Lai, Chee Sern; Spöttl, Georg; Straka, Gerald A.

Learning with worked-out problems in Manufacturing Technology: The effects of instructional explanations and self-explanation prompts on acquired knowledge acquisition, near and far transfer performance

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Zusammenfassung:

In der vorliegenden Untersuchung wurden zwei unterschiedliche Lehrmethoden – instruktionale Erklärung und Aufforderung zur Selbsterklärung – angewandt auf das Lernen mit Lösungsbeispielen in einer computergestützten Lernumgebung, die thematisch im Bereich der Fertigungstechnik angesiedelt ist. Die computergestützte Lernumgebung bestand aus einer vom Autor erstellten Lernsoftware, die mit Macromedia Authorware entworfen und entwickelt wurde. Hauptziel der Studie war ein Vergleich der Effekte beider Lehrmethoden auf die Aneignung von Sachwissen sowie die Leistung beim nahen und weiten Transfer. Außerdem wurden die Auswirkungen von Gegenstandsinteresse auf die zuvor genannten Kriterien untersucht und die Beziehungen zwischen Gegenstandsinteresse, mentaler Anstrengung und Lernergebnissen.

Insgesamt wurden 76 Studierende im zweiten Jahr ihres Studiums an der Fakultät für Technische Bildung, Universität Tun Hussein Onn Malaysia (UTHM), nach dem Zufallsprinzip in drei Gruppen aufgeteilt: Selbsterklärungsaufforderung (SE: n = 25), instruktionale Erklärung (IE: n = 25) und Kontrollgruppe (n = 26). Mit Pre- und Post-Tests wurden die Aneignung von Sachwissen sowie die nahe und weite Transferleistung erhoben. Gegenstandsinteresse und mentale Anstrengung wurden mit dem Topic Interest–Fragebogen und dem NASA-TLX gemessen. Das Statistik-Paket für die Sozialwissenschaften (SPSS) wurde verwendet, um die Hypothesen an den gesammelten Daten zu prüfen. Die Hypothesenprüfung erfolgte mittels quantitativ statistischer Auswertungsverfahren (Korrelation, Varianzanalyse).

Abstract:

In the present research, two different explanatory approaches – namely, instructional explanation and self-explanation prompts – were applied in worked-out-problem-based learning (learning with worked-out problems) in a computer-assisted instructional environment in the domain of manufacturing technology. This research aims at comparing the effects of both explanatory approaches on topic knowledge acquisition, near transfer performance, and far transfer performance. Additionally, this research also attempts to examine the impact of topic interest on the aforementioned variables, in addition to the relationships between topic interest, mental effort, and learning outcomes.

A total of 76 second-year students were randomly assigned to experimental and control groups. The pre- and post-tests were used to measure topic knowledge acquisition, near-transfer performance, and far-transfer performance, whereas topic interest and mental effort were measured by means of Topic Interest Questionnaire and NASA Task Load Index (NASA-TLX) respectively. The analysis outcomes revealed that the self-explanation prompts approach was significantly superior to the instructional-explanation approach in terms of topic knowledge acquisition and near transfer performance. In addition, the results demonstrated that the impact of topic interest was significantly noticeable on far transfer tasks, but not on topic knowledge acquisition and near transfer tasks. On the other hand, the relationship between mental effort investment and test performance was not statistically significant. Finally, an equivocal relationship, which varied depending on the treatment conditions, was discovered between topic interest, mental effort, and test performance.

1 Introduction

The technological development has altered the trend of workforce requirements in the marketplace, particularly in manufacturing sector. The employers not only place high demands on engineering knowledge, but also emphasise the need for employee competence in solving problems related to manufacturing technology (Mohamed Rashid & Mohd Nasir, 2003). As even those who are well-schooled in the basics academic skills (e.g., maths and reading) might still lack the problem solving skills sought by cutting-edge manufacturing firms, there are strong reasons to suggest that pragmatic and effective actions should be undertaken by those institutions responsible for training the next generation of highly skilled workers. Given that the technical workers in the manufacturing sectors are often asked to solve problems, there is an obvious need for instructional designers to develop methods to help students become more effective problem solvers.

Some educationists suggest that problem-based learning could be a way to acquire both domain knowledge and problem solving skills that are transferable from the classroom to the workplace; however, the effectiveness of this learning strategy has not been adequately supported by theoretical and empirical evidence. According to some educational researchers (e.g., Sweller, van Merriënboer, & Paas, 1998), learning through problem solving might induce a high extraneous cognitive load and cause an overload of the human working memory because problem-solvers, especially the novices, tend to use weak problem solving methods, such as means-end analysis, which may consume a great amount of cognitive resources. Furthermore, it has been argued that learning by solving problems is unlikely to promote knowledge acquisition, as it only stresses problem solving. This method is also more time-consuming because learners spend relatively more time to understand the unfamiliar terminology and concepts when confronted with a problem (Barrows & Tamblyn, 1980).

To counteract the shortcomings of problem-based learning, it is recommended that, instead of unresolved problems, worked-out problems are used in problem-based learning as they do not impose high extraneous cognitive load and may reduce human working memory consumption. This will help foster learning because cognitive activities, such as organising of information and construction of knowledge, can take place in the sufficient memory space.

2 Theoretical Framework and Research Questions

The following sections will be focused on the discussion concerning the theoretical framework, literature review and the research questions will be drawn finally.

2.1 Theoretical Framework and Research Questions

Basically, a worked-out problem consists of a problem statement, solution procedures, and a final solution (Renkl, Stark, Gruber, & Mandl, 1998). The problem statement describes both the problem state and the goal state that needs to be achieved, whereas the solution procedures consist of a series of steps that lead to the final solution. In general, learning by worked-out problems or worked-out-problem-based learning comprises four major characteristics: (1) fundamental domain knowledge is provided at the beginning of learning process; (2) worked-out problems, instead of unresolved problems, are used as the primary learning tool; (3) individual learning approach is used for studying worked-out problems; (4) The use of multiple worked-out problems during instruction. Additionally, in the present study, the worked-out problems were structurally ill-designed and presented in an order of increasing complexity (e.g., low-, medium-, and high-complexity).

The positive effects of worked-out problem can be explained by cognitive load theory. Dealing with a task that contains a certain number of interacting elements may induce a demand on the working memory capacity. This demand on human working memory capacity is regarded as cognitive load (Sweller, 1988). Cognitive load can be distinguished between intrinsic, extraneous, and germane cognitive load. Intrinsic cognitive load refers to the demands on working memory capacity caused by the complexity of a learning material or an instructional task. In this context, complexity is dependent on the number of interacting elements that must be simultaneously processed and kept active in the human working memory during the learning process. Extraneous cognitive load is induced by the format of the instruction, rather than by the intrinsic characteristics of a material or learning task. Extraneous cognitive load is commonly conceived of as ineffective load because it is not directly related to learning and interferes with schema acquisition. Similar to extraneous cognitive load, germane cognitive load is also influenced by the format of instruction or the external learning activities. The crucial distinction between these two types of cognitive loads is that germane cognitive load is attributed to the instructional activities that facilitate the acquisition of schema and new knowledge. This is to say that germane cognitive load is an effective type of cognitive load (Paas, Renkl, & Sweller, 2003).

From a cognitive load perspective, learning from worked-out problems can avoid human working memory overload because learners, especially novices, do not have to interact with a large number of elements (e.g., the problem state, goal state, problem-solving operators and strategies) and do not have to look for a solution using weak problem solving methods (Sweller, 1988). Thus, the working memory load can be substantially reduced. In turn, more working memory space of a person is available. In order to make the most of this free working memory, additional supportive instructional activities, which may bring on germane cognitive load (directly benefit learning), can be employed during the process of learning from worked-out problems (Kirschner, Sweller, & Clark, 2006). For instance, providing explanations or prompting learners to generate explanations to the solution steps of a problem is a learning activity that might produce germane cognitive load because either providing or generating explanations may directly contribute to learning. These explanatory activities play an important role in worked-out problem learning because most of the worked-out problems typically contain unexplained solution procedures (Renkl, 2005). Due to the incompleteness of the worked-out problem solution, the learners might not be able to fully understand the solution procedures, thereby failing to generalise from the worked-out problems. Either providing explanations or generating explanations might help eradicate, or at least reduce, the inadequacy of solution information of a worked-out problem, which in turn can foster the construction of a more complete problem solving schema.

2.2 Instructional Explanation

It is a common problem that students do not fully understand the example solutions given in a textbook because the solutions are not thoroughly explained. This is the reason why instructional explanations are needed as an instructional support to provide accurate and complete additional information to counteract the incompleteness of example solutions (Chi, 1996). Instructional explanations are designed to communicate a particular aspect of subject matter knowledge to ensure that learners are able to gain experience, which may create or modify their knowledge representations (Duffy, Roehler, Meloth, & Vavrus, 1986). This type of explanation can be contributed by the teacher, peer, or teaching materials (e.g., textbooks, courseware) during the learning process, and it is regarded as a tool to help students understand the concepts, ideas, events, and procedures of a subject and apply that knowledge in different situations (Leinhardt, 1997).

Instructional explanations are perceived as an important instructional strategy particularly for learners with low entry knowledge. This is because instructional explanations are usually correct and may help the learners deal with comprehension difficulties (e.g., complicated solutions steps) that they have trouble figuring out for themselves (Renkl, 2002). The completeness of instructional explanations also may come into play, especially when gaps exist in a learner's knowledge representations. This occurs because instructional explanations provide additional information that is not only able to cover the knowledge gaps, but also to help extend a learners' existing knowledge to new situations (Wittwer & Renkl, 2008). Nevertheless, it is important to note that the positive effect of instructional explanation is largely related to the high quality of explanations because such explanations can actually be conceived of as a scaffolding agent that can enhance learning outcomes (Leinhardt, 1997; Lovett, 1992). Additionally, some researchers (e.g., Engle & Conant, 2002) argued that the non-cognitive elements, such as topic interest or individual interest, might also influence the impact of instructional explanations.

From a cognitive load perspective, instructional explanations tend to explain the complicated situations in a simpler way and gives hints to the learners as to how the solutions work, so that students' working memories do not have to 'work hard' to figure out what the relationship is between the variables, why the solution is done in a certain way, and so on. As a result, more cognitive resources or working memory space can be freed up. Thus, working memory overload can be avoided. The free memory space or cognitive resources can be optimally used to process and analyse the complex information (Wittwer & Renkl, 2008). Therefore, it is believed that provision of instructional explanations might reduce extraneous cognitive load and, at the same time, generate germane cognitive load, which has a facilitative effect on learning.

In addition to the discussion above, the learners, in some cases, might be confronted with illusion of understanding; that is, the learners overestimate their understanding of the learning materials, and they are likely to erroneously assume that they understand what they are studying. Hence, those learners will be reluctant to delve more deeply into the learning contents in order to close the gaps existing in their knowledge (Keil, 2006). Sometimes, the learners do not even realise that they misinterpret the to-be-learned information, and thereby constructing an incorrect mental model. This, of course, will lead to decreased learning performance (Renkl, 1999). The use of instructional explanations is able to avoid the illusion of understanding because instructional explanations can show students that they are still lacking understanding of the contents to be learned. Such awareness of insufficient comprehension may trigger the learners to actively process the instructional explanations and, hence, lead to an increase in further cognitive engagement. This is important because without processing explanations actively, the learners are very likely to gain only a superficial comprehension on the subject matter and, in turn, they may not be able to construct meaningful mental models or knowledge representations from the explanations (see Wittwer & Renkl, 2008).

A good instructional explanation helps convey both the content of knowledge, and the paradigms and methods of establishing new knowledge in the discipline. However, too much elaboration in instructional explanations may bring negative effect to learning. A study by Catrambone and Carroll (1987) shows that students can become lost by information overload during instruction, which can jeopardise the transfer performance. Recently, Gerjets, Scheiter, and Catrambone (2006) discovered similar findings: they found that instructional explanations did not enhance learning performance when learning modular and molar worked examples with a high amount of instructional explanations. Therefore, they considered the instructional explanations as superfluous.

In the present research, when the participating learners are studying the worked-out problems, they are provided with instructional explanations by an instructor. For example, the instructor will explain how and why certain type of product problem can be solved in a specific way. By doing so, the learners do not have to consume a large amount of cognitive resources to decipher the problem model (e.g., relation between the variables) because everything is explained. Instead, the cognitive resources can be utilised to process and to analyse the complex information and construct a new mental model.

2.3 Self-Explanation Prompts

Although instructional explanations can be used as an instructional support for worked-out-problem-based learning, in some cases it is beneficial for transfer of learning if the students attempt to understand the solution steps by actively constructing an interpretation of each solution step in the context of domain principles. This constructive explanatory activity is termed self-explaining (Chi & Bassok, 1989).

According to Crippen and Earl (2007), self-explaining is a form of self-talk. However, to some authors (e.g., Chi, 2000), 'talking to oneself' cannot be categorised as self-explaining because the purpose of talking does not necessarily aim at understanding the learning materials and may not generate any content-related inferences. Conversely, self-explaining puts the stress on producing inferences to close the information gaps in a piece of learning material. Therefore, self-explanations are content relevant (Chi, 2000). Specifically, Chi describes self-explaining as the activity of generating contentrelated explanations for oneself in order to promote comprehension of the learning material. Recently, Roy and Chi (2005) provide an even more explicit definition of self-explaining, which they define as:

> *"...... a domain general constructive activity that engages students in active learning and insures that learners attend to the material in a meaningful way while effectively monitoring their evolving understanding. Several key cognitive mechanism are involved in this process including, generating inferences to fill in missing information, integrating information within the study materials, integrating new information with prior knowledge, and monitoring and repairing faulty knowledge." (p. 273)*

Based on this definition, self-explanation can be perceived as an explanation generating activity that may produce information beyond what a learning material (e.g., text, graphic) presented in order to supplement the incomplete information, uphold new knowledge representation constructions, and modify incorrect mental models of the content. In principle, self-explanation can be performed by self-explaining overtly (to speak aloud) or covertly (to think). However, in a laboratory setting, it is common to self-explain overtly, either in a verbal form (e.g., Chi, Bassok, Lewis, Reimann, & Glasser, 1989) or a written form (e.g., Große & Renkl, 2006). It is due to the fact that most of the learners are passive and do not attempt to generate explanations on their own initiative, especially when additional sources of information (e.g., instructional explanations) are easily available (Schworm & Renkl, 2006). Therefore, it is not pragmatic to expect self-explanation to occur spontaneously and naturally. That is the reason why the learners have to be prompted to self-explain in order to get them involved in this constructive learning activity.

It is clear that the goal of self-explaining is to eradicate the inadequacy of information by generating inferential information. When a learner is trying to self-explain, the learner's entry knowledge is activated, and s/he begins to construct the interpretations of the worked-out solution procedures based on her/his existing entry knowledge and understanding. This interpretation can be done by encoding the information from the incomplete solution procedures. To encode the information via self-explanation can be regarded as generating inferences on the basis of missing information from the worked-out solution procedures. Provided that the learner has adequate entry knowledge to generate self-explanations or inferences, a mental model, which is isomorphic to the text model (a model conveyed by worked-out problem solutions), can be constructed. This newly constructed mental model is integrated into the existing incomplete knowledge base and closes the information gaps, thereby forming a more complete knowledge representation. This series of cognitive events implies that there is a correspondence between both text model and learner's mental model, and the construction of new knowledge has taken place when the knowledge gaps have been successfully filled (Chi & Bassok, 1989; Renkl, 2002). According to Lovett (1992), this phenomenon is called the generation effect. As mentioned in previous section, whenever learners generate explanations on their own words, the information will be more memorable. As a consequence, learning performance can be increased.

The beneficial effect of self-explanation is mainly attributed to the fact that the self-generated explanations are consistent with the learners' knowledge levels and fit perfectly with the learners' level of understanding. Therefore, generating self-explanations can avoid the variation in knowledge between what a text introduces and the learners' existing knowledge (Chi & Bassok, 1989). This can reduce the chance of being misunderstanding and avoid building an incorrect mental model.

From a cognitive load perspective, learning from worked-out problems can free up part of the working memory capacity because the learners are not required to look for the solutions using ineffective means (Sweller, 1988). These freed up cognitive resources can then be used for self-explanation prompts, which might impose germane cognitive load during the learning process, and thereby facilitating learning. However, prompting a learner who lacks entry knowledge and relevant experiences to produce an explanation on her/his own is very likely to bring about an overload in working memory (Gerjets, Scheiter, & Catrambone, 2006). If this is the case, there will not be sufficient cognitive resources available to learn from the information in the learning materials, through such activities as analysing the learning contents, integrating new information with existing knowledge, and repairing flawed cognitive representations. Principally, this may hinder construction, modification, and integration of knowledge mental model.

Similar to the case of instructional explanation, the learners who engage in self-explaining might be confronted with illusion of understanding. It is expected that the self-explainer is able to detect the flaws and incompleteness in her/his cognitive knowledge representations throughout the process of self-explaining, and then executes appropriate cognitive actions (e.g., reorganise or re-establish mental model) that lead to cognitive change (Chi et al., 1989). However, some learners fail to realise that they do not understand what they have learned or assume that they have fully mastered the topic even though they have not. In such circumstance, the learners might be reluctant to generate explanations and work harder towards a better understanding (Renkl, 1997; 2002). To counteract the problem of illusion of understanding, the instructional arrangement should be designed to provide hints to the learner that there is incompleteness in her/his knowledge.

To do so, feedback can be provided as an instructional support after the learners generate explanations. Here, feedback simply means the information provided by an agent (e.g., teacher) regarding a given aspect of learner's understanding, and it can be corrective, alternative, or clarified information (Hattie & Timperley, 2007). According to Hattie and Timperley, providing feedback is most effective when the learner encounters a faulty interpretation of information instead of experiencing a total lack of understanding. Feedback allows learners to relate and compare the correct information with the wrong one, and thereby repairing their incorrect concepts.

Within the context of the present study, the participating learners are required to study the learning contents (fundamental information of manufacturing technology and worked-out problems) via the learning courseware. When learning the worked-out problems, they are prompted to produce explanations or rationales for the worked solutions. For instance, the participants will be asked how a product's surface defect can be sorted out or why a specific manufacturing method is only suitable for certain types of products. It is expected that the learners will produce explanations based on their level of understanding. This, in turn, might help fill the knowledge gaps and reduce the chance of building flawed mental model because, as previously mentioned, the self-generated explanations are regarded as the inferential information for the incomplete worked-out solutions. Besides, the explanations will be generated in a written form instead of a verbal form. This is because in a classroom setting, generating verbal explanations might prove disturbing and distracting for other students. Additionally, as a way to eliminate the impact of the illusion of understanding, the instructor plays the role as a feedback agent in the experiments. That means, the instruction will provide feedbacks to the participating learners after they have self-explained. In the next chapter, the operationalisation of the treatment will be explicitly explained.

2.4 Review of Literature

Research interest in the role and contributions of explanation in teaching and learning has increased in recent years. A majority of the research has focused on the investigation of the impact of self-explanation and instructional explanation on learning outcomes. The existing research findings are summarised in the following table.

Researcher/s (learning domain)	**Relevant Research Questions/ objectives***	**Participants Sampling**	**Measurement/ data collection**	**Results**
Putnam & Duffy (1984) (reading skills)	Is there any evidence regarding the effectiveness of explanation in creating student outcome?	24 children from the 3rd and 4th graders were assigned to group A (poor readers) and group B (good readers)	Students' outcome: Pre-test and post-test	No significant correlation between explanation and students' outcome
Duffy, Roehler, Meloth, & Vavrus (1986) (reading skills)	Do teachers who are verbally explicit in explaining reading strategies to low group students produce students who are more aware of what was taught and better achievers on measures of reading comprehension?	4, 22, 7, and 20 teachers for low reading groups were observed in 1st, 2nd, 3rd, and 4th year respectively.	students' awareness: interview students' reading comprehension: criterion measure and achievement test	Strong correlation between explicitness of explanation and students' awareness of lesson content. Students being more thoughtful and strategic in test suggest a relationship between explicit explanation and achievement.
Leinhardt (1997) (history)	To investigate the nature of instructional explanation.	Students from Advanced Placement United State History class.	The lessons were audio and video taped and had been transcribed. Semi-structured interviews	Instructional explanation shares the properties of disciplinary explanation and self-explanation. Students learn from instructional explanation both the content and the manner of explanation.
Leinhardt (1987) (mathematics: subtraction with regrouping)	To examine the impacts of instructional explanation on computational performance and in-depth performance	8 second-grade students	Computational performance: pre-test and post-test In-depth performance: pre interview and post interview	Students' ability increased from the level of not knowing to high computational performance. Significant increase of performance on near transfer (familiar tasks) and far transfer tasks (novel tasks).
Chi, Bassok, Lewis, Reimann, & Glaser (1989) (Physics)	To assess how the quality of self-generated explanations influenced students' performance on isomorphic problems, far transfer problems.	10 university students were divided into 'good' (5) and 'poor' (5) groups based on test performance.	Near transfer performance: isomorphic problems test Far transfer performance: far transfer test Students' self-generated explanations were analysed	Good students were able to generate many concept- and principle-based explanations and gained higher scores on both tests.

Researcher/s (learning domain)	Relevant Research Questions/ objectives*	Participants Sampling	Measurement/ data collection	Results
Chi, de Leeuw, Chiu, & Lavancher (1994) (Biology)	To see if the self-explanation effect can generalised to non-procedural domain, a different task, and a different outcome measure.	24 eighth-grade students were separated into explanation prompted group (14) and unprompted (10) group.	Students' performance: pre-test and post-test Students' self-generated explanations were analysed	The prompted group had a greater gain from the pre-test to post-test, generated more explanations, and were able to construct correct mental model.
Siegler (2002) (number conservation)	Do young children, as well as older individuals, benefit from encouragement to provide explanation? Is explaining other people's reasoning more useful than explaining your own reasoning?	5-year-old children were assigned to three different groups (feedback only condition; explain-own-reasoning condition; explain-correct-reasoning condition)	Performance: pre-test (interviews) and post-test (interviews)	5-year-olds as well as older children can benefit from encouragement to explain. Explaining other people's answers is more useful than explaining your own, at least when the other people's answers are consistently correct and your own answers include the incorrect ones.
Legare, Wellman, & Gelman (2009) (biological phenomenon of contamination)	To compare young children's explanations and prediction for the biological phenomenon of contamination.	24 preschool children, 24 college students, 12 preschoolers for control group (non-contamination)	Interviews were recorded and transcribed.	Children performed significantly better on the explanation tasks than prediction tasks. Adults significantly outperformed the children on prediction tasks but equally well on explanation tasks. Explanation prompts might play a role in children's causal knowledge structure and learning of causal knowledge.
Stark, Gruber, Hinkofer, Mandl, & Renkl (2002) (accounting)	To compare uniform versus multiple examples and guided versus unguided explanation.	2x2 factorial design. Factor 1: uniform versus multiple solutions Factor 2: guided versus unguided explanation 56 vocational school students divided into 4 groups (uniform + guided; uniform + unguided; multiple + guided; multiple + unguided)	Near and far transfer performance: post-test	Students with guided explanation (high quality explanation) outperformed unguided students.

Researcher/s (learning domain)	Relevant Research Questions/ objectives*	Participants Sampling	Measurement/ data collection	Results
Hilbert & Renkl (2009)				
(biology: stem cells)	Experiment 1: To study whether students who were trained in concept mapping with examples show better learning outcomes and better conceptual knowledge about concept mapping than students who learner by practicing.	15 students learning by examples; 15 students learning by practicing.	Learning outcome: pretest and posttest Conceptual knowledge of concept mapping: posttest	No significant differences between two groups
(marketing)	Experiment 2: To study whether students who learned with example and self-explanation prompts show better learning outcomes and conceptual knowledge about concept mapping.	24 students learning with examples; 24 students learning by practicing; 28 students learning with example and self-explanation prompts	Learning out come: pre-test and post-test Conceptual knowledge of concept mapping: posttest	Providing only examples is sufficient for fostering conceptual knowledge about concept mapping. Self-explanation prompts help attain the benefit of mapping with regard to the acquisition of domain knowledge.
Große & Renkl (2006) (Mathematics)	Are self-explanation prompts or instructional explanations more effective in fostering example-based learning with multiple solutions with respect to procedural skills and conceptual knowledge?	2 x 3 factorial design. Factor 1: multiple versus uniform solution Factor 2: no support versus instructional explanation versus self-explanation 28 students (multiple solutions + no support); 28 students (multiple solutions + self-explanation) 28 students (multiple solutions + instructional explanation) 31 students (uniform solution + no support); 29 students (uniform solution + self-explanation) 26 students (uniform solution + instructional explanation)	Prior knowledge: pre-test Procedural skills and conceptual knowledge: post-test	The positive effect of multiple solutions was not moderated by instructional supports except self-explanation prompts, which had a negative effect when learning with multiple solutions. Instructional explanation was significantly more helpful than self-explanation prompts in general. Self-explanation prompts had a negative effect on conceptual knowledge acquisition.

Researcher/s (learning domain)	**Relevant Research Questions/ objectives***	**Participants Sampling**	**Measurement/ data collection**	**Results**
Catrambone & Yuasa (2006) (programming)	To explore the effect of active learning (self-explaining) and types of elaboration on declarative knowledge and procedural knowledge acquisition.	16 undergraduates for every groups 2 x 2 factorial design. Factor 1: active (self-explanation) versus passive (instructional explanation) Factor 2: condition elaboration versus condition-action elaboration	Learning time, transfer tasks time, and errors were recorded. Declarative knowledge: criterion declarative test Procedural knowledge: transfer task	Active learners (who self-explained) required longer training time but shorter problem solving time and made fewer errors. No significant difference between active and passive learners in terms of declarative knowledge acquisition. Condition-action elaboration improved procedural performance the most in both active and passive conditions.
Schworm & Renkl (2006) (geometry and physics)	Is there a positive effect of prompting self-explanation on learning outcomes? Is there a positive effect of providing instructional explanations on learning outcomes? Does the availability of instructional explanations reduce self-explanation activity?	2 x 2 factorial design. Factor 1: with and without self-expla nation prompts Factor 2: with and without instructional explanations 80 high school students were separated into 4 groups (20 students in each group)	Near and far transfer performance: post-test Written explanations were coded using coding system Thinking aloud protocols were transcribed.	Self-explanations are crucial when learning by solved example problems. Prompts for written self-explanations have positive effects even when instructional explanations are not provided. Instructional explanations have ambiguous effects. They can foster or hinder learning depending on context conditions. Instructional explanations could reduce self-explanation activity.
Lovett (1992) (probability)	To explore the generation effect and quality of information effect.	2x2 factorial design. Factor 1: problem solving versus worked example Factor 2: self-explanation versus instructional explanation 12 university students in every group	Very near transfer, near transfer, and far transfer: post-test	Either generating solutions and explanations, or receiving solutions and explanations, or generating solutions and receiving explanations might enhance very near transfer performance. Both Generation effect and the effect of high quality explanation might positively influence near transfer performance. Students who generated solutions and explanations and who received solutions and explanations performed the best on far transfer performance. The positive effects of generation and high quality explanation were found.

Table 1: Summary of empirical research.

2.5 Research Questions:

A closer look at the sources shows that the study on the respective topic concentrates on individual disciplines. Natural science subjects such as mathematics, physics, and biology as well as “reading skills” are dominating. Surveys on accounting and marketing were only carried through and named for individual cases. There is no indication of publications on the research questions with a clear relationship to occupations or disciplines of vocational education and training. This does not mean that such surveys are inexistent. A number of such surveys have been carried through and published in the German speaking countries. Many surveys concentrate all on economic and handicraft occupations and above all on car technology. They are, however, not yet available in English.

Based on the existing literature, the effectiveness of self-explanation prompts and provision instructional explanations in learning by worked-out problems are still inconclusive, especially with respects to knowledge acquisition, near and far transfer performance. Furthermore, most of the existing research focused on well-structured learning domains, such as mathematics, programming, and physics. Due to the differences between well- and ill-structured learning domains, the findings obtained from well-structured domain cannot be generalised into an ill-structured domain, like manufacturing technology. In addition, the motivational dimension, particularly topic interest, is often neglected in worked-out-problem-based learning. Some researchers (e.g., Del Favero, Boscolo, Vidotto, & Vicentini, 2007) have mentioned that different learning contexts may have an influence on learner’s interest, which in turn might affect learning. Hence, it is not advisable to only focus on learners’ performance measurement without considering the motivational dimension (in this case, motivational dimension is always referred to topic interest) as a component of efficient learning conditions. In order to shed some lights on this issue, research is needed to examine the impact of topic interest on students’ learning outcomes.

From the cognitive point of view, it is argued that learners who are interested in a learning topic tend to engage actively and are willing to invest mental effort into the activities related to that topic. Some researchers have studied the relationship between mental effort and learning performance; however, those studies did not involve the motivational aspect and, more importantly, those findings are not able to be generalised to other learning contexts. In any learning settings, it is important to look into how much mental effort is devoted by a learner to learning, as it may provide a more comprehensive insight about the effectiveness of an instructional strategy.

In sum, the present research is conducted in order to narrow the research gaps identified above.Specifically, this research is guided by the following questions:

1. Is there difference between instructional explanation and self-explanation prompts on:
   a. knowledge acquisition,
   b. near and far transfer performances?

2. Is there an impact of topic interest on:
   a. knowledge acquisition,
   b. near and far transfer performance?

3. Is there a relationship between mental effort and learning performance?

4. Is there a relationship between topic interest, mental effort, and learning performance?

3 Method

In order to provide an idea regarding the research method, this part will emphasise the discussion concerning research design, sample, instruments, as well as experimental procedure.

3.1 Research design

To achieve the above mentioned objectives, a two-treatment-group and a control group with a pre- and post-tests measurement design was used. Specifically, in this research two experimental groups (Group 1: self-explanation prompts, and Group 2: instructional explanation) and one control group were used to determine the transfer performance in worked-out-problem-based learning with two different explanatory procedures – namely, self-explanation prompts and instructional explanation – in a computer-assisted instructional environment. Using Campbell's and Stanley's terminology (Campbell & Stanley, 1963), the research design can be illustrated in the following diagram:

O_1 -- X_1 -- O_2 (Experimental group 1)
O_3 -- X_2 -- O_4 (Experimental group 2)
O_5 --------- O_6 (Control group)

Where:
X = treatment/intervention
O = observation/measurement

In general, topic knowledge acquisition, near and far transfer performance, and mental effort were measured before and after the treatments, whereas topic interest was only measured before the treatments. The overview of the research design is shown in Table 2.

Observational Variables before treatment	Treatment Conditions	Observational Variable after treatment
i Topic knowledge acquisition ii Near transfer performance iii Far transfer performance iv Mental effort v Topic interest	Group 1: worked-out problems with self-explanation prompts. Group 2: worked-out problems with instructional explanations. Group 3: control group	i Topic knowledge acquisition ii Near-transfer performance iii Far-transfer performance iv Mental effort

Table 2: Overview of research design.

3.2 Participants

In this study, a total of 76 participants (50 female and 26 male; average age 20.99 years) from the Faculty of Technical Education, University Tun Hussein Onn Malaysia (UTHM), were randomly assigned to the three groups: self-explanation prompt (n=25), instructional explanation (n=25), and control group (n=26).

3.3 Instruments

The self-developed pre-test (λ_6=0.63) and post-test (λ_6=0.65) were used to collect the data concerning topic knowledge acquisition, near and far transfer performance. Topic knowledge in the context of this research refers to the concepts, principles, schemas, and theories within the domain of manufacturing technology (plastics injection moulding, rotational moulding, blow moulding, and extrusion process). The example of topic knowledge item:

A product will be produced using plastic injection moulding method. Which of the following materials cannot be used for this production process?

a) thermoset
b) porcelain clay
c) polymers
d) thermoplastic

Near transfer performance is realised with the tasks that have the same underlying structures as the worked-out example problems presented during the learning phase but different surface characteristics. This means that the worked-out problems and the to-be-solved problems have the same pattern of questioning but with different surface story. Generally, these questions require students to perform the same tasks as they have learned in the worked-out problems. The example near transfer item:

Kamal, a process engineer at General Plastics, Inc., has just received a report from the quality control department. According to the report, more than 70% of the first batch products were rejected due to the poor surface quality. Kamal must response quickly to solve the products' quality problem. He checked the injection moulding machine and tried find out the problem. Can you figure out what the probable causes are? You are required suggest a solution for each probable problem.

Far transfer performance is measured by far transfer problems in which the problem contexts have different underlying structures and surface features as compared to the worked-out problems presented in the learning phase. In addition, the far transfer problems contain more than one problem situation, which require the students to provide a solution.

An oil container was designed and produced using rotational moulding method. At the final stage, there was a difficulty to remove the product from the mould. A few samples were taken for the specification and quality inspection. The inspection findings revealed that the stiffness of the products did not meet the minimal requirements. The inspection team had checked the design of the mould; however, it showed no problem in the mould. If you were one of the inspection team members, can you figure out what the possible cause could be? And what steps should be taken to overcome the problems?

Mental effort was measured using NASA Task Load Index (α=0.80) (NASA-TLX, developed by Hart and Staveland, 1988). Mental effort is regarded as the amount of cognitive resources that are invested in a learning task (Paas & van Merriënboer, 1994). Operationally, mental effort is the amount of cognitive effort introspected by a learner when s/he is working out manufacturing technology problems. NASA-TLX consists of six subscales focusing on mental demand (how much mental effort is required to accomplish the task), physical demand (how much physically activity is required to accomplish the task), temporal demand (how hurried or rushed is the pace of the task), performance (how successful one is when accomplishing what s/he is asked to do), effort (how hard does one have to work to accomplish her/his level of performance), and frustration (how insecure, discouraged, irritated, stressed, and annoyed s/he is). NASA-TLX was modified to 6-point scale.

Topic interest was measured using the Topic Interest Questionnaire (α=0.75) (developed by Schiefele, Krapp, Wild, & Winteler, 1993). Topic interest is a motivational variable which is modelled as a combination of value-related valence and feeling-related valence (Schiefele, 1996; Schiefele & Krapp, 1996). Operationally, topic interest is indicated by the ordinal levels of value perception and emotional perception toward manufacturing technology. The Topic Interest Questionnaire consisted of two parts. The first part was focused on the expected feeling of the participants. For instance, the participants were asked: while reading the text on Manufacturing Technology, I expect to feel – 'bored', 'stimulated', 'interested', and 'involved'. The second part of the questionnaire asked about value-related valences. The participants were asked to described their value of the topic in terms of 'meaningful', 'useful', and 'worthless'. The rating scales ranged from '0 = not at all true' to '7 = very true'.

3.4 Experimental procedures

The treatments were performed according to the following procedures:

(a) Self-explanation prompts (group 1):

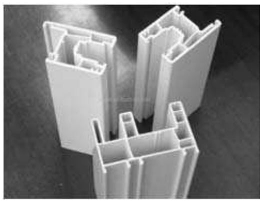
(i) The participants were first presented with two low-complexity worked-out examples. Example of low-complexity worked-out example:

> **Question:**
> *General Plastic Manuf. Company will produce 50,000 units of recyclable bottle of fruit juice. The production will be done using blow moulding method. Could you suggest a type of material that is suitable for the production?*
>
> **Possible answer:**
> *PET*

(ii) For each low-complexity worked-out problem, the participants were prompted to generate explanations. The prompted question for the above example would be: why is PET suitable for the production?

(iii) The participants were then presented with two medium-complexity worked-out examples. Example of medium-complexity worked-out example:

FuturePlastic Company will produce new plastic profiles according to the following designs:



PVC, which has certain mechanical properties, is suitable to be used as a raw material. Imagine that you are the person to be in charge of the production. What type of process do you think is the best way to produce the products? What are the reasons behind your choice?

Solution:

Possible process:	*Extrusion process.*
Reason:	*Extrusion process can be used to create a variety of shapes, minimal of waste, and high productivity.*

(iv) In each medium-complexity worked-out problem participants were prompted to generate explanations. The prompted question for the above example would be: *What is the principle of extrusion process? Why does extrusion process have a relatively low material waste? Why is extrusion process productive?*

(v) Lastly, the participants were presented with two high-complexity worked-out examples. Example of high-complexity worked-out example:

The plastic containers were produced using injection moulding process. The report from the quality control department of HiTech Manufacturing Company showed that a majority of the products did not fulfil the product requirements. The report revealed that the main problem was related to the product's surface quality. The production engineer checked the injection moulding machine and tried to find out the problem. Can you help the engineer to figure out what the possible causes of the poor surface quality are? You are required to explain why the problem occurred and suggest a solution for each problem.

Solution:

Defect:	*Flow marks.*
Cause:	*The injection speed is too slow.*
Solution:	*To overcome the problem the injection speed should be increased.*
Defect:	*Blister.*
Cause:	*The tool or material is too hot.*
Solution:	*To overcome the problem make sure the cooling system is working and the cooling temperature is set to the suitable level.*

(vi) For each high-complexity worked-out problem, the participants were prompted to generate explanations. The prompted question for the above example would be:
What is a flow mark? Why does low injection speed will create a flow mark? What is a blister? How come the tool or material can become too hot?

(b) Instructional explanation (group 2):

The procedures for the instructional explanation group was exactly the same as the steps used in group 1. The only difference between the two groups was that the participants in group 2 were provided with instructional explanations instead of prompted to self-explain.

(c) For the control group:

The participants were required to study from the learning courseware but were not presented with any worked-out problems.

4 Results

4.1 Is there a different between instructional explanation and self-explanation prompts in topic knowledge acquisition, near and far transfer performance?

The research outcomes revealed that the learners who were prompted to self-explain may acquire more topic knowledge (Table 3) and tended to achieve higher gain scores in near transfer tasks (Table 4). In contrast, the learners who were provided with instructional explanations did not achieve the same performance level as the prompted learners did. In other words, self-explanation prompts demonstrated a superior effect on knowledge acquisition and near transfer performance in comparison with instructional explanation. In terms of far transfer performance (Table 5), there were no significant differences found between the instructional explanation, self-explanation prompts, and control groups.

	Control Group	Instructional Explanation	Self-Explanation Prompt
Pre-test: topic knowledge acquisition	6.25 (1.11)	6.26 (1.01)	5.32 (1.60)
Post-test: topic knowledge acquisition	6.29 (1.33)	6.83 (1.03)	6.92 (1.29)
Gain score (change from pre- to post-test)	+ 0.04	+ 0.58	+ 1.60

Table 3: Topic knowledge acquisition.

	Control Group	Instructional Explanation	Self-Explanation Prompt
Pre-test: near-transfer	9.69 (2.58)	11.96 (3.71)	10.88 (4.10)
Post-test: near-transfer	9.73 (2.02)	12.22 (3.22)	13.96 (3.27)
Gain scores	+ 0.04	+0.26	+3.08

Table 4: Near transfer performance.

	Control Group	Instructional Explanation	Self-Explanation Prompt
Pre-test: far-transfer score	8.19 (3.00)	8.54 (2.34)	7.98 (3.41)
Post-test: far-transfer score	9.50 (2.87)	11.20 (3.39)	10.24 (3.01)
Gain score	+ 1.31	+2.66	+2.26

Table 5: Far transfer performance.

In short, self-explanation prompts demonstrated a superior effect on knowledge acquisition and near transfer performance in comparison with instructional explanation. In terms of far transfer performance, there were no significant differences found between the instructional explanation, self-explanation prompts, and control groups.

4.2 Is there a relationship between topic interest and topic knowledge acquisition, near and far transfer performance?

The data analysis demonstrated that topic interest did not play an influential role in topic knowledge acquisition ($r(72) = 0.07$, $p > 0.05$) and near transfer performance ($r(72) = 0.09$, $p > 0.05$). The possible explanation for this outcome might be that high topic interest learners might tend to engage more in the more difficult and challenging questions which require deeper cognitive processes. The topic knowledge items were largely focused on retrieval of information, and the near transfer problems were superficially and structurally similar to the worked-out problems, therefore it is argued that solving those problems might not involve complicated cognitive processes. This might be the reason why high topic interest learners were not interested in putting enough attention on topic knowledge and near transfer problems, but on far transfer problems.

Contrary to topic knowledge acquisition and near transfer performance, a statistically significant correlation was found between topic interest and far transfer performance ($r(72) = 0.23$, $p < 0.05$, $r^2 = 0.05$). This relationship appears to suggest that learners with high topic interest are likely to get involved in more challenging and complicated tasks.

4.3 Is there a relationship between mental effort and learning performance?

The results (refer Table 6) reveal that the relationship between mental effort and test performance was positive, but it was too weak and not statistically significant. That is to say, a high mental effort investment does not guarantee a fruitful learning performance.

			Accumulative Mental effort	
Control Group	Pearson Correlation	PS score	,22	
	Sig. (2-tailed)		,31	
Instructional explanation	Pearson Correlation	PS score	,15	
	Sig. (2-tailed)		,50	
Self-explanation	Pearson Correlation	PS score	,01	
	Sig. (2-tailed)		,98	

Table 6: Correlations between accumulative mental effort and problem-solving score.
(PS = problem solving)

Perhaps the findings from Borghans, Meijers and ter Weel (2008) can serve as a support for the present outcomes. According to the authors, the performance on a cognitive test depends on both an individual's level of cognitive ability and non-cognitive factors, such as the willingness to put mental effort towards complicated problem solving tasks in the absence of extrinsic rewards. They suggest two reasons for their findings. First, students, who have a positive attitude towards work and are motivated to perform well, might tend to do their best on a test without considering the rewards offered. Second, students only put mental effort in a task when there are sufficient rewards. Although the authors did not conduct direct measurement of mental effort invested by the research participants, their findings seems to suggest that test performance might be dependent on the cognitive (e.g., problem solving skills) and non-cognitive factors (e.g., interest) but not directly influenced by the level of mental effort investment.

4.4 Is there a relationship between topic interest, mental effort, and learning performance?

The present research has come up with an equivocal relationship between topic interest, mental effort, and test performance (see Table 7). The relationship seems to be dependent on the instructional approaches. In the non-explanatory instructional condition (the control group), there was a significant relationship between topic interest, mental effort, and test performance. For the explanatory instructional conditions (the self-explanation prompts and instructional explanation), there was no significant relationship between the variables.

			PS Score/ performance	**Accumulative mental effort**
Control Group	Pearson Correlation	PS Score	-	,22
		Topic Interest	,49	,38
	Sig. (1-tailed)	PS score	,	,16
		Topic Interest	,008	,03
Instructional Explanation Group	Pearson Correlation	PS Score	-	,01
		Topic Interest	-,14	-,30
	Sig. (1-tailed)	PS score	,	,25
		Topic Interest	,39	,32
Self-Explanation Group	Pearson Correlation	PS Score	-	,15
		Topic Interest	-,06	-,11
	Sig. (1-tailed)	PS score	,	,49
		Topic Interest	,25	,07

Table 7: Pearson correlations (topic interest, problem-solving scores, and accumulative mental effort).

Taken together, student with high topic interest is likely to invest more mental effort on a problem-solving task, and the problem-solving performance is influenced by topic interest rather than the amount of mental effort. For the explanatory instructional conditions (the self-explanation prompts and instructional explanation), there was no significant relationship between the variables. This result suggests that problem-solving performance is not likely to be influenced by topic interest and mental effort investment if the student is involved in explanatory activities.

5 Conclusions

The present findings provide some contributions to the body of literature. Numerous studies have shown that self-explanation prompts have a facilitative effect on learning in well-structured domains, such as mathematics, biology, and physics. The present research largely supports the conclusion that the positive effect of self-explanation prompts can be generalised into ill-structured domains, like manufacturing technology, using multiple low-to-high complexity worked-out problems within a computer-assisted instructional environment. The results suggest that the stimulation of cognitive processes by self-explanation prompts might result in a better topic knowledge acquisition and near transfer performance, but not in far transfer performance, for novice learners. In terms of far transfer performance, the provision of instructional explanations works as well as self-explanation prompts, despite having a tendency to outstrip self-explanation prompts.

Apart from the above, the present findings show that the topic interest does not have an impact on topic knowledge acquisition and near transfer performance, but that it does positively affect far transfer performance. Meanwhile, it has also been found that the learning performance is not dependent upon the quantity of invested mental effort. When topic interest, mental effort, and test performance were concurrently analysed, the result suggests that the relationship varies according to the different instructional conditions. The test performance is dependent upon topic interest and mental effort investment when there is no any explanatory activity involved. However, when explanatory activities are applied in instruction, the test performance is not likely to be influenced by the levels of topic interest and mental effort investment

6 Educational and Scientific Importance of the Study

The results from this study appear to be important for scientific and educational development. The yielded results have brought the relevant body of knowledge a step forward. For example, it is learned that the positive effect of self-explanation prompts in worked-out-problem-based learning is not only visible in well-structured learning domains, but also traceable in an ill-structured learning domain, especially in manufacturing technology. This findings is absent in the previous literature. Furthermore, the research outcomes have also shed additional light on the relation between the cognitive load and instructional strategies. For instance, the present finding confirms the assumption that self-explanation prompts induce higher cognitive load during learning process, but the self-explainers may experience lower mental effort investment on a test. Apart from that, the findings have also suggested that the relationship between topic interest, mental effort, and test performance is dependent upon the instructional conditions. This finding is important because it provides clues to an instructor about how an instructional activity or material should be optimally conducted or designed when an explanatory activity is involved.

In addition, the current findings have several practical implications for structuring and designing such an instructional environment to facilitate the development of cognitive functioning and the construction of mental models. First, in order to eliminate, or at least reduce the students' knowledge gaps, the worked-out problems have to be carefully designed. The present research suggests that the worked-out problems presented to students should be conceptually connected in order to allow students to organise and interrelate the important information from multiple worked-out problems. In addition, a mechanism (e.g., asking diagnostic questions) should be developed to raise students' awareness of the knowledge gaps and identify the flawed knowledge representation in their knowledge base.

Second, worked-out-problem-based learning using low-to-high complexity worked-out problems appears to be effective, at least on topic knowledge acquisition and near transfer performance. This is especially the case when the learning is supported by self-explanation prompts. In order to produce a more fruitful learning outcome, particularly in far transfer performance, the self-explanation prompt procedures should be further optimised. There are at least three possible ways for improvement, namely, (i) to ensure high quality of explanations generated by learners. This can be achieved by providing more comprehensive learning materials and contents to allow the learners to acquire sufficient entry knowledge; (ii) to conduct group-based self-explanation prompts, which means the learners in a small group are prompted to generate explanations. By doing so, the knowledge of individual group members can be complementary to other members and serve to build a more complete knowledge representation, which may enable them to generate higher quality explanations (e.g., explanations based on domain principles); (iii) to increase the frequency of self-explanation prompts. Prompting learners to self-explain more often may actively provoke the processing of information and, at the same time, help the learners to detect more knowledge gaps. A more complete mental model can be formed when more knowledge gaps are eliminated.

Third, when explanatory events are incorporated into an instructional strategy, the instruction designer should place more stress on the learning activities and procedures instead of focusing on mental effort investment and topic interest. In addition, the learning materials should include tasks with different levels of complexity to cater for the needs of students who have different degrees of topic interest.

Last but not least, many important ideas for future research have been generated from the present study. These include, just to name a few, (i) placing the focus on higher-level factorial experiment by using more factors. For instance, learners could be classified into low and high topic interest, and low and high mental effort investment to examine the interaction effect between these variables; (ii) using multiple assessment methods to enhance the validity of assessment outcomes; (iii) investigating mid-term or long-term effect on learning under the influence of topic interest; and (iv) conducting an aptitude-treatment interaction studies to find out some information concerning whether different modes of complex worked-out problem presentations can be more or less effective for particular learners, for example, low versus high entry knowledge learners. Insights gained from such studies could assist in the development of more effective worked-out problems and instructional strategies.

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