The Example-Problem-Based Learning Model: Applying Cognitive Load Theory

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Abstract

Cognitive Load Theory (CLT) suggests that learning best takes place in a situation that is equivalent to individual cognitive design. Thus, this article proposes a learning model called Example-Problem-Based Learning (EPBL) which is a combination of two learning strategies: worked-examples and problem-solving. This teaching method guides students to go through several cognitive developments. At the early stages of knowledge acquisition, novice students benefit more from worked-examples, which is a model of problem-solving. After they have gained sufficient knowledge, worked-examples may no longer be appropriate because the positive effects of worked-examples will be lost. Therefore, learning through problem-solving should be applied since students have already equipped themselves with profound domain knowledge. Established in an experiment conducted, the EPBL teaching method enhances students’ knowledge acquisitions, learning transfer, and mental effort during learning, as well as increasing their learning efficiency.

Keywords: Example-problem-based learning; cognitive load theory; worked-example; problem-solving

1. Introduction

According to the Cognitive Load Theory (CLT) (Sweller, 1988), students can only process some information in one-on-one time in working-memory (Miller, 1956; Moreno, 2006). Due to this limitation, information processing beyond the working-memory limits will result in memory saturation; which means that the working-memory can not provide sufficient memory space or cognitive resources to perform cognitive activities such as learning.
terminologies. CLT also states that the study of complex cognitive skills, such as problem-solving, is often constrained by limited information processing capacity. If the learning activities requiring cognitive capacity exceeds the limits, learning will be hindered (De Jong, 2010). Thus, strategies that optimize the allocation of cognitive resources are important to determine the effectiveness of these learning strategies.

Information enters the working-memory either through sensory memory or retrieved from long-term memory (Sweller, 2004). In the working-memory, information is compiled in a way that allows students to store information in their long-term memory, available to be recovered in the future. Therefore, understanding the structure of working-memory’s capacity limitations and long-term memory is important to develop an effective approach to learning. The approach requires excessive working-memory in learning activities which may produce results that are not effective to increase the development schemes (Kirschner et al., 2006). The development of scheme is very important in learning because it is a structure that consists of complex contents in the long-term memory. This structure allows the individual to accept, think and solve the problem. Thus, this is a structure that contributes to individuals’ knowledge base (Sweller, 1988). Learning requires structural changes in the long-term memory and the failures encountered during the learning process will form that changes. The students will understand and familiarize themselves with the learning materials and the properties of lead-related cognition, causing the performance changes to occur.

Cognitivity imposed on students can be judged either excessive or not based on the interaction of elements related to the skill or task being learned. For example, finding the solution for problems in the electrical circuit analysis domain is a complex task because it requires a lot of interaction between the elements, causing a high cognitive load. The electrical circuit analysis domain requires multiple processing elements to be connected and are always active in the working-memory during learning activities. Specific knowledge of the functions of the component (e.g., a voltage source and a resistor) and general knowledge of the relationship between voltage, current and resistance (Ohm's law) as well as the conservation of energy and charge (Kirchhoff’s law) are required to determine how the circuit should work. In addition, knowledge of how to measure voltage, current, and resistance at different points in the circuit is also required.

According to Sweller and Chandler (1994), to generate a solution to a problem, each analysis step is an element that must interact with other elements in order to solve the problem. Thus, the analysis steps cannot be studied in isolation, but must be learned simultaneously. As the interaction of elements needed to solve the problem is high, the level of cognitive load will also be high and cause some learning difficulties among students (Sweller & Chandler, 1994). To ensure that the process of schema acquisition can occur, CLT suggests that the learning process should reduce the load on working-memory and help in changing long-term memory.

1.1. Types of Cognitive Load

CLT distinguishes three types of cognitive load; intrinsic, extraneous and germane.

Intrinsic load – intrinsic load is the cognitive load caused by the complex nature or difficulty of learning content in a domain. According to De Jong (2010), learning materials which contain many of the elements of interaction is more difficult than learning materials with less elements of interaction. Thus, complex tasks such as electrical circuit analysis contain some element of interaction and require a substantial cognitive capacity to process information. Intrinsic load cannot be changed with the approach or treatment of learning, but can be changes with the level of expertise that a student can affect. Expert students with a high level of initial knowledge are able to combine the elements of complex information with the existing schemes and manipulate the schema development as one of the elements in the working-memory. Thus, expert students will have a low intrinsic load despite performing tasks or solving complex problems.

Extraneous load - extraneous load is an ineffective load for learning (Van Gog, Paas, & Van Merriënboer, 2004). This load is caused by weak learning approaches (Sweller, 1994) that do not directly contribute to learning (schema construction). De Jong (2010) listed three sources of extraneous cognitive load. The first source is the split-attention effect. This effect refers to the elements of the domain to be processed simultaneously, but must be obtained from a separate source. Students need to store elements in their memory while trying to find other elements to be associated with the first element. The second source is identified when students need to solve problems where they do not have a schema in the domain. In this situation, students may use the means-ends analysis strategy to find a solution (Sweller, Van Merriënboer, & Paas, 1998). Use of the means-ends analysis strategy resulted in a greater demand for working-memory resources to solve the problems, and at the same time reduce the cognitive resources available for
learning (for example, construction and schema automation). Lack of cognitive resources will cause cognitive activities to not be carried out in the working-memory, resulting in impeded learning.

**Germane load** - germane load is the load of effective teaching to learning (Paas & Van Merriënboer, 1994) and it refers to the load imposed by the learning process (De Jong, 2010). For example, providing students with worked-examples in the learning process is expected to increase germane cognitive load, because it will indirectly help the students to develop problem-solving schema (Van Gog, Paas, & Van Merriënboer, 2006). Scheme construction is achieved by understanding the key steps needed to solve a particular problem. Focused learning activities like these encourage students to be better able to develop appropriate problem-solving schemes for the transfer and storage of information. The three different cognitive loads are illustrated graphically in Fig. 1.

Moreover, all three loads must be within the limits of mental resources and the amount of cognitive load on working-memory, as shown in Fig. 2.

| Situation 1 | When the intrinsic cognitive load is low (learning content is easy) and mental resources are inadequate, the student can still make the learning process extraneous, thus the cognitive load is high. |
| Situation 2 | When the intrinsic cognitive load is high (learning content is difficult) and the extraneous cognitive load is very high, the amount of cognitive load will overcome the mental resources and the learning process will probably fail. |
| Situation 3 | When the extraneous cognitive load in Situation 2 is reduced by increasing the germane cognitive load, it helps in the learning process. |

In short, for a given task, the nature (intrinsic) of the assignment cannot be changed. However, the germane and extraneous cognitive loads can be changed and it is inversely proportional to each other. The more extraneous a load, the less germane it will be, and vice versa. Therefore, the teaching approaches used must reduce the amount of extraneous load and promote germane load or a formation scheme to achieve effective learning.

2. **Example-Problem-Based Learning**

The Example-Problem-Based Learning (EPBL) is a combination of worked-examples and problem-solving. Worked-examples is a model of problem solving that consists of three components: a statement of the problem, solution steps and the final solution to the problem (Wittwer & Renkl, 2010). EPBL guides learners to go through several stages of cognitive development: starting from a novice stage and advancing to an expert stage. At the early
stages of knowledge acquisition, novice students should benefit more from worked-examples. After they have gained sufficient knowledge, worked-examples may no longer be appropriate because the positive effects of worked-examples will be lost. Increase in expertise among students will result in lower intrinsic loads imposed on the problems to be solved; this leaves more space for the processing of cognitive information related to the problem. Expert students may be familiar with the information given in worked examples and are not motivated to have a better understanding of the information; this results in a passive learning process (Atkinson & Renkl, 2007). Therefore, learning through problem-solving should be applied since students have already been equipped with profound domain knowledge.

An experiment with pre-test and post-test designs was conducted to investigate the effect of EPBL in Circuit Theory teaching and learning on 38 first year vocational diploma-level Malaysian students’ knowledge acquisition, learning transfer and mental effort as well as efficiency. The study included a control group to compare the validity of the findings. EPBL teaching methods have been implemented to the treatment group, whereas the existing teaching methods based Teacher Centered Learning (TCL) is maintained for the control group. Based on this study, the results showed that students taught using EPBL have better knowledge acquisitions than students taught using TCL (Jalani & Lai, 2015). Students taught using EPBL also benefitted in terms of learning transfer than students taught using TCL (Jalani & Lai, 2014a). In terms of cognitive load, the results showed that students taught using the EPBL method do not require high mental efforts compared to the students taught using TCL in the process of completing tasks during the learning phase (Jalani & Lai, 2014c). Therefore, it can be concluded that the EPBL teaching method enhances students’ knowledge acquisitions, learning efficiency and learning transfer, as well as reduces the mental efforts during the learning phase (Jalani & Lai, 2014b).

It is believed that some elements in the design of EPBL contribute to the improvement of achievement performance and reduction of mental effort in learning. EPBL optimizes the allocation of cognitive resources by reducing the extraneous load and fostering the germane load, seeking to achieve effective learning. It includes the worked-examples that were designed carefully to avoid means-ends analysis strategies and split-attention effects, working as a team to solve the problem, and being an effective facilitator for student learning. In addition, an additional analysis was conducted to investigate the effects of the EPBL method on learning efficiency. The results showed that learning efficiency taught using EPBL showed positive results, where the performance was higher with lower mental effort.

2.1. Theoretical Aspect of the EPBL Instruction Procedures

It is important to not induce a high extraneous load, especially when it is coupled with an intrinsic high load. This is because high levels of extraneous and intrinsic loads can cause the "space" for germane load to become smaller (Renkl & Atkinson, 2003). From a teaching perspective, it is very important to discover the rules, especially for the fostering of the germane load. Thus, EPBL was designed based on CLT to ensure that EPBL gives a positive impact on the acquisition of knowledge, transfer of learning, mental effort, and thus the efficiency of student learning.

In this design, firstly, in the early stages of learning the students were given a brief lecture on the basic principles and concepts of the knowledge domain by the facilitator. Next, students were exposed to worked-examples that do not require excessive working-memory in its learning activities. Worked-examples given enabled students to acquire the conceptual schema of knowledge that can help solve similar problems. Finally, problem-solving methods were presented after students have the schematic knowledge to positively impact the transfer of learning. Thus, the knowledge gained was stored for automatic use on new problems. Learning by worked-examples followed by problem-solving alleviate the use of working-memory capacity because students do not need to find solutions in an inefficient manner, thus positive learning efficiency can be achieved.

2.2. Practical Aspects of the EPBL Instruction Procedures

In general, the researchers identified three components and five key elements in the EPBL design. The components are (i) exposure, (ii) comprehension, and (iii) reinforcement. The elements of each component are (i) methods of learning, (ii) role of teachers and students, (iii) learning strategies, (iv) purpose of learning, and (v) learning outcomes. A review of a previous model showed that each component has a different function and each forms an
EPBL model, as illustrated in Fig. 3. In fact, each component determines the performance of students and the successful implementation of EPBL.

<table>
<thead>
<tr>
<th>Element</th>
<th>Exposure</th>
<th>Comprehension</th>
<th>Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Method</strong></td>
<td>Short Lecture</td>
<td>Work-Example</td>
<td>Problem-Solving</td>
</tr>
<tr>
<td></td>
<td>A brief lecture was given on</td>
<td>Review and understand each step in problem-</td>
<td>Propose a solution to a given problem</td>
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<td></td>
<td>the basic knowledge of the</td>
<td>solving given in the worked-examples</td>
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<td></td>
<td>principles and concepts</td>
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<tr>
<td><strong>Role</strong></td>
<td>Facilitator</td>
<td>Student</td>
<td>Student</td>
</tr>
<tr>
<td><strong>Strategy</strong></td>
<td>Teacher-Centered</td>
<td>Student-Centered</td>
<td>Student-Centered (Group)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Individual)</td>
<td></td>
</tr>
<tr>
<td><strong>Purpose</strong></td>
<td>Disclosure of basic knowledge</td>
<td>Development of knowledge schema and reduce</td>
<td>Knowledge stored automatically for use</td>
</tr>
<tr>
<td></td>
<td>domain</td>
<td>extraneous load</td>
<td></td>
</tr>
<tr>
<td><strong>Outcome</strong></td>
<td>Basic knowledge of the</td>
<td>Understanding and retention of information</td>
<td>Learning transfer and learning efficiency</td>
</tr>
<tr>
<td></td>
<td>principles and concepts</td>
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Fig. 3. The model of Example-Problem-Based Learning

The design focuses on the components in ensuring the effectiveness of the EPBL. Description of each of the elements found in EPBL components are as follows:

*Exposure* – firstly, students were given a brief / short lecture by a facilitator to provide basic knowledge of the principles and concepts for each sub-topics. Students acted passively, receiving information from lecturers who reacted violently in delivering the lectures. Teacher-centered learning strategies were practiced where lecturers gave a brief or short lecture and students only listened the explanation. Students acquired basic knowledge about the principles and concepts of the topic in the domain.

*Comprehension* – then, to understand how to apply the principles of the domain, students received a complete printed form worked-example complete with solution steps and final answer. Students were required to individually study and understand each of the solution steps. Students actively studied and understood the self-explanation of each solution steps given and lecturers had to act as facilitators. Student-centered learning strategies were practiced in which students individually study and understand the worked-examples given. The individual self-explanations were complementary to the worked-examples strategy because both strategies are useful to increase the understanding and retention of information. The individual self-explanations were identified as an effective way to reduce extraneous cognitive loads because students can devote all their working-memory capacities to study the solutions of worked-examples and build schemes in their long-term memory to solve the same problem. Positive effects on the knowledge acquisition (understanding and retention of information) and mental load reduction were achieved through self-explained worked-examples.

*Reinforcement* - finally, students were given problem-solving exercises to improve their problem-solving speed and accuracy. Students should solve the problems collaboratively by discussing with group members. Students
actively sought to propose solutions to solve the problem, and lecturers acted as facilitators. Student-centered learning strategies is where students solve and propose problem solutions in groups. The EPBL method seeks to develop techniques to manage the working-memory load imposed by a learning task in order to facilitate changes in the long-term memory associated with schema construction and automation. To achieve this purpose, extraneous cognitive load must be eliminated and at the same time enhanced intrinsic load management must be achieved. Based on CLT, working-memory limitations can be overcome through the manipulation of individual teaching methods appropriate to the structure of human cognitive memory. One way to overcome individuals working-memory limitations is to use a combination of working-memories of collaborative groups. When teamwork is considered as a system of information processing, this means that the information needed to carry out the tasks of learning and intrinsic cognitive load can be shared by every member of the group. This situation allows each member’s cognitive load to be reduced because the working-memory capacity has increased. On the other hand, each individual’s working-memory combined together can create a collective work and thus provide more processing capacity. Positive impacts are seen on the efficiency of transfer and learning through problem-solving speed and accuracy as well as reducing the mental load through group learning strategies.

3. Discussion

3.1. In Terms of Knowledge Acquisition

Worked-examples given in the initial phase of learning to be studied and understood enabled students to acquire knowledge and organize information in a way that enhances the development of the scheme. In line with CLT, increases in the development scheme can be achieved because worked-examples do not require excessive memory for learning activities, but are still able to produce effective results. This means that worked-examples optimize the allocation of cognitive resources by reducing the extraneous load and foster germane load or the formation of scheme with the aim to achieve effective learning. As a result, the scheme is obtained and stored in the long-term memory. In addition, the individual self-explanatory strategy also complements the worked-examples because the coupling of both strategies is useful for improving concentration and understanding required in the retention of information. Self-explanatory concentration was also obtained by giving worked-examples in the form of printed materials. It aims to prevent disruption so that students can be more focused rather than if given verbal descriptions.

3.2. In Terms of Learning Transfer

Learning by worked-examples alone without the continuation using problem-solving is not sufficient to develop the knowledge that has a positive impact on learning transfer. The same level of information processed in the worked-examples cause repetitive information (redundant) given to students. As a result, students who already know the information given in these examples will not try to work towards a deeper understanding, encouraging the learning process to become passive. When the information needed is not be given to a student, an increase in extraneous load may lead to decreased learning performance. This situation is known as the redundancy effect. These effects are eliminated by providing problem-solving exercises after reviewing worked-examples. Thus, the knowledge gained from worked-examples are used to solve new problems. Focused learning activities like these encourage students to be able to develop appropriate problem-solving schemes for the transfer and storage of information. In addition, problem-solving by groups aim to improve the effectiveness and efficiency of transfer tasks. A working-memory capacity limitation on the individual level is the main cause why complex tasks such as problem-solving should be solved in groups rather than individually. In groups, the cognitive load imposed by a task can be shared and distributed among the members of the group. This means that the cognitive load experienced by each member of the group can be reduced compared to the cognitive load experienced by an individual who is solving a problem on their own. By doing so, everyone’s working-memory capacity is relieved and the process can be used to solve many complex problems and develop cognitive schema than individuals. The scheme is obtained and stored in the long-term memory, allowing students to avoid processing too much information and it is effective to reduce the load on limited working-memory capacity. As a result, students should be able to use the procedures to solve new problems. They also have a deeper understanding of the rationale behind the step-by-step solution. They not only know the step by step procedures to solve problems, but they also understand when to use the different measures and how they
work. In addition, they are able to use the content knowledge, concepts, or skills learned even when the given problem is not the same as the example given in the learning sessions.

3.3. In Terms of Mental Effort

Learning performance doesn’t only depend on the quantity of mental effort invested in learning tasks (Lai, 2010). High mental effort does not necessarily guarantee high performance learning. Therefore, learning through worked-examples followed by problem-solving can provide part of the working-memory capacity, because students do not need to find a solution using inefficient manners. Low mental effort in EPBL can be justified from several perspectives. First, the use of means-ends analysis that generates extraneous expenses can be avoided through worked-examples. Extraneous load rate is reduced by preventing students from irrelevant search processes so that students can concentrate all their working-memory capacity to study the problem-solving examples and build schemes in their long-term memory. Second, the extraneous load of the finding-and-match process which causes split-attention effects was also reduced by integrating the learning information. Texts and figures used in the teaching materials are presented in an integrated format which aims to prevent students from dividing their attention and mental capacity in combining such information. This method can reduce extraneous load; where low extraneous loads show that students do not invest a lot of mental effort in completing the task. Third, the solution of problems found using EPBL conducted in groups also contributed to the reduction of mental effort rather than individual learning efforts. According to the CLT, members of a group will form a working-memory capacity which is larger than the individual’s own capacity when completing a task. Individuals’ working-memory is limited in terms of storage and ability to process information. Besides problem-solving which generates an extraneous load, higher difficulties and complexities of the learning content also results in high intrinsic loads. If the intrinsic or extraneous load is high, limited working-memory resources are insufficient for the learning task. Therefore, the limitation of working-memory capacity at the individual level is considered an important reason why complex learning tasks must be completed in groups rather than individually.

3.4. In Terms of Learning Efficiency

The findings of previous studies have shown that the use of EPBL has improved performance (Jalani & Lai, 2014a, 2015) and reduce extraneous cognitive load (Jalani & Lai, 2014c) which in turn can create optimal learning conditions (Jalani & Lai, 2014b). The findings of this study indicate that EPBL enables students to acquire cognitive schema that can help in solving given problems. Students will also be able to filter out external information (extraneous) and optimize the cognitive resources available to develop problem-solving schemes to store in their long-term memory.

4. Implications

There are some important theoretical and practical implications, especially for future research, practice, and policy-making.

4.1. Implications for educational research

The EPBL methodology combines self-explanatory worked-examples in the early phase of learning followed by problem-solving in groups to improve performance (encouraging germane load) and at the same time reduce mental effort (reducing extraneous expenses) thus improving the efficiency of learning.

4.2. Implications for instructional designers

The learning process should take into account the ability of students and not just designed without the involvement of students. Students must participate with enthusiasm and diligence in the process of reviewing the examples given. Students also need to be involved in a given problem-solving in groups such as discussions, interactions, feedback, coaching colleagues, and other active learning methods. Mental effort in learning can also be used as a guide when
designing learning methods. Learning methods need to be more efficient by reducing the mental workload during the learning process (avoiding extraneous activities that hinder learning) and improving performance (promote germane activities that foster learning). Learning outcomes do not only include performance, but also mental effort invested.

4.3. Implications for instructors

Lecturers can improve their performance and reduce the cognitive load of students by using EPBL. The findings of previous studies showed positive implication to lecturers who changed their traditional teaching practices towards teaching that activates both lecturers and students. Some lecturers may have implemented student centered learning but without specific teaching guidelines. Therefore, the results of a detailed study on EPBL provides some ideas for enhancing the effectiveness of EPBL and is useful for teaching and learning purposes, especially for students who are lacking in academic achievement.

4.4. Implications for policy makers

Lecturers should focus on the application of engineering knowledge or "know-how / why" and not only "know-what". In this aspect, EPBL is used to enhance students' ability to apply their knowledge and skills to solve problems through worked-examples and problem-solving exercises. The traditional method that conveys information through lectures cause students to memorize engineering concepts more, but are not able to relate the knowledge of the principles to the procedure. As a result, students are not able to optimize the use of knowledge in real life situations.

5. Suggestions

The findings from the EPBL study have a positive impact on students learning process. Thus, the implication of this study serves some useful suggestions for several quarters, specifically are as follows:

(i) It is recommended that students apply some aspects of learning in the process of EPBL. This study suggests that lecturers and students take into account the effect of EPBL on the retention of information in long-term memory where students can focus on reviewing the steps in the solutions given in worked-examples. Problem-solving also affects deeper understanding, so students not only know every step of solving the problem, but also understand when and how to use different steps.

(ii) Students are also recommended to take into account the learning methods that reduces mental effort such as studying worked-examples and understanding each step solution available. Students also need to work together in groups to solve a given problem. The results of this study show that the assessment of worked-examples and problem-solving in groups can reduce the mental efforts used during the learning process. Mental effort management is very important in learning because high mental effort does not guarantee high performance standards.

(iii) Determination of the learning efficiency is important because learning outcomes do not only include the achievement of performance alone, but also take into account the mental effort invested during the learning process. The previous study discussed the use of technique in determining the efficiency.

6. Conclusion

Based on the positive results obtained from a previous study, an EPBL model was proposed which contains three important components and the five elements of implementation. EPBL emphasizes that learning achievement is maximized and at the same time the necessary amount of cognitive load is minimized in achieving more efficient and effective learning processes.
References


