COMPUTER-ASSISTED EXAMPLE-BASED LEARNING: THE EFFECTS OF SELF-EXPLANATION AND INSTRUCTIONAL-EXPLANATION ON TRANSFER PERFORMANCE

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Abstract

This research examined the effect of applying two different explanatory procedures (self-explanation and instructional explanation) on topic knowledge acquisition performance, near transfer performance, and far transfer performance. A total of 76 students were randomly assigned into three groups and pre- and post tests were used to assess the learning outcomes. The analysis showed that the effect of self-explanation was more pronounced than instructional explanation especially in topic knowledge acquisition performance and near transfer performance. On the other hand, the positive effect of self-explanation was not noticeable in far transfer performance.

Introduction

Incorporating computer technology into learning can offer major advantages with regards to its flexibility, presentation, communication facilities, and reuse of materials (Van Merriënboer, Bastiaens, & Hoogveld, 2004). Moreover, computer technology supports many of the instructional methods that are necessary for transfer of learning. For instance, computer technology can be integrated into example-based instruction which may promote transfer of learning (Schworm & Renkl, 2006).

Computer-assisted example-based instruction is often accompanied by certain types of explanatory activities such as receiving instructional explanation or generating explanation (e.g. Reisslein et al., 2006; Scheiter & Catrambone, 2006). A wealth of research pertaining to self-explanation prompts and instructional explanation has been done in various learning domains. However, most of the research only put emphases on well-structured domains such as mathematics, physics, mechanics, and programming (see Chi & Bassok, 1989; Conati & VanLehn, 2000; Pirolli & Anderson, 1985; Renkl, 2002). Hence, not much is known about the effect of applying different explanatory procedures on a less well-structured domain such as Manufacturing Technology.

Example-Based Learning and Cognitive Load Theory

Example-based learning is a learning strategy in which worked examples are used as a primary learning tool for supporting the construction of mental model and the acquisition of cognitive skills. Generally, worked example encompasses two major components, namely, background story of the problem and solution procedure.

According to previous research findings, learning with worked example is effective for skills acquisition as well as transfer performance (Renkl, 2005). The efficiency of worked example learning approach is underpinned by the cognitive load theory which is distinguished between intrinsic, extraneous, and germane cognitive load. Intrinsic load refers to the complexity of learning contents or instructional task in relation to a learner's prior knowledge and depends on the number of interacting elements that have to be processed simultaneously and kept active in working memory during the learning process (Sweller, 1988; Van Gog, Paas, & Van Merriënboer, 2006), whereas extraneous load is referred to as an ineffective cognitive load because this load is unnecessary and it interferes with schema acquisition and automation (Paas, Renkl, & Sweller, 2003). Extraneous load is usually imposed by the design of the instructional task or by the activity which is not directly related to learning or schema acquisition (Van Gog, Paas, & Van Merriënboer, 2006). Lastly, germane load refers to cognitive load which is beneficial to schema acquisition and enhances learning. Unlike intrinsic load and like extraneous load, germane load is induced and influenced by instructional design. (Paas, Renkl, Sweller, 2003; Sweller, 1988).

By offering a worked-out problem, the use of an ineffective problem solving strategy (e.g. means-end analysis) which may induce extraneous cognitive load is prevented because the learner does not have to look for solution for the practice problem and, instead, can invest all available cognitive capacity to studying the solution given and constructing problem schema (Gerjets, Scheiter & Catrambone, 2006; Große & Renkl, 2006; Sweller, 1988). The cognitive capacity that is freed-up by reducing the extraneous load can be used to increase the germane load by some activities that improve learning, such as asking the learner to generate reasoning for each solution step or receive explanation related to the solution procedures (Chi & Bassok, 1989; De Leeuw & Chi, 2003).

Example-Based Learning with Self-Explanation Prompts and Instructional Explanation

Worked-out problems or example solutions typically do not include explicit explanation of each solution procedure. This is problematic because without completeness of information the learner may not fully understand the solution procedures. In order to learn with understanding, students need to overcome the incompleteness of a worked-out solution by generating inferences from the presented information (Chi, Bassok et al., 1989). Most students, therefore, will try to generate explanations (self-explanations) about the rationales behind each solution procedure. Renkl (1999) has argued that self-explanation is an effective means because it is easier to adapt to the learner's prior knowledge, it is better timed which means that self-explanation only takes place when it can be integrated into ongoing cognitive activities, and it can be more memorable for students when they can explain the solutions in their own words.

The reason why students often prefer to rely on self-explanation in order to optimise learning is that, the rationales of poorly-constructed example solutions are seldom spelled out and some provided rationales confuse students' understanding. In other words, the explanations provided for the example solutions do not fit with the students' understanding (Chi & Bassok, 1989). Self-explanation, by contrast is consistent with the students' own levels of understanding. This may help students to construct new knowledge and integrate it into existing knowledge effectively. Of course, the usefulness of self-explanation depends greatly on the accuracy, completeness, and quality of the explanation. Students, especially novices, may sometimes not generate explanations that are helpful for learning (Renkl, 1999).

In contrast to self-explanation, instructional explanation is designed to communicate a particular aspect of subject matter knowledge. This type of explanation is contributed by the teacher and teaching materials (e.g. text books, computer courseware) during the learning process and is regarded as a powerful tool to help students understand concepts, ideas, events, and procedures. Instructional explanations are usually correct and may help students to deal with comprehension difficulties when they discover the existence of gaps in their domain-specific knowledge.

A good instructional explanation helps convey both content of knowledge as well as the paradigms and methods of establishing new knowledge in the discipline. Provision of instructional explanation may be able to lead to optimistic outcomes, especially when students are incapable to self-explain on their own, or when they generate inaccurate explanations (Renkl, 2002). In this case, instructional explanation can be more advantageous compared to self-explanation because instructional explanations are usually correct. According to Gerjets, Scheiter and Catrambone (2006) instructional explanation should be very helpful for students especially when dealing with high complexity worked-out examples (high intrinsic cognitive load). This is because instructional explanation supports students in overcoming the comprehension difficulties due to the complicated solutions procedures or steps. That is, the intrinsic cognitive load is decreased with the help of instructional explanation. Instructional explanation tends to explain the complicated situations in a simpler way and gives hints to students of how the solutions work, so that students' working memories do not have to 'work hard' to figure out what is the relationship between the variables and why the solution is done that way because everything is explained.

However, too much elaboration in instructional explanation may bring negative effect to learning. The study by Catrambone and Carroll (1987) has shown that students can become lost in the overloaded information of instruction and it jeopardises the transfer performance. In addition, previous researches have shown controversial conclusions about the role of instructional explanation. For example, Renkl (2002) asserts that instructional explanations do not foster learning because they may not be adapted to the prior knowledge of students. When instructional explanation does not match the level of a student's prior knowledge, the student will face difficulty in understanding what is being explained in the instructional explanation. Likewise, Chi (2000) argues that instructional explanation should not be used because it not only impedes the self-explanatory activities which help discover erroneous information in one's knowledge, but it also hinders learners in trying to generate rationales for solution procedures on their own (Schworm & Renkl, 2006).

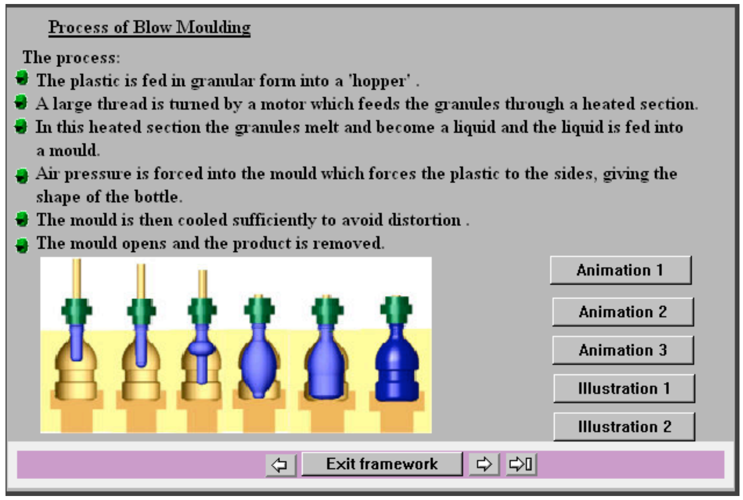
Purpose of Research

The purpose of this research was to investigate the impacts of applying self-explanation prompts and instructional explanation on (a) knowledge acquisition, (b) near transfer performance, and (c) far transfer performance. The research was implemented using worked-out problems in a computer-assisted instructional environment for an ill-structured domain (Manufacturing Technology).

Computer-Assisted Learning Environment

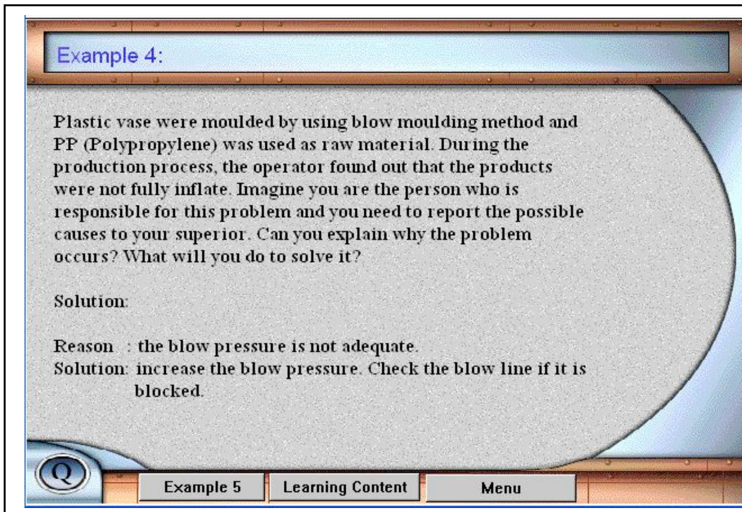
A self-developed courseware CD (using Macromedia Authorware 7.0) was used to create computer-assisted learning environment for Manufacturing Technology. The courseware CD consisted of fundamental knowledge of Manufacturing Technology and six examples of worked problems. The first part of the courseware delivers instruction on the basics of injection moulding, rotational moulding, blow moulding and extrusion process. The following is the example of a screen shot of the blow moulding process:

Figure 1: Screen shot of Blow Moulding Process



The worked examples were constructed in the manner of increasing complexity (low complex, medium complex, and high complex). A low-complex worked-out problem contains comparatively fewer variables, a single-goal, and the solution steps are relatively short compared to medium and high-complex worked-out problem. The following screen shot illustrates one of the worked examples:

Figure 2: Screen Shot of Worked Example



Participants

In the experiment, 76 students from University Tun Hussein Onn Malaysia (UTHM) attended the experiments (50 female and 26 male; mean age 20.99 years). All participants were randomly assigned into three groups, namely, Self-Explanation prompt (n = 25), Instructional-Explanation (n = 25), and control group (n = 26).

Pre-test

The assessment of entry knowledge was done before the treatment and it was divided into three parts which assessed factual knowledge acquisition, near-transfer, and far- transfer problem solving performance. The factual knowledge pre-test contains 10 multiple-choice items. The correct answer would be scored 1 point and no credit point was given or subtracted for the wrong answer. The second part measured near-transfer performance. This part consisted of five problems which required participants to write in short answers. The maximum score which could be obtained was five points. The actual score varied from 0 to 5 depending on the accuracy of the given answer. The final part of the pre-test was to assess far-transfer performance. The scores of between 0–5 points could be achieved by the participants. The pre-test was found reliable (Guttman coefficient lambda: 0.63).

Post-test

Basically, the post-test has an identical structure as the pre-test which consists of three sections (10 multiple-choice items for the first section, 5 short essay items for the second section, and 5 short essay items for the third section). The reliability was found to be acceptable for analysis (Guttman coefficient lambda: 0.65)

Experiment Procedures

The entire experiment comprised four phases, namely, introductory phase where participants learn the basics of Manufacturing Technology, pre-test phase, worked-example learning phase, and post-test phase. In the first introductory phase, the participants were required to fill out the demographic questionnaires and then were presented with learning material using the courseware CD. After the introduction phase, participants were required to work on the pre-test. After the pre-test, the treatment (worked-out problem learning phase) was administered. In order to minimise the effect of pre-testing, the second learning phase was carried out a week after the introductory phase and the pre-test.

For the self-explanation prompts (SE) group, the participants would have to try to understand the solution steps that were displayed on the computer screen. Then, the participants would be asked to justify and explain why or how the solution procedures were done in the way they were displayed on the computer screen.

Participants had to write down their explanation on the papers. For the instructional explanation (IE) group, the worked-out problem and solution procedure were presented to the participants. The instructor explained the problems and the complete solution to the students. After completion of the treatment phase, participants were required to sit for the post-test.

Results

Table 1 shows the means and standard deviation of the pre-test and post-test results in the experimental groups. Firstly, we examined whether all participants had the same level of entry knowledge. The ANOVA on the pre-test scores showed significant difference between the experimental groups beyond the level of 0.05 ($F(2,73) = 4.29$, $p = 0.02$, $\eta^2 = 0.08$: medium effect). The entry knowledge difference has to be eliminated in order to make the experimental groups comparable.

Table 1: Means (Standard Deviations) of Pre-test and Post-test Scores in the Experimental and Control Groups

	Control Group	Instructional-Explanation (IE)	Self-Explanation Prompt (SE)
Pre-test: topic knowledge acquisition	6.25 (1.11)	6.26 (1.01)	5.32 (1.60)
near-transfer	9.69 (2.58)	11.96 (3.71)	10.88 (4.10)
far-transfer score	8.19 (3.00)	8.54 (2.34)	7.98 (3.41)
overall score	24.12 (4.19)	26.76 (4.83)	24.18 (6.50)
Post-test: topic knowledge acquisition	6.29 (1.33)	6.83 (1.03)	6.92 (1.29)
near-transfer	9.73 (2.02)	12.22 (3.22)	13.96 (3.27)
far-transfer score	9.50 (2.87)	11.20 (3.39)	10.24 (3.01)
overall score	25.52 (3.79)	30.24 (5.12)	31.12 (6.05)
Difference between overall pre- and post test score	+1.40	+3.48	+6.94

This difference could be attributed to some participants in the respective groups who possibly did exceptionally well or poorly in the pre-test. A thorough examination of the pre-test scores distribution between experimental groups revealed that two participants of Instructional-Explanation group scored exceptionally high (39.5 and 40.0). Meanwhile, there were also two participants of the control group who scored exceptionally low (11.5 and 11.0). In order to eliminate this potential influence on treatment, those four participants (5.3% of the sample) were excluded and their data was left out from consideration. The re-analysed results revealed no significant differences between the experimental groups ($F(2,69) = 1,700$, $p > 0.05$). Thus, the experimental and control groups are now comparable with respect to the treatment prerequisite.

With regards to topic knowledge acquisition performance, both IE and SE groups did slightly better than the control group (IE: $M = 6.83$, $SD = 1.03$; SE: $M = 6.92$ (1.29); control group: $M = 6.29$, $SD = 1.33$). Therefore, it can be said that worked-out problem learning with explanatory activities enhanced learners' achievement with regard to topic knowledge acquisition. In addition, the IE group was also compared with the SE group using t test. The outcomes of the t test showed that the participants of both experimental groups were not statistically different ($t(46) = -0.28$, $p = ns$). However, from the aspect of test score increment, the SE group learners had significantly improved their performance from pre-test to post-test ($t(24) = -5.43$, $p < 0.01$ (two-tailed), cohen's $d = 1.09$ (large effect). In contrast to SE, the increases of knowledge acquisition performance for the other groups did not yield a significant difference.

With respect to near transfer performance, both IE and SE groups scored statistically significantly better than the control group, $F(2,69) = 13.19$, $p < 0.01$, $\eta^2 = 0.26$. However, this result did not tell exactly which explanatory activity is more superior. By taking a glance at the near-transfer test scores (Table 1), although the SE group obtained higher post-test scores compared to the IE group, the scores did not differ significantly ($t(46) =. -0.54$, $p > 0.05$). On the other hand, we discovered that the SE group had gained a significant increase of near transfer test score (increase from pretest to post test) ($t\ (24) = -3.75$, $p < 0.01$, two-tailed), whereas the gain scores of the IE group were not statistically significant ($t(22)=-0.33$, $p>0.05$). The significance of *t*-value for the SE group showed that the increase of near transfer test performance might be attributed to the self-explanation effect.

In terms of far transfer performance, participants of the both the IE and the SE groups outperformed the control group participants (IE: $M = 11.20$, $SD = 3.39$; SE: $M = 10.24$, $SD = 3.01$; Control: $M = 9.50$, $SD = 2.87$). Although the experimental group participants yielded higher far-transfer post-test scores, the ANOVA returned a non-significant value ($F(2,69) = 1.70$, $p > 0.05$), which indicates that the differences between the experimental and control groups were not statistically significant. Based on these findings, it is clear that neither instructional explanation nor self-explanation instructional procedures would help foster far-transfer learning outcome.

Discussion

It is astonishing to find out that self-explanation prompt group did not significantly outperform its counterpart in post test topic knowledge acquisition performance.

However, this partial result does not mean that the self-explanation prompt lacked a positive effect on topic knowledge acquisition performance. The reason behind this point is that we have discovered that learners who generated self-explanations had gained significant improvement from pretest to post test compared to learners who received explanations. This significant test improvement might be attributed to the self-explanation effect. Although the favourable effect of self-explanation was not very pronounced in topic knowledge acquisition, it did exist to a certain extent. Therefore, it is still plausible to conclude that application of self-explanation prompts may enhance topic knowledge acquisition.

Similarly, the learners of both the self- and instructional explanation achieved the same level of near-transfer performance (no significant difference was found in post test scores). However the distributions of near-transfer test scores illustrated that self-explanation learners had gained a significant increase of near-transfer test scores (pre-test to post-test). Again, this significant increase illustrates that the self-explanation effect was actually playing its role to push learners' performance to a higher end and promote deeper understanding than students who were not prompted to generate explanation. Therefore, applying self-explanation in the learning process is more advantageous over instructional explanation to a certain extent because learners who self-explain are likely to achieve higher gain scores.

Lastly, the positive effects of self-explanation prompts on far-transfer performance can be found in a wealth of previous researches (e.g. Renkl & Atkinson, 2003; Wong, Lawson, & Keeves, 2002). However, such a positive effect is not replicable in the present research. Based on the analysis outcomes of this research, it is very astonishing that no significant favourable effect was found either in self-explanation or instructional explanation in terms of far-transfer performance. Even worse, in terms of far-transfer gain scores, even worse, the self-explanation learners underperformed instructional explanation learners. This pattern of result clearly illustrates that the effects of self-explanation which are widely proved to be more effective (e.g. Aleven & Koedinger, 2002; Chi & Bassok, 1989) was not outstanding in the context of this research.

There are a few possible factors that might contribute to the detrimental effect of self-explanation prompts in the present learning context. First of all, the worked-out problems were presented from a low to high level of complexity which is expected to be able to facilitate learning (Collins, Brown, & Newman, 1989). For the low complexity or easy worked-out problems, it would be relatively easier for learners to comprehend the knowledge. When the learners move on to the more complicated worked-out problems, perhaps the existing mental model of the learners are not adapted to the complex information, and in turn, they fail to generate correct explanations. Thus, new knowledge cannot be accurately constructed on the existing knowledge. Therefore, the existence of knowledge gap between the worked-out problems might not bring out the favourable effect of self-explanation and thus impair transfer performance.

Apart from that, the participants of the SE were required to write down the explanations of each solution. It is important to note that the act of writing self-explanation does not directly contribute to knowledge representation or mental model construction. Any learner's physical activity (e.g. writing or typing) will inevitably impose an additional demand on cognitive resources which may not necessarily translate into cognitive processes (Kalyuga, 2007). Therefore in the context of this research, the process of writing can be viewed as an activity that introduces extraneous cognitive load which might disturb learning. This interpretation is in line with the cognitive load theory which claims that high intrinsic and extraneous cognitive loads are likely to deteriorate transfer performance (Schnotz & Kürschner, 2007; Sweller, 2005).

Although self-explanation imposes germane cognitive load that can enhance acquisition of knowledge and problem solving skills, it should be noted that germane cognitive load is only beneficial to learning if sufficient working memory capacity is available (Sweller, 2006). In the case of using both complex worked-out problems and written self-explanation, it tends to impose high intrinsic cognitive load as well as extraneous cognitive load which could have occupied a huge piece of working memory capacity leaving insufficient space for germane cognitive load. If self-explanation is implemented beyond the working memory capacity, even though germane cognitive load is increased, the learning performance is unlikely to be fruitful.

Future Direction

The present findings are focused on the domain of Manufacturing Technology. More studies are needed to determine if these results are replicable in other ill-structured non-engineering domains such as psychology, law, and education. Certainly, to know more about the relation between learner and instructional approach in different domains of knowledge, the tools of assessment must extend beyond commonplace multiple-choice item or the widely-used Likert scale. Qualitative method such as interviews and observations can be used cooperatively with quantitative strategies in order to supply a better understanding on the related issues.

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