding the task and the PBL process. The results also showed that the learners were very exhausted and had difficulty in coordinating group discussion. Moreover, the learners had difficulty in identifying the goal of PBL task because the task of PBL dealt with an ill-structured situated problem and the process of PBL was complicated and unfamiliar for them. Due to the complexity of the task, the learners had to spend a lot of time completing the assignment at each stage.

Therefore, these difficulties that the learners experienced during the early stage of PBL caused intrinsic cognitive load. In the meantime, the difficulties in collaborative work including distributing roles, creating plans, sharing different opinions, the difficulty in coordination of different opinions, and lack of guidance were challenging for most learners and it caused extraneous load. Regarding germane load, a lot of learning resources hindered the learners' effective learning because it was very hard for the learners to choose appropriate resources for the task. Therefore, learners should spend much effort and time choosing and collecting proper learning resources. In addition, lack of self-efficacy made the learners experience hardship when they performed the PBL task. Those difficulties caused the learners' germane load. The learners'

cognitive difficulties during e-PBL and more specific example responses are shown in Table 6.

Table 6. Category of cognitive difficulties during e-PBL

Category of cognitive difficulties		Learners' selected responses
Intrinsic Load	Lack of prior knowledge	"The lack of prior knowledge made it hard to understand the concept of PBL and the paradigm of teaching 2.0; I didn't know what I should do."
	Difficulty of task	"The problematic situation was too difficult to understand." "We were at a loss as to what to do during the first and second stages of the e-PBL course." "Understanding and processing each stage of e-PBL was vague."
	Complexity of task	"We tried to solve problems and then failed several times… It made me exhausted." "There was a lot of work to do. I felt a heavy burden regarding the PBL tasks." "The problem-solving process was very complicated and I should spend a lot of time."
Extraneous Load	Difficulty of collaboration	"All members were too busy to meet together to discuss the tasks." "It was difficult to communicate to share the members' opinions." "A conflict among opinions arose over problem-solving among the team members."
	Uncertainty	"My group and I were nervous about the ambiguity of the problem-solving processes." "The lack of guidance for the task made us worried."
	Limitations on online communication	"Online discussions were harder than face-to-face." "We often misunderstood others' opinions during the online discussion." "It's very hard to type our own opinions online instead of speaking face-to-face."
Germane Load	Lack of self-efficacy	"I felt that I lacked the capability of taking on the task." "I had no creative idea for problem-solving."
	Lack of references	"We didn't know how to find the correct references because there were a lot of references." "It was uncertain whether my references were suitable for our project or not."
	Difficulty of reflection	"We were not sure how to write reflective journals."

Conclusion and Discussion

Cognitive load and its relationship with group performance

In this study, in order to effectively support e-PBL, we have examined the level of cognitive load at each stage of PBL, the relationship between cognitive load and group performance, and cognitive difficulties experienced by the learners during the process of PBL. In addition, we have examined how cognitive load and factors that cause cognitive load affect group performance and group coherence. The results have shown that the cognitive load was significantly higher at the first stage in e-PBL than at the other stages and there was a significantly positive correlation between the cognitive load and group performance.

Meanwhile, the difficulties that the learners experienced in the PBL learning process could be analyzed separately by intrinsic factors, extraneous factors, and germane factors. First, the factors that caused intrinsic load were related to the lack of prior knowledge, the difficulty of the task, and the complexity of the task. Second, the factors that caused extraneous load were related to the difficulty of collaboration, uncertainty, and the limitations on online communication. Last, the factors that caused germane load were related to the lack of self-efficacy, the lack of references, and the difficulty of reflection.

The finding that the cognitive load at the first stage in e-PBL was a significantly positive correlation between the cognitive load and group performance runs counter to previous research (Kalyuga et al., 2003; Sweller et al., 1998) as well as our expectation that high level of cognitive load would negatively affect performance. That is, the early learning of cognitive activities such as understanding the task, setting a goal, and sharing roles play an important role in leading to successful learning. Due to those factors, the level of cognitive load is high in the early learning stage but factors would promote germane load to enhance learners' activities. This finding suggests that instructors need to encourage learners to be

immersed in the early learning stage and instructors should support them by providing guidelines and instructional resources.

In addition, the findings regarding the difficulties that learners experience in the PBL learning process suggests that instructors should focus on supporting instructional strategies for the early stage in PBL and helping learners' collaborative learning and active communication. They should provide learners with instructional strategies or supportive scaffoldings for promoting active communication and coordinating different opinions. In addition, instructors should consider instructional strategies for promoting germane load when they design an instructional model.

Cognitive difficulties in e-PBL and the causes of cognitive difficulties

As Hoffman and Ritchie's study (2000), this study shows that e-PBL can make learners utilize various resources and overcome spatial and temporal limits; however, learners experience some difficulties such as low motivation and limitations on online communication due to the e-PBL environment. Therefore, we should consider some strategies that can support learners in overcoming the online learning environment and promoting their motivation and involvement.

As a result of correlation analysis regarding how the factors that affect cognitive load are related with cognitive load, group performance, and group coherence, there are significantly negative correlation between the cognitive load and satisfaction in communication, flow, and all group performances. Learners' participation in collaborative activities with satisfaction at the learning process and learners' involvement in learning could contribute toward reduced cognitive load. As a result, a positive impact on learning performance can be found. The factors significantly associated with group performance among learning performance are prior knowledge and flow.

The results show that only prior knowledge is negatively correlated and higher

levels of prior knowledge result in lower scores in group performance. In other words, a high level of prior knowledge does not always lead to successful learning performance in PBL learning situations. Based on this study, future research could investigate effective instructional strategies for reducing cognitive load as well as managing learners' cognitive load in the early learning stage of an e-PBL environment.

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