EFFECT OF AN ONTOLOGY-BASED REASONING LEARNING APPROACH ON COGNITIVE LOAD AND LEARNING ACHIEVEMENT OF SECONDARY SCHOOL STUDENTS

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ABSTRACT

Previous studies show that the concept mapping approach could organize students' cognitive schema, decrease student’s cognitive load and help promote meaningful learning in any educational settings. However, concept mapping has its limitation in the representation of knowledge for complex concepts and domain knowledge. Thus, in the study, we proposed and implemented an ontology-based Reasoning learning system. To examine the effectiveness of the proposed system, a quasi-experimental design method was conducted in the study with three groups. A total of ninety-five seventh graders participated in the experiment. The graders were randomly distributed to three groups, one experimental group and two control groups. The experimental group with 31 students was conducted ontology-based reasoning approach. The first control group with 32 students was managed ontology learning approach, while the second control group with 32 students was guided with concept map learning approach. The experimental findings show the proposed approach could help learners improve students’ misconceptions and improve their learning performance; moreover, it could reduce students’ cognitive load in the learning process. Relevant suggestions are advised in the results of the study.

KEYWORDS

Ontology; Concept Mapping; Cognitive Load; Secondary Education; Meaningful Learning.

1. INTRODUCTION

Due to wide progress and development of Information and Communication Technology (ICT), the traditional teacher-centered learning has been transforming to the learner-centered learning context. There are suggestions for providing early childhood educators IT integrated instructions (Chou, 2012). When students are guided the domination, the learning course is not only employed with the identical learning contents to students, but also give distinct contents to different students, so how to carry out learning systems to assist learners for personalized learning that would become a challenging issue. Therefore, the learning system ought to be able to lead and facilitate students promote their cognitive schemas to the experts or instructors’ cognitive structure. On the other side, the system should be able to evaluate learners’ knowledge structure.
Moreover, previous studies reported that ICT embedded in instruction would allow teachers to use computers at any time and any place based on the features of the subject matter. Computer programs allow learners to use for practice, revision, problem solving, or simulations during any application in learning, in which bring great advantages for teachers and students (Demirel, 1996; Durbin, 2002; Lord, 1999; Redish, Saul & Steinberg, 2000). For instance, Naik and Teelock (2006) indicated that ICT embedded in instruction or learning activity were able to enhance the teaching efficacy and learning performance of elementary in history and geography courses. However, ICT embedded in instruction oppositely also generated major problems, containing self-learning control, learning confusion, as well as cognitive loads (Eppler & Mengis, 2004). To address these problems, researchers (Chen, Lee, & Chen, 2005; Dahl, Zheng, Williamson, & Flygare, 2008; Sweller, 1988, 1994) believed that concept maps are similar to the mental schema in long term memory and hence it can reduce cognitive load well. Moreover, concept map can facilitate students reorganize cognitive schemas, and reflect on their knowledge (Conlon, 2006; Novak, 2002). However, concept map has its limitation in the representation of knowledge for complex concepts and domain (Eppler, 2006). For instance, a drawback of concept mapping approach is that the link types of visual map are restricted to simple associations. Without clear links between ideas is a constraint.

Thus, researchers found that ontology technology could recover the disadvantage of concept map in this manner. For example, Chu et al. (2011) indicated that ontology technology could help learners navigation and classification in the concept-map-based learning system. Weinbrenner, Engler and Hoppe (2011) found that taking domain ontology could generate better intelligent feedback than by concept mapping way.

The ontology describes the correlation among concepts that could assist learners in resources sharing and reusing. Moreover, with ontology reasoning function, it could provide the adaptive learning content for learners. Chen (2009) stated that ontology technology empower a linguistic foundation to stand for conceptual correlations among learning materials. Ontology can be regarded as a structured and visual knowledge scheme, which can help learners in the production of an individualized learning trail.

In the study, we created the ontology-based inference learning system to assist students in searching, comparing and integrating essential concepts to build knowledge structure easily. As mentioned previously, the study attempts to address two research questions below:

1) Do students who accepted the proposed learning approach gain better significant learning achievement than other groups of students?

2) What is the cognitive load of students among the different learning approach?

2. LITERATURE REVIEW

Concept Mapping

Concept mapping technique, developed by Novak and Gowin (1984) under Asusbel’s meaningful learning theory, refers to a visible skill to show different essential concepts and the correlations among these concepts. At the beginning, it was used to promote learner’s learning effectiveness in learning science. Concept map is regarded as assistant tool for classifying students cognitive schemas that is a way to engage learners in a deeper level of thinking. Students who use concept map technique obtain significant learning and even understand the meaning of how to learn effectively. Concept map helps
learners realize what they are learning (Liberato, 2004). By illustrating concept map, the knowledge structure could be virtualized on learners’ thought (Shambaugh, 1995). Concept map is employed to abstract learners’ knowledge, so the teacher could know what learners learn after seeing learner’s concept map.

Concept maps (Novak & Gowin, 1984) can be viewed as a graphical image for domain knowledge that involves essential concepts and relationships among them. During the process of designing concept maps, students are able to make reflection, and build their knowledge concepts after conducting learning activity, so concept maps provide a clear and visible perception for a specific domain knowledge structure. Francisco, Researchers (Nakhleh, Nurrenbern, & Miller, 2002) illustrated that concept map was sketched to present how learners connected hierarchical materials, it is essential to them to excavate new ideas from original knowledge. In addition, concept map could be viewed as an amendment tool for misconception, in which links concepts with specific keywords, and assist learners to see connected relations among them.

Concept map comprises nodes and links, and the nodes are linked with certain kinds of links, and reasonable relations among nodes (Sowa, 1984). One label links two nodes that is a proposition, and the concept position and link orientation could decide the knowledge framework. A concept refers to a hierarchy relationship; that is, the normal concepts will put on the top layer, and the specific and concrete concepts will put on the bottom layer.

Learners are often astonished by the complex knowledge and information in resource-based learning context. The external interactive image of individual knowledge with visual format may assist them to address complicated issues (Sigmar-Olaf Tergan, 2006). Furthermore, concept map could increase learners simple memory and decrease their cognitive loads (Sweller, 1994). There are many evidences show concept map is a useful approach to support and enhance learners comprehension ability in the different learning contexts (Jonassen, 1987; O'Donnell et al., 2002).

Ontology Technology

Tim Berner-Lee et al. (2001) argued that Semantic Web refers to a structured and meaningful content of webpage, and establishing a learning environment. Thus, the web pages ought to be labeled semantic message with tags for page searching, and these tags must be readable and processing by machines. Ontology technology provides effective information, and made Semantic Web workable and readable.

There are many different definitions on ontology technology between scopes in the learning context. Ontology describes a set of significant foundation that form a domain knowledge. That is, ontology is a specific form of a conception. Ina domain knowledge, ontology depicts a set of objects, as well as describable relationships between objects, in which described with meaningful terms to represent knowledge (Gruber, 1993).

Why we want to develop ontology? Natalya et al. (2007) offer some reasons are described as followed:

- To distribute familiar understanding of domain knowledge structure among people
- To make domain knowledge applicable and reusable
- To let hypotheses of domain knowledge clear
- To extract operational knowledge from domain knowledge
- To interpret the meaning of domain knowledge
Ontology is creating a conceptual sign system, including objects, concepts and other entities, in a domain of discourse by well-known experts. Semantic Web, concept map, Resource Description Framework (RDF) and project map etc., are viewed as identical knowledge expression for simple presentation, for this reason, these could be created via ontology technology (Natalya et al., 2007; Soares & Sousa, 2008).

Ontology is an authoring tool based on concept map, such as searching as well as tracing learners learning status, and it is also able to present and store the concept map information.

Cognitive Load

Sung (2000) indicated that cognitive load presents the state of loading on a person's cognitive system raised by mental competence and the number of resources forced to conduct a required task. Likewise, Chen (2003) thought that cognitive load as the combination of mental load and mental effort that a person experiences while managing a given task, a mission or an assignment. As soon as information processing is mentioned, cognitive load is mostly related to the finite volume of a person's working memory. Meanwhile, Pass (1992) indicated that cognitive load comprises two elements: (1) mental effort: it concerns a person's feelings in responding to hard learning materials; and (2) mental load: it is usually caused by complex tasks or external environment. That is, cognitive load is the accumulation of a person's mental effort and mental load. Sweller (1988) revealed that mental load raised because an individual learner over-highlighted the problem-solving skills, and was forced to center heavily on his/her memory competence; then, he/she lacks extra cognitive competence to obtain cognitive schema of new learning.

Mental load is related to the interplay among learning activities, subject features and learning contents, which is highly correlated to the complicacy of the course contents that learners have to carry out (Verhoeven, Schnotz, & Paas, 2009). In the study, two groups were distributed to learn identical course materials and was taught with the same learning contents; thus, it can be inferred that mental load for two group students would present no significant difference. On the contrary, mental effort is with respect to learning methods used in the designed learning contexts (Verhoeven et al., 2009); as a result, there could be significant correlation between mental effort and learning performance of students further shows that the learning performance is attributed to the intervention of the technology-enhanced learning approach, which could decrease learners mental effort, and achieve higher learning performance. This finding is consistent with what has been found by previous studies, namely students learning performance could be negatively influenced by mental effort (Verhoeven, Schnotz and Paas, 2009).

In short, cognitive load emphasizes on the effect of learning contents as well as instructional approach on the construction of concept nodes and cognition. Theory of cognitive load (Sweller, 1994; Sweller et al., 1998) was proposed on the basis of four assumptions interpreted on human cognitive structure: including (1) the volume of a person's working memory is finite, (2) long-term memory is related to a large amount of information preserved during one’s lifetime, (3) long-term memory is collected in network-based form of schemas, and (4) schema automation and construction refers to an essential process of building cognitive schema.
3. RESEARCH METHOD

Participants
A total of 95 seventh graders participated in the experiment. The graders were randomly distributed to three groups, one experimental group and two control groups. The experimental group with 31 students was conducted ontology-based reasoning approach. The first control group with 32 students was managed ontology learning approach, while the second control group with 32 students was guided with concept map learning approach.

![Experimental Procedure Diagram]

At the beginning of the experiment, three groups were required to do pretest to acquire students’ learning status for thirty minutes before the formal experiment. After that, the researcher gave orientation of different learning platforms for different groups of students, in which they were allowed to practice for forty-five minutes. Then, the prior knowledge of nervous system of human being for three group students was constructed before going into the learning activity. After construction of fundamental knowledge of nervous system, students in different groups started learning activity for ninety minutes respectively. Finally, post-test of students’ learning performance and measurement of cognitive load were conducted to evaluate their learning outcome after the intervention of different learning platforms.

Learning environment
First of all, students in the control group two were conducted to learn concept map of nervous system of human being with the software, Xmind, shown in Figure 1. Students of control group two were guided by the teacher to complete the concept map of nervous system of human being so that students have the same cognitive schema as the educator when the course unit finished.
Fig. 1: Students of Control Group Two Learning Concept Map with Xmind Learning System

The learning system provided to students of control group one is proposed by Chu, Lee and Tsai (2011). As seen in figure 2, students of control group one were also conducted by the educator to complete the concept map of nervous system of human being. However, the difference between two control groups is the system can allow students of control group one to construct more instances of a concept than those of the control group two with Xmind. Consequently, students in control group one could understand nervous system of human being deeper than those in control group two, as shown in figure 3.

Fig. 2: Students of Control Group One Learning Concept Map of Nervous System with Ontology Learning System
Students of experimental group was given an additional function, as shown in figure 4, which provides relationships between concepts and instances with reasoning form to learning concept map of nervous system via the Ontology-based Reasoning Assistant Learning System (ORALS). The additional function could enhance students' cognition of concepts of nervous system via meaningful sentences and visual forms of concepts and relevant instances.
Measuring Tools

Measurement of Learning Achievement

The assessment for students’ learning achievement was collaboratively made by three secondary teachers and one expert. A total of items for pre- and post-test include 20 and 25 respectively, covering with the range of the unit of human nervous system in the nature science. The perfect score of the assessment is up to 100. The higher the score a student obtains, the better learning achievement the student presents. Moreover, before the formal rating of the experiment, 20 non-experimental seventh graders participated in the test in an attempt to verify the wording of two assessments.

Measurement of Cognitive load

The measurement of cognitive load developed by Brattisch, Borg, and Dornic in 1972, is used in this study. The measurement is mainly to scale if learners suffer from an over-loaded cognitive system induced by external factors that would affect their learning performance. The measurement mainly comprises two dimensions, including mental effort and mental load, with seven-point Likert-type response alternatives ("7= very strongly agree", "1= very strongly disagree"). The higher the mental effort score gains, the more need there is to spend effort in learning contents. Likewise, the higher the mental load score gains, the higher stress learners experience during the learning context. In other words, the higher the cognitive load is, the lower achievement the learners will gain. As to the reliability test of the measurement, researchers (Gimino, 2000) have showed the reliability of the scale, and convergent, construct, as well as discriminate validity respectively. In the study, the reliability of the scale was examined with non-experimental subjects (n=25), and reached higher reliability with Cronbach's $\alpha=0.85$, indicating that the scale equips with a high reliability of the measurement for cognitive load.

4. RESULTS AND DISCUSSION

Analysis of Learning Achievement

One-way analysis of variance (One-way ANOVA) was conducted to analyze the difference of learning achievement among three different groups. As you can see in Table 1, there exists no significant difference among three groups, implying that students of three groups have equivalent basic ability in nature science. Thus, this condition won’t be a factor influencing experimental result in the experiment.

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>S.D.</th>
<th>Mean</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Control group one</td>
<td>32</td>
<td>10.77</td>
<td>32.81</td>
<td></td>
</tr>
<tr>
<td>(2) Control group two</td>
<td>32</td>
<td>11.20</td>
<td>36.88</td>
<td>1.605</td>
</tr>
<tr>
<td>(3) Experimental group</td>
<td>31</td>
<td>15.20</td>
<td>38.23</td>
<td></td>
</tr>
</tbody>
</table>

One-way analysis of variance (One-way ANOVA) was also conducted to analyze the difference of learning achievement among three different groups. As you can see in Table 2, there is significant difference among three groups ($F=3.42$, p<.05), implying that students among the three groups exist significant difference in learning outcomes after different learning approach intervened. Scheffe method was employed to analyze the difference among these three groups. The result shows that students of experimental group gains better learning performance than those of control group one, inferring the ontology-based reasoning system could benefit student in learning achievement.
Table 2
ANOVA of Posttest of Learning Performance Among Three Different Learning Groups

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>S.D.</th>
<th>Mean</th>
<th>F</th>
<th>Post hoc</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Control group one</td>
<td>32</td>
<td>21.81</td>
<td>63.75</td>
<td>3.42*</td>
<td>(3)&gt;(1)</td>
</tr>
<tr>
<td>(2) Control group two</td>
<td>32</td>
<td>25.97</td>
<td>69.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) Experimental group</td>
<td>31</td>
<td>10.63</td>
<td>77.26</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p<.05

Analysis of Cognitive Load
Cognitive load for different learning system was measured in the post-test phase to examine the students’ cognitive loading level including “mental effort” and “mental load.” Firstly, we analyzed the difference of mental effort among three different groups. One-way analysis of variance (One-way ANOVA) was also conducted to analyze mental effort. As you can see in Table 3, there is significant difference among three groups (F=5.65, p<.01), implying that students among the three groups exist significant difference in mental effort after different learning approach intervened. Scheffe method was employed to analyze the difference among the three groups. The result shows that students of control group one acquire higher mental effort than those of experimental group, indicating that students have to spend more time in learning with ontology learning system.

Table 3
ANOVA of Mental Effort for Three Different Learning Groups

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>S.D.</th>
<th>Mean</th>
<th>F</th>
<th>Post hoc</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Control group one</td>
<td>32</td>
<td>9.25</td>
<td>2.72</td>
<td>5.65**</td>
<td>(1)&gt;(3)</td>
</tr>
<tr>
<td>(2) Control group two</td>
<td>32</td>
<td>8.63</td>
<td>2.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) Experimental group</td>
<td>31</td>
<td>6.84</td>
<td>3.33</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p<.01

Then, we analyzed the difference of mental load among three different groups. One-way analysis of variance (One-way ANOVA) was also conducted to analyze mental effort. As you can see in Table 4, there is significant difference among three groups (F=6.61, p<.01), implying that students among the three groups exist significant difference in mental load after different learning approach intervened. Scheffe method was employed to analyze the difference among the three groups. The result shows that students of control group one obtain more mental load than those of experimental group, indicating that students felt stressed in the learning contexts. In other words, mental load of control group one is significantly higher than that of the experimental group.

Table 4
ANOVA of Mental Load for Three Different Learning Groups

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>S.D.</th>
<th>Mean</th>
<th>F</th>
<th>Post hoc</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Control group one</td>
<td>32</td>
<td>8.66</td>
<td>2.93</td>
<td>6.61**</td>
<td>(1)&gt;(3)</td>
</tr>
<tr>
<td>(2) Control group two</td>
<td>32</td>
<td>7.13</td>
<td>2.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) Experimental group</td>
<td>31</td>
<td>5.84</td>
<td>3.34</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p<.01
As to cognitive load, the result shown in Table 5 is different from results in Table 3 and Table 4. One-way analysis of variance (One-way ANOVA) was also conducted to analyze cognitive load. As you can see in Table 5, there is significant difference among three groups (F=9.29, p<.001), implying that students among the three groups exist significant difference in mental load after different learning approach intervened. Scheffe method was employed to analyze the difference among the three groups. The result shows that students of control group one and control group two acquire more cognitive load than those of the experimental group, indicating the students of two control groups obtained highly cognitive load to spend more time to learning traditional learning system so as to feel stressed during the learning activities.

\[
\begin{array}{|c|c|c|c|c|}
\hline
\text{Groups} & \text{N} & \text{S.D.} & \text{Mean} & \text{F} & \text{Post hoc} \\
\hline
(1) Control group one & 32 & 17.91 & 4.78 & 9.29*** & (1), (2)>(3) \\
(2) Control group two & 32 & 15.75 & 4.41 & & \\
(3) Experimental group & 31 & 12.68 & 5.29 & & \\
\hline
\end{array}
\]

\*p<.001

CONCLUSION

Concept map can facilitate students reorganize cognitive schemas, reduce cognitive load and reflect on their knowledge (Conlon, 2006; Novak, 2002). However, concept map has its limitation in the representation of knowledge for complex concepts and domain. Thus, in the study, we proposed and implemented the ontology-based concept learning system to help learners in searching, comparing as well as integrating concepts that develop their cognitive structure. To assess the effectiveness of the system and learning process toward students’ cognitive load, we conducted an experiment with one experimental group and two control groups. The experimental group was conducted ontology-based learning system with reasoning rules. Control group one was conducted ontology-based learning system without reasoning rules, while control group two was guided with concept map learning system. After three-week period of experiment, The result shows that students of the experimental group gains better learning performance than those of control group one, denoting that ontology-based reasoning system could benefit student in learning achievement of nervous system course. As to the learning process toward students’ cognitive load, The result shows that students in the control group one and the control group two have higher cognitive load than those in the experimental group, implying that the students in two control groups obtained highly cognitive load to spend more time to learning traditional learning system so as to feel stressed during the learning activities.

To sum up, the learning approach we proposed not only could benefit students in learning complex concepts of nervous system, but also spend less time as well as feel less stressed in the learning process for the learning activity. In the future, we would further investigate the effectiveness of the proposed learning system by adding more participants and in-depth interview for more information.
REFERENCES


