The effect of cognitive preferences and prior knowledge on web-mediated instruction

Marlina MOHAMAD
RMIT University, Melbourne, Australia
Universiti Tun Hussein Onn Malaysia, Parit Raja, Malaysia
marlina.mohamad@rmit.edu.au

Elspeth McKAY
RMIT University
Melbourne, Australia
elspeth.mckay@rmit.edu.au

ABSTRACT

This paper reports the results of quasi-experimental research aimed at investigating the effects of prior knowledge and cognitive preferences on learning introductory programming concepts through web-mediated instruction. Participants in this study included 125 students classified as both novice and experienced learners. Each group received either text-plus-textual or text-plus-graphical web-mediated instructional formats. The results show that novice and experienced students learn differently from web-mediated instruction. Novice participants benefited more from the text-plus-textual format while more experienced participants preferred the text-plus-graphical format. This finding suggests that the design of effective web-mediated instruction should take into account the level of prior domain knowledge of the targeted users.

Keywords: *Cognitive style, prior knowledge and web-mediated instruction.*

INTRODUCTION

For several decades now, the practice of teaching (and learning) has undergone significant changes as it has developed from more traditional approaches to incorporating constructivist approaches towards knowledge construction (Verhoeven et al., 2009). The basis of constructivist learning theory is that the construction of knowledge involves linking new information with prior knowledge and individual experiences. Knowledge construction (or acquisition) demands various cognitive mapping processes in order to construct a coherent mental representation. These processes include selecting relevant information, organising selected information and integrating information with prior knowledge, and such information (online instruction) is usually presented in the format of so-called multimedia (Mayer, 2005).

Recent developments in web-mediated instruction in educational settings assume that a highly graphical multimedia instructional format constitutes effective and attractive learning (McKay, 2007). According to Sorden (2005), this type of format might be effective to hold the attention of some learners, but may hinder learning for others. Ensuring effective knowledge construction in web-mediated instruction depends on various interaction factors. Khan (2001) clustered these factors under the following areas: pedagogical, technological, interface design, evaluation, management, resource support, ethical and institutional. Among these factors, ethical considerations, which relate to individual differences, will be a focus of this paper. As learners differ from one another, it is important to develop web-mediated instruction that is able to accommodate these differences (McKay, 2000). For instance, novice and experienced learners apply different cognitive strategies when constructing new knowledge, with novices preferring a more structured strategy over a constructed strategy (Tennyson & Bagley, 1991). Furthermore, Mayer's multimedia principle suggests that people learn better from text and graphics than from text alone (Mayer, 2001).

Therefore, the aim of this study is to gather more evidence on the effects of individual differences (prior knowledge and cognitive preferences) on knowledge acquisition with both the text-plus-textual format and the text-plus-graphical instructional format, delivered via web-mediated technology.

LITERATURE REVIEW

People learn better with text and graphics rather than text alone. This is the main assumption of the multimedia principle of cognitive theory of multimedia learning (Mayer, 2005). One explanation for this is that people understand more deeply when they can mentally connect the graphical and verbal representations of an explanation or piece of information, and this is more likely to occur when materials are presented in a multimedia format (Mayer, 2002). However, the multimedia principle is not always applicable to knowledge acquisition, which sometimes may be strongly affected by the task-appropriateness of the instructional representation (Schnotz & Bannert, 2003). Furthermore, according to the expertise reversal effect, the instructional format that is effective for novice learners may hinder learning for more experienced learners, and vice versa (Kalyuga et al., 2003). This opinion is supported by a number of studies that have demonstrated the interactions between the level of prior domain knowledge and instructional strategies. For instance, an empirical investigation conducted by Kalyuga (2008) reveals the presence of the expertise reversal effect within instructional formats. The result suggests that novices benefited more from static diagrams than from animated diagrams, whereas more knowledgeable learners gained greater advantage from animated diagrams. Furthermore, Park et al. (2009) demonstrate that low prior knowledge learners show higher learning efficiency when using low interaction simulation, while high prior knowledge learners display higher learning efficiency with high interaction simulation.

Designing and developing web-mediated instruction is a difficult task in that it must meet the needs of diverse users (Chen & Macredie, 2010). Various human factors have been identified to have significant impacts on web-mediated instruction such as gender differences, prior knowledge and cognitive styles. This study examines cognitive preferences—one of the key dimensions of individual differences. Riding and Cheema (1991) propose that there are two dimensions of cognitive preference or style, labelled as the wholist-analytic and verbaliser-imager dimensions. The wholist-analytic dimension describes the way an individual tends to process information as a whole or in parts, while the verbaliser-imager dimension explains the preferences of individuals to represent information during thinking, either verbally or in images.

The findings from Riding and Douglas's (1993) research demonstrated that imagers performed better when the materials on a motor car's braking systems were presented in a text plus illustration format rather than text alone, while verbalisers scored equally on the text-plus-text format and the text-plus-illustration format. These findings are supported by research by Lee (2007), which examined users' learning performance when learning how to build a personal homepage using visual metaphors and a hyperlink interface. The author explored how users' cognitive styles affected learning performances. The findings from the interaction analysis of presentation modes and cognitive styles suggest that verbalisers tend to prefer a hyperlink interface. For instance, the wholist-verbaliser performed better when learning with a hyperlink interface but did not benefit from a visual metaphor interface. The learning of imagers, on the other hand, whether wholist or analytic, was enhanced with the visual metaphor interface. More interesting, the analytic-verbaliser participants were more flexible in selecting their preferred learning strategies when presented with any interface in order to develop their mental models. Therefore, developing learning materials in the visual-metaphorical mode might be effective on users with different cognitive styles, particularly in developing mental models.

METHOD

A quasi-experimental 2 x 4 factorial research design was implemented in 2009 to observe and analyse the variables. Two independent variables were used: instructional strategy (text-plus-textual and text-plus-graphic), and cognitive style preference (wholist-verbaliser, wholist-imager, analytic-verbaliser and analytic-imager). This study applied non-equivalent group design which involved a pre-test and post-test for two different treated groups (Trochim, 2001; Trochim & Donnelly, 2006). One can assume that the groups in this study are non-equivalent due to the lack of randomisation in assigning participants to them. Thus, the non-equivalence of the groups in this study denotes that each group received different treatment. The rationale of this design is based on the unfeasibility of randomly assigning participants from different universities in specific classes, occasions, treatments and groups (Trochim, 2001). Therefore, it was not possible to implement randomisation.

Materials

The online instructional modules: These materials were developed in two versions in a web-mediated environment, according to McKay's (2000) treatment booklets (however, her study was conducted in the context of paper-based instruction). Instead the two formats for this online study were a text-plus-textual metaphor (T1) and a text-plus-graphical metaphor (T2). The learning content was developed based on a lesson plan at a Malaysian university. However, the instructional format, programming concepts and examples of the C++ program were established according to the work of McKay (2000), Deitel and Deitel (2008), Malik (2008) and Zak (2008). The objective of this online module was to develop algorithms and programming which use the While, Do While and For control structures using C++ language. Instruction for the text-plus-textual and text-plus-graphical module commenced with instructional strategies on how to browse the module. The learning content consisted of six sub-topics: (1) logic pattern (control structure) defined; (2) repetition using the While control structure; (3) repetition using the Do While control structure; (4) repetition using the For control structure; (5) comparison of While, Do While and For control structures; and (6) example algorithms and problems in C++.

The Experiment

The participants received the instructional modules in sequential order. However, participants were able to browse the module at their own pace by using the mouse and clicking the 'next' or 'previous' button to view the next or previous topic (this button was located at the bottom right corner of each instructional frame). To browse a sub-topic, the participant could click on the 'next or previous' button which appeared at the bottom left corner of frames which had a sub-topic. Furthermore, to obtain more knowledge on certain topics, participants were allowed to browse a topic by putting a mouse over the graphic or coloured text. Figure 1 shows an excerpt of the text-plus-textual format and Figure 2 shows an excerpt of the text-plus-graphical format for the same learning topic.

The computer executes a repetition statements one or more while (or until) condition tests true.

```
start
while <expression>
    statement
end
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Figure 1: An excerpt of the text-plus-textual format (T1).

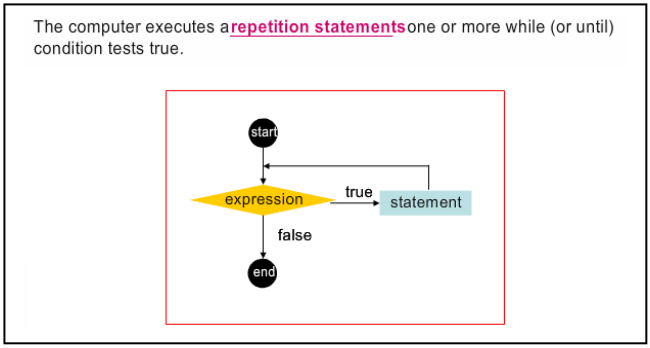

Figure 2: An excerpt of the text-plus-graphical format (T2).

Practice Problem Booklet: Learning procedural knowledge requires practice. This booklet allowed participants to practise what they had learned from the web-mediated instructional module. The participants were required to apply six problem-solving steps to two new problems. By repeating this process, participants could build schemas and reinforce their learning (Jonassen, 1997). As Jonassen states, '[*the combination of worked examples plus extended practice is most likely to facilitate the acquisition of problem schemas and the transfer of those schemas to novel problems*' (Jonassen, 1997, p. 12).

Measures

A *Cognitive Style Analysis (CSA)* (Riding & Rayner, 1998): This research used as a screening test to classify cognitive style preference (wholist-analytic and verbal-imagery). The computer-based test consists of three sub-tests. The verbal-imagery ratio is determined in the first sub-test by identifying whether the relationship between two words is such that they belong to the same category. For instance, fork and shovel are in the same group. The second sub-test establishes the wholist-analytic ratio, and comprises two sets of geometric images. In the first, the individual needs to decide whether two shapes are the same or different. This sub-test determines a wholist dimension of style. The second task requires the individual to make judgements about whether one geometric shape, shown to them first, is embedded in a more complex geometric figure shown to them next to the first figure. This sub-test determines an analytic dimension of style. The participants are required to respond by simply pressing a 'true' or 'false' button for each question. To determine an individual's position in relation to each style dimension, the computer compares the response times for verbal and imagery items and wholist and analytic items.

Pre-test: The test for prior domain knowledge consisted of 41 test-items. The participants completed this paper-based pre-test before being given access to the online instructional module. Of the test-items, 20 were dichotomous and 21 were partial credit (up to 4 levels). For test-items that required a clear-cut answer, a dichotomous scoring strategy was adopted such that the value of 0 represented an incorrect answer and 1 was the result for a correct answer. This dichotomous scoring is usually found on the test-items where learning outcomes require knowledge and skill related to verbal information. Problem solving in programming usually involves an ordered sequence of steps, such as writing an algorithm to calculate monthly pay. For this type of question, partial credits were assigned values of 0, 1, 2, 3 and 4 based on the appropriate strategies applied, that is, partial marks were awarded for partially correct responses. One partial credit item received a score of 0, 1 or 2, while another received a score of 0, 1, 2 or 3, with the maximum being 4.

The test-items were structured from easiest to most difficult. The rationale for this was to reduce the stress for participants as this test was administered prior to them accessing the online module. The pre-test was designed to test 14 learning domains in relation to the abstract concepts of programming knowledge. These concepts were defining diagrams, the programming process, basic mathematics, control structures, including sequential, conditional and repetition, the characteristics of While, Do While and For, programming using While, Do While and For; and solution algorithm. These 14 learning domains constitute the three levels of Gagne's instructional sequence theory (1985). These include verbal information (basic skill), intellectual skill (intermediate skill) and cognitive strategy (advanced skill).

Post-test: There were 7 new test-items used in the post-test within the 41 overall test-items. Again, 20 dichotomous test-items and 21 partial credit test-items were used in the post-test. The new test-items were designed to be more difficult than those in the pre-test. For instance, in the pre-test, one question was 'Add 2 to the variable *myAge* and assign the new value to *myAge*', while in the post-test, the similar item was written as 'Write a statement to increase the variable *myGrade* by 2'. These test-items were designed to measure the same verbal information skill but were not identical in wording. All test-items were randomly structured to reduce the memory effect that might be resulting from the pre-test. Consequently, both the pre-test and post-test were intended to measure the same construct.

Participants

The quasi-experiment was conducted in two Malaysian universities. Forty undergraduate students from the Bachelor of Technique and Vocational Education course and 85 undergraduate students from the Bachelor of Bioprocess Engineering course participated in this study. The former were classified as a novice group and the latter were classified as an experienced group. Their participation was voluntary. The novice group was assumed to have little or no knowledge on programming as they had no previous experience in studying introductory programming. Whereas the experienced group was deemed to have prior knowledge of introductory programming as they had enrolled in this subject during the previous semester. Table 1 presents the data on the participants in terms of their cognitive style.

Table 1: Cognitive Style Groups.

Cognitive style	Novice n=40	Experienced n=85
Single Dimension Cognitive Style (SDCS)		
Wholist	16	37
Analytic	24	48
Verbaliser	20	40
Imager	20	45
Integrated Cognitive Style (ICS)		
Wholist-verbaliser	7	15
Wholist-imager	9	22
Analytic-verbaliser	13	25
Analytic-imager	11	23

Procedure

The quasi-experiment was conducted on two separate days. It commenced with the CSA test on day 1, which was conducted in the computer lab According to the CSA results, the participants were randomly assigned to treatments, receiving either T1 or T2. On day 2, which was held during week 8 of their normal semester, participants received the pre-test first. The pre-test consisted of 41 test-items ordered according to their level of difficulty. The easier test-items preceded the more difficult test-items to reduce the students' stress in answering questions in a new learning environment. They were then required to learn about introductory programming, particularly the subject of repetition control through a web-mediated instructional system. During the instruction period, they were given a practice problem booklet to assess their understanding of the topic being learned. Immediately after they completed the instruction, they received the post-test. The post-test also consisted of 41 test-items, but it was ordered randomly regardless of difficulty level to reduce the memory effect from the pre-test.

DATA ANALYSIS

The validity and reliability of the measures (instruments) were confirmed in the first instance according to Rasch's model using Quest Interactive Test Analysis System software (QUEST) (Adams & Khoo, 1996). The validity and reliability of the measures was reported in Mohamad and McKay (2010). Quantitative researchers in social science tend to concentrate more on statistical analyses, rather than focusing their efforts on ensuring the quality of measures they use to obtain the data for these statistics (Bond & Fox, 2007). In this regard, the 2009 study attempts to provide an objective measure to capture more evidence to justify the findings. Further analyses conducted in the 2009 study were based on the effect sizes in order to report the interaction of prior knowledge and cognitive styles in the acquisition of programming concepts through web-mediated instruction. The Cohen's *d* effect size (Cohen, 1977) was utilised to compare the magnitude of difference between groups. Because the participants were volunteers, not all were keen to take the time to finish the whole procedure. Only those participants who completed the whole experiment were included in the data analysis.

RESULTS AND DISCUSSION

A mean analysis of the QUEST outputs was conducted to measure the effect of prior knowledge, cognitive style and instructional treatment on cognitive performance. Performance was measured using the difference estimate logit-value (*dlv*). The value was obtained by subtracting the post-test estimate logit-value (*polv*) from the pre-test estimate logit-value (*prlv*). The results showed that the experienced group (mean= - 0.67, median= -0.72) out-performed the novice group (mean= - 1.34, median=0.58) in the pre-test (see Figure 3), as earlier anticipated. The box-plots were created according to the QUEST estimate logit values.

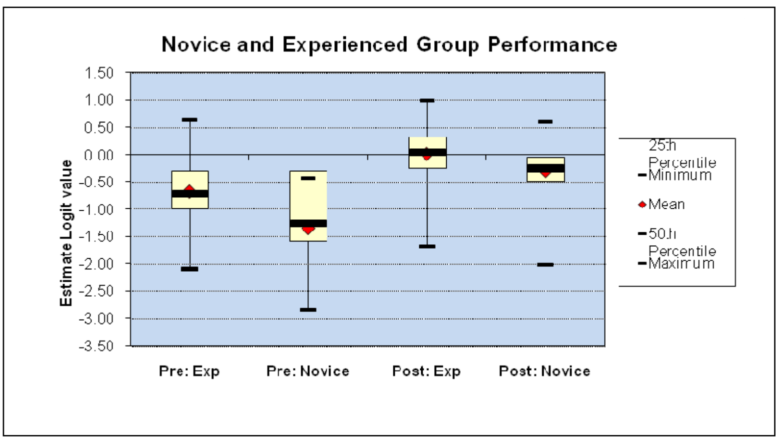

Figure 3: Novice and Experienced Groups Performance on Pre- and Post-test.

The results parallel the conclusions of cognitive load theory (Sweller et al., 1998), which posits that working memory is severely limited. It can only store about seven elements at a time when dealing with novel information (Miller, 1956). Human expertise (whether novice or experienced) varies according to knowledge schemata stored in the long-term memory (van Merrienboer & Sweller, 2005). The knowledge schemata possessed by experienced learners allows them to integrate information into a larger chunk and be treated as a single element. This cognitive process reduces the working memory limitations and thus develops the ability to combine information into more complex ideas. In contrast, when dealing with new information novices have little or no knowledge schemata available to them, and therefore have limited capacity and duration in their working memory, reducing the number of elements they can process simultaneously. Likewise, the experienced group (mean=0.02, median=0.04) displayed better performance on the post-test than did the novice group (mean= -0.30, median= -0.25). Both the novice and experienced groups showed improved performance from the pre-test to the post-test, irrespective of the treatment they received.

The results of the mean analysis and effect size for the novice and the experienced group are summarised according to a single dimension of cognitive style (SDCS) in Figure 4 and Figure 5, respectively. For the novice group, all the SDCS groups achieved greater improvement with T1 than with T2. The verbalisers were the best performers, with a mean improvement of *dlv*=1.24, *d*= 0.67. The second best performer was the analytic group with a mean improvement of *dlv*=1.19, *d*= 0.86 when given the same treatment. However, the size of the effect for the analytic group was large and for the verbaliser group, medium to large.

Conversely, all the SDCS groups in the experienced group obtained greater improvement with T2 than with T1. The wholist, verbaliser, imager and analytic groups had successive higher means of improvement in T2, with *dlv* mean values of 0.71, 0.75, 0.76 and 0.78, respectively. The Cohen's *d* for analytics was medium (0.52) and Cohen's *d* for the rest of the SDCS groups were calculated to have a small practical significant effect.

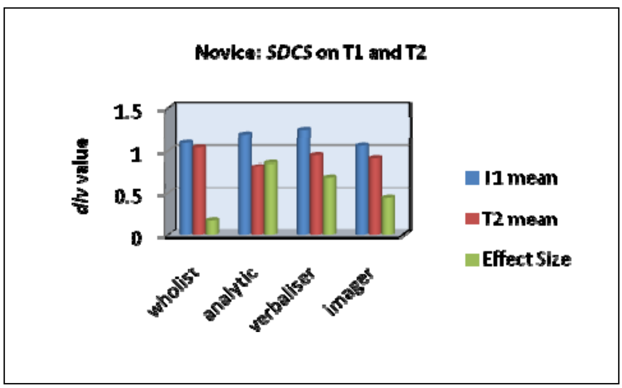

Figure 4: Novice Single Dimension Cognitive Style Groups -Performance on T1 and T2.

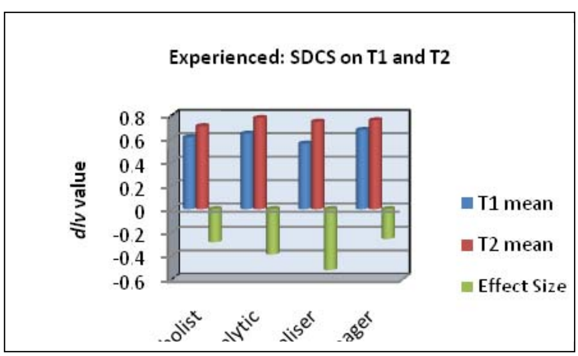

Figure 5: Experienced Single Dimension Cognitive Style Groups - Performance on T1 and T2

Integrated cognitive style was analysed to investigate the effect it has on instructional treatments. Two groups were compared, the novice and the experienced group on the effect of integrated cognitive style (ICS) on T1 and T2. The mean analysis and effect size were calculated to determine the statistical and practical significant difference between the groups and treatments. Figure 6 shows the results for the novice group. The analytic-verbaliser group given T1 was the top performer (mean dlv= 1.32). The Cohen's *d* was computed to be 0.94, indicating a large effect size. The other ICS groups given T1 out-performed the groups given T2, except for the wholist-verbaliser group which performed better in T2 than in T1.

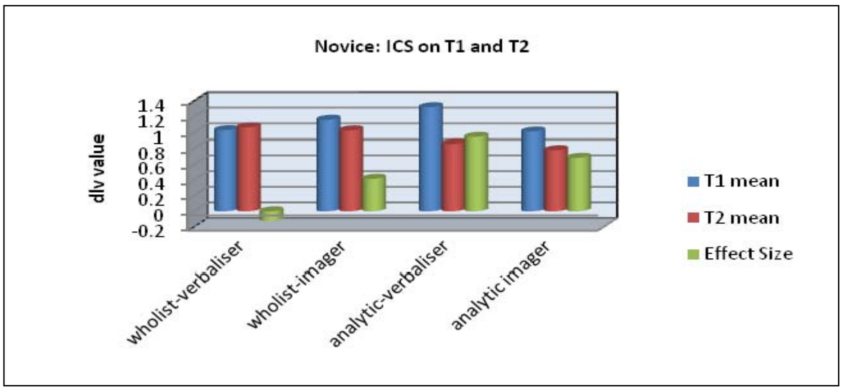

Figure 6: Novice Integrated Cognitive Style Groups - Performance on T1 and T2

The ICS groups of experienced students (see Figure 7) showed a degree of variance in their performance. In general, all ICS groups performed better with T2 than with T1, with the exception of the wholist-imager group (T1 *dlv* mean= 0.75, T2 *dlv* mean=0.70, d=0.14). The wholist-verbaliser group was found to have a large practical significant difference (d= -1.07) on instructional treatments. A medium to large effect was calculated for the analytic-imager group (T1 *dlv* mean= 0.60, T2 *dlv* mean= 0.81, d=-0.71).

Figure 7: Experienced Integrated Cognitive Style Groups -Performance on T1 and T2

Figure 8 shows the interactive effects for the novice group. A significant effect was found for the analytic-verbalisers and analytic-imagers, which performed better on the text-plus-textual metaphor than on the text-plus-graphical metaphor. Conversely, the wholist-verbaliser showed enhanced performance when given T2. The wholist-imager performed slightly better in T1 than in T2.

Figure 9 illustrates the interactive effects of integrated cognitive style and instructional format on cognitive performance for the experienced group. In contrast to the results for the novice group, the cognitive performance of the analytic-imager was superior with T2 than with T1. The wholist-verbalisers in the experienced group showed significantly better performance in T2 than did those in the novice group. Further, there was no significance effect for the wholist-imager group on both treatments as they performed slightly better in T1 than in T2.

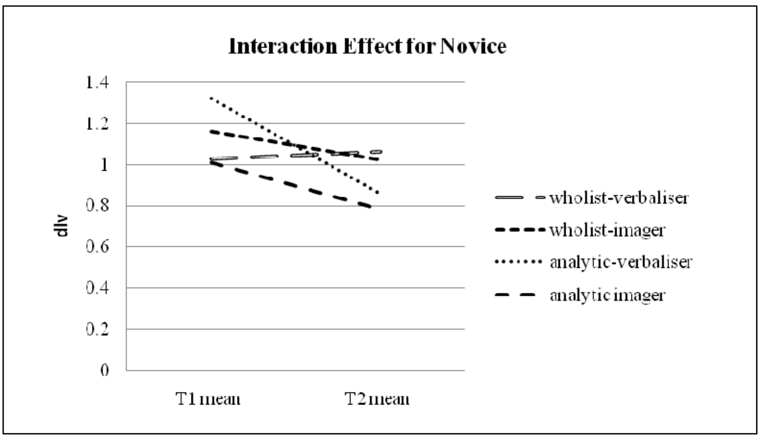

Figure 8: Interactive Effect - Novice Group.

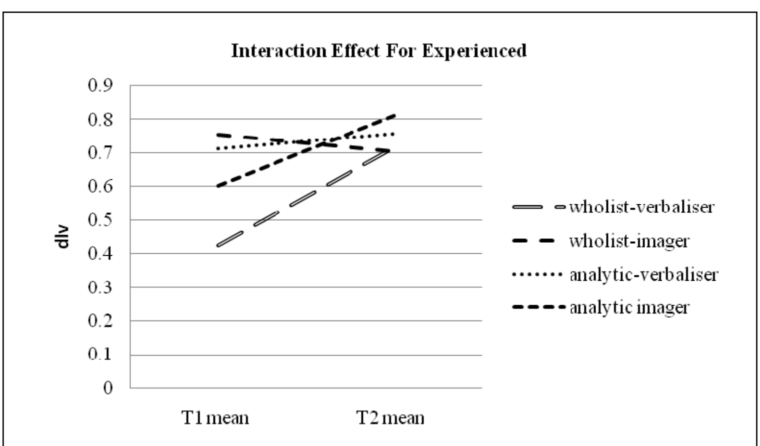

Figure 9: Interactive Effect - Experienced Group.

CONCLUSION

Web-mediated or web-based instruction comes in various formats or screen-based representations. These instructional formats include verbal (written or auditory), graphical, or a combination of both formats. This paper demonstrates the interactive effects of instructional formats with prior domain knowledge and cognitive style. This paper proposes that novices and experienced learners possess different preferences when learning from web-mediated instruction, with novices showing preferences for textual formats and more experienced learners working better with multimedia formats, regardless of their cognitive styles. In conclusion, parallel with the expertise reversal effect as proposed by Kalyuga et al. (2003) and other researchers such as Park et al. (2009), the findings suggest the need to consider the prior domain knowledge of the targeted students when designing web-mediated instruction, particularly in relation to teaching introductory programming language.

With regards to cognitive learning preference, the findings show no clear evidence that imagers learn better with text-plus-graphical formats or that verbalisers prefer the text-plus-textual format. Rather, learning ability is strongly influenced by the level of prior domain knowledge. Experienced imagers improve most with instruction that naturally suits their preferences because it may help create spontaneous mental pictures (Riding & Sandler-Smith, 1992). In addition, this learning process may be assisted by the available knowledge base among experienced learners.

Experts and novices may differ in the way in which they represent information (Chi, 2000). Identifying how students form their strategies when navigating web-mediated instruction is important. Attention should also be given to how learning materials should be organised to maximise student learning and ease of the knowledge development navigation. As novices and experienced learners tend to represent various types of information and knowledge differently when learning through web-mediated environments, further research is recommended. Dealing with novel information is difficult for novices, particularly without an appropriate instructional format, and they may experience cognitive overload, which thus reduces their performance.

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