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Impact of Multimedia Instructional Materials on Creative Thinking

Hafizoah Kassim[1*], Wan Ng[2] and Howard Nicholas[2]
[1]Centre for Modern Languages and Human Sciences,
Universiti Malaysia Pahang, Pahang, Malaysia
[2]Faculty of Education, La Trobe University, Australia
[*]E-mail: hafizoahkassim@gmail.com

ABSTRACT

This study aimed to investigate the impact of utilising multimedia instructional materials (MIM) on engineering students' creative thinking in Malaysia. Fifteen MIM were developed based on the principles of Cognitive Theories of Multimedia Design (Mayer, 2001) and Cognitive Load Theory (Sweller et al., 1998). The MIM were used by 27 mechanical engineering students in lab sessions over a period of 5 weeks. Torrance Tests of Creative Thinking (TTCT) verbal forms A and B were administered to the students as pretest and posttest respectively to measure students' creative thinking in terms of fluency, flexibility, originality, and overall creativity capabilities. Two semi-structured focus group interviews were also conducted with five volunteer students in each group. Data were analysed using a paired sample t-test comparing pre and posttests results and also between genders. The t-test analysis shows that there was a significant increase in the students' creative thinking in the posttest for all the creative thinking elements stated. Students' responses during the interview supported the statistical findings.

Keywords: Cognitive load, creative thinking, multimedia learning

INTRODUCTION

Creativity requires knowledge. Creative acts do not simply appear in a flash although it is undeniably true that some individuals are naturally gifted with such a talent (Guildford, 1950). For all other individuals born without the natural gift of creative potential, creativity is a skill that can be learnt (Amabile, 1998). It requires among other things, knowledge, and it entails the cognitive interplay between new and existing knowledge (de Bono, 1990; Sweller, 2009). De Bono (1990) states that the cognitive process of creativity involves the ability to use and communicate ideas, and how new and old ideas are manipulated to create one's own novel ideas. This cognitive manipulation of ideas and knowledge is part of the complex phenomenon of the human cognitive system which is often explored as an information processing system (Sweller, 2009). A system which includes working memory, long term memory and schemas, and how these three components are able to process, integrate, and transform information into knowledge which might lead to novel ideas.

The advancement of knowledge and changes in how information can be represented in today's technological era also affect how information can be cognitively manipulated. The growth of computer technology has made it possible to transform commonly static and paper-based representations into pictorial and dynamic representations (Mayer, 2001). It was generally based on this development that Cognitive Load Theory (CLT) (Sweller et al., 1998) and Cognitive Theory on Multimedia

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[*]Corresponding Author

Design (CTMD) (Mayer, 2001) were proposed in order to address how multimedia instructional materials can be designed effectively to ensure appropriate load on learners' cognitive systems, and therefore, facilitate meaningful learning.

Studies of multimedia learning are not entirely new in educational research. The emphasis has however been mostly on retention, transfer and problem-solving performance (Mayer and Anderson, 1992; Mayer et al., 2007; Paas et al., 2007; Seufert and Brünken, 2006). The literature that relates the significance of multimedia learning to the enhancement of creative thinking is scant. Sweller (2009) has recently described the human cognitive architecture based on evolutionary biology and instructional processes (in relation to CLT) that could facilitate creativity. There is however no description of the cognitive architecture and its association with multimedia learning. This study, therefore, was an attempt to investigate whether the use of multimedia instructional materials (MIM), which were designed based on four principles of CTMD, could enhance engineering students' creative thinking.

APPROPRIATE DESIGN OF MULTIMEDIA INSTRUCTIONAL MATERIALS FOR CREATIVE THINKING

This study has its basis in cognitive load, multimedia learning, and creativity theories. *Fig. 1* depicts the framework which was used for the design of the MIM. The framework was adapted from the principles of CTMD and CLT (Mayer, 2001; Sweller et al., 1998). The framework considered the load on students' cognitive system in order to ensure that information can be processed appropriately to assist students in the enhancement of their creative thinking.

Cognitive Load and Multimedia Instructional Design

Cognitive Load Theory (CLT) focuses its argument on the assumption that effective and meaningful learning occurs when the interaction between the architecture of the human cognitive system and the learning environment is understood and accommodated. There is a need to understand firstly, what is

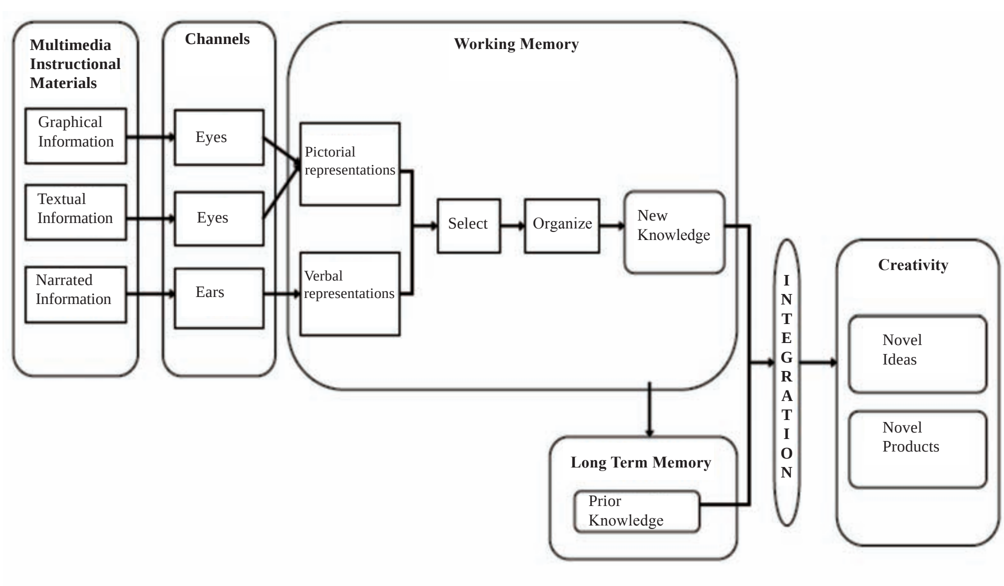

Fig. 1: Framework for the design of multimedia instructional materials to promote creative thinking

involved in building the complex system of human cognition and in what ways the elements function and secondly, how the instructional materials should be designed and developed in order to accommodate this complexity (Cook et al., 2009; Paas and Kester, 2006). CLT posits that the human cognitive system consists of a working memory which is limited in its capacity and duration and the effectively unlimited but schematic long-term memory. Schema is the form in which knowledge in long-term memory is stored, and schema is the categorisation of information according to its manner of use (Sweller et al., 1998). The design of the learning materials should accommodate this structure to ensure that information processed in the working memory can be constructed and transferred into and retrieved from long-term memory without cognitively overloading the working memory (Cook et al., 2009; Paas et al., 2003; Sweller et al., 1998). Appropriate load in the working memory can ensure that students are able to process the interacting elements of information and even process novel ideas in the working memory. Cognitive load in the working memory is therefore an essential part of the human cognitive system that should be considered when designing instructional materials.

According to CLT, there are two types of cognitive load: intrinsic and extrinsic cognitive loads. *Intrinsic cognitive load* refers to the natural load imposed by the complexity and interacting elements of the information which has to be simultaneously processed in working memory. These interacting elements are the different types of information that students have to assimilate from the instructional materials for comprehension, and that the instructors have no control over this load (Ayres and Paas, 2007; Cook et al., 2009; Sweller et al., 1998). *Extrinsic cognitive load* can be further categorised into two: a) extraneous and b) germane cognitive loads. *Extraneous cognitive load* is imposed by design of the instructional materials that can hinder students' understanding whereas *germane cognitive load* is extrinsic cognitive load imposed by instructional materials that can actually foster the learning process (Paas et al., 2007; Sweller et al., 1998). *Fig. 1* shows that both textual and graphical information enter into the cognitive system through the eyes, and the narrated information through the ears. Hence, instructional designers have to ensure that each type of information presented in the instructional materials accommodates the other type. Too much textual information to support a graphical image or narrated information which is not synchronous with the graphics may inflict extraneous cognitive load, and therefore, hinder students' understanding.

Moreover, all the cognitive loads are considered additive in CLT, and together they build the overall construct of cognitive load (Cook et al., 2009; Paas et al., 2007). In order for learning to be maximized, the total load should not exceed working memory capacity. CLT also postulates that learning can be affected by students' individual characteristics. Thus, the design of instructional materials, use of multimedia, complexity of task and even students' characteristics need to be considered to ensure increase in germane cognitive load without increasing extraneous load. When this occurs, schemas can be constructed and transferred into long-term memory, and the interaction between the newly built schemas and previously constructed schemas in the long-term memory may assist in the production or construction of novel ideas.

Principles of Multimedia Instructional Design

Studies of multimedia learning have been conducted for several decades, and the focus has been mostly on the design of the multimedia instructional materials and its impact on students' learning and understanding (Mayer, 2001: 2002). The Cognitive Theory of Multimedia Design which was developed based on numerous studies (Harp and Mayer, 1998; Mayer and Anderson, 1992; Mayer and Chandler, 2001; Moreno and Mayer, 1999; Moreno and Mayer, 2000) lists eight principles of how MIM should be designed. The theory suggests ways to ensure appropriate load on students' cognitive system so that effective learning can be facilitated (Mayer, 2001: 2002). This paper describes four of the principles (Mayer, 2001: 2002) in relation to the design of the MIM used in the study.

- *Multimedia principle*: Meaningful learning can be attained when the MIM include both relevant pictures and words rather than words alone. This is based on the assumption that pictorial information enters into the cognitive system through the eyes while verbal information enters into the cognitive system through the ears. Therefore, both channels of receiving information should be used effectively so that one channel is not overloaded when only one kind of representation of information is presented (Mayer, 2001: 2002).
- *Contiguity principle*: Meaningful learning can be attained when the MIM presents the animated and narrated information simultaneously rather than sequentially. This is based on the assumption that when both the visual and auditory channels are used to enter information into the cognitive system, the chances are high that matching words and pictures may be in the working memory at the same time. Therefore, learners should be able to construct mental connections between them. Studies of this principle indicated that concurrent presentation between animation and narration increases the temporal processing of the cognitive system, reduces overall cognitive load and positively affect students' retention and transfer (Mayer and Anderson, 1992; Moreno and Mayer, 1999).
- *Coherence principle*: Meaningful learning can be attained when the MIM excludes irrelevant and extraneous words, sounds, and animations. This is based on the assumption that extraneous information may increase the extraneous cognitive load, and therefore, overload working memory. Studies by Mayer and colleagues on the insertion of interesting but irrelevant words and pictures (Harp and Mayer, 1998), or sounds and music (Moreno and Mayer, 2000) showed that understanding was negatively affected.
- *Interactivity principle*: Meaningful learning can be attained when the MIM provides students with the ability to control the presentation rate. This is based on the assumption that user interactivity can reduce the chances of cognitive overload by enabling students to be involved in the cognitive process at their own pace. Studies of this principle revealed that as an instructional technique, pacing could assist students to reduce extraneous cognitive load in their cognitive system because pacing allows students to adapt the multimedia presentation to their own cognitive abilities and needs (Hasler et al., 2007; Mayer and Chandler, 2001; Mayer et al., 2003).

Cognitive Process Leading to Creative Thinking

Due to the complexity and mystery of its nature, different researchers and theorists have come up with different interpretations of creativity. Yet, most of them agree that one of the important criteria in being a creative individual is knowledge, and how a person is able to use new information and connect prior knowledge to produce something original, novel and practical (Amabile, 1998). Therefore, based on the framework in *Fig. 1*, in order to relate CLT and CTMD, we are assuming that the design and development of the MIM should consider the students' cognitive system. Since MIM can include graphical, textual and narrated information, the manipulation of these representations of information should ensure that the MIM creates appropriate load in the cognitive system so that new information can be effectively constructed into the learners' new schemas. Newly constructed schemas can be successfully transferred into long-term memory, or they can be manipulated or integrated in working memory with the existing schemas from long-term memory in order to produce novel ideas. Essentially, to develop MIM that would be helpful to enhance students' creativity, students' cognitive load (as outlined in CLT) needs to be considered in the instructional design of the MIM (as outlined in CTMD).

METHODOLOGY

The objective of this study was to explore the impact of multimedia instructional materials on engineering students' creative thinking. On the other hand, learner characteristics such as attitudes, learning styles, academic achievement, and gender are also essential factors in both CLT and CTMD that are worth exploring, but for this study the distinction in the creative thinking results were compared against learner characteristics only in terms of one learner characteristics, gender.

Participants

The sample consisted of 27 third year mechanical engineering undergraduates (20 males and 7 females) from an engineering-based university located in Kuantan, Malaysia. The age range of the students was from 21 to 26 (M = 22.22), and they were all enrolled in a Mechanism Design subject, one of the compulsory subjects required for graduation. Third year students were chosen since many creativity theorists postulated that to illustrate creative abilities, knowledge is a component that plays an important part in the process (Amabile, 1998; Sweller, 2009). When the pilot study was conducted, the participants had completed 17 credit hours of the university compulsory courses and 45 – 50 credit hours of program courses. They had also passed the pre-requisite course, Dynamics.

Materials

Fifteen multimedia instructional materials (MIM) were designed and developed based on the content of chapter one of the textbook entitled *Machines and Mechanism: Applied Kinematic Analysis* by David H. Myszka (2005). A computer engineering student from a different university was recruited to design and develop the MIM. The content of the MIM covered concepts from almost 80% of the chapter, and the topics chosen were based on the topics that were outlined in the course syllabus. There were five main topics with individual MIM and two of them contained multiple sub-topics with several MIMs. The length of each MIM ranged from 13 to 86 seconds (M = 33.69).

The design and development of the MIM were based on the four principles of Mayer's (2001) Cognitive Theories for Multimedia Design (CTMD) as described in the earlier section. Three different software tools were used in the development of the MIM. These included software to 1) build the models and animation, 2) edit the audio and the video clips, put the text and sound together, and finally 3) combine all MIM and present them according to chapters, topics and sub-topics in a multimedia program.

Fig. 2 shows the screenshot of one multimedia element. The list of the topics for the chapter appears on the right, and by double-clicking on the topic, the multimedia element could be played. Since studies have shown that interactivity elements can reduce cognitive load (Hasler et al., 2007; Mayer and Chandler, 2001; Mayer et al., 2003), the interactivity principle of the CTMD was applied in the design of this MIM. The students were able to control the multimedia by right-clicking anywhere on window, which causes the menu option to appear. Through this drop-down menu, students were able to pause, play and stop, control the speed and volume and even zoom the multimedia to full screen.

To adhere to the coherence principle, there were also no extraneous images, words or sounds added into the MIM. Even though the list of topics appears on the right, students were able to zoom the multimedia to full screen to solely watch the MIM. The textual information was limited to (i) the identification of the parts of the mechanism, (ii) representation of the mechanism in graphics, and (iii) calculation steps to show the use of equations whenever they were necessary. Both the multimedia principle and the contiguity principle were also applied where animation and narration were presented

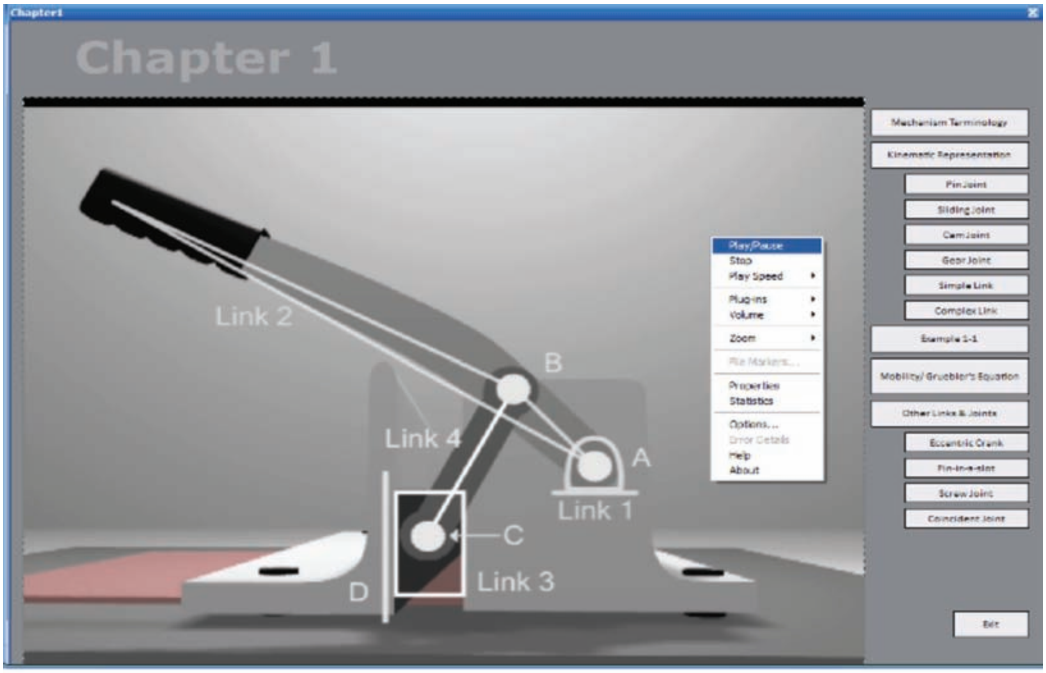

Fig. 2: Screenshot of multimedia instructional materials

concurrently. For instance, while the movement of the mechanism was shown, the explanation of the mechanism was narrated, and sometimes the link would either be highlighted or the graphical representations of the mechanism would be shown.

After the completion of the development of each MIM, the individual multimedia file was sent to the lecturer teaching the course as the content expert to check on the accuracy of the textual, narrated, and graphical representations of information as well as the dynamic representation of the information.

Instruments

Torrance Tests of Creative Thinking (TTCT)

The Torrance Tests of Creative Thinking (TTCT) were developed by E. Paul Torrance and his associates in 1966, and are among the most quoted and referred creative thinking tests. The tests have been renormed several times (Cramond and Kim, 2002) and the latest version of the tests (Torrance, 1998a, b) was used in this study. The creative thinking tests consist of (i) two verbal forms which require respondents to provide answers in words and (ii) two figural forms which require respondents to draw the answers. Both verbal forms (A and B) of the TTCT were used in this study. TTCT verbal form A was used as the pretest, and TTCT verbal form B was used for the posttest. The purpose of using TTCT was to measure whether there was any significant difference in the students' creative thinking as a result of the exposure to the use of the MIM.

The verbal forms of the TTCT contained 6 timed word-based activities which included asking the students to improve a product and provide unusual uses of a common item (Torrance, 1998a, b). The tests measured three elements of cognitive processes of creativity which are fluency (the number of meaningful and relevant responses), flexibility (the diversity of categories of the relevant responses), and originality (the uniqueness of the responses). All scorings were carried out based on the Scoring Workbook and Norms-Technical Manual (Torrance, 1998c).

Students' interview

A set of semi-structured interview questions in English for the students was also used (*see* Appendix). The purpose of the focus group interview was to find out students' opinions about the use of the MIM, and whether the MIM helped them in their learning or the development of creativity.

Procedures

The study was conducted in the first 5 weeks of the university term. In the first week, in a separate meeting with students during class time, the TTCT verbal form A was administered to all 27 students as a pretest. They then attended their normal weekly lectures (2 meetings x 1 hour), and a lab session (1 meeting x 2 hours). The exposure to the MIM began in the second week of the term in order to avoid the obstacles of the administration and students' registration.

Access to the MIM was during the lab session. Each student was provided with an individual computer and headset. Students were asked to spend the first 10-15 minutes of the class on the MIM, then they could continue with the normal activities during the lab session, which included solving case studies and working on their group project. However, they could refer back to the MIM whenever they needed to. The TTCT verbal form B was administered in a separate session after the fourth lab session as a posttest. Ten volunteer students were interviewed in two focus group interviews with each group consisting of five students.

DATA ANALYSIS

A mixed method approach to the research was used. The quantitative data from the TTCT were analyzed in two ways. Firstly, sample pretest results' for fluency, flexibility, originality, and the overall creativity scores were compared to the sample posttest results. Secondly, the mean scores of all the creative thinking elements of the pre and posttests were compared according to the gender group of the sample. It was hypothesized that the use of the MIM among engineering students would lead to an increase in the overall creative thinking performance as well as in the creative thinking elements.

A paired-samples t-test was conducted to evaluate the impact of using the MIM on students' scores on TTCT elements (fluency, flexibility, originality, and overall creative thinking scores). The quantitative data were then triangulated against the qualitative data from the focus group interview which provided more in-depth information on their learning using MIM.

FINDINGS AND DISCUSSION

Table 1 illustrates descriptively that the posttest scores portrayed an upward trend when compared to the pretest scores for all the elements in the TTCT. All differences were significant. In addition, fluency shows the highest statistically significant increase from the pretest (M = 77.15, SD = 7.466) to the posttest (M = 90.41, SD = 5.380), $t(26) = -10.825$, $p < .005$ (two-tailed) compared to the other two elements (flexibility = -11.96, originality = -10.78). A slightly lower mean score difference was reported for the overall TTCT mean score (-12.00). This indicates that the number of answers provided by the students increased considerably, but the production of varied and novel answers was slightly lower. This is most probably attributed to the incongruence between the information represented in the MIM with the type of questions asked in the TTCT. The MIM presented information on concepts of engineering design whereas only two questions in the TTCT dealt with this theme (*see* Appendix for a sample of TTCT questions). We assumed that there is a high chance that students were not able to identify the appropriate schemas from the long-term memory as a result of utilizing the

TABLE 1
Paired samples statistics and test scores of the creative thinking elements and overall creative thinking score

Creative thinking	N	Pretest		Posttest		
		M	SD	M	SD	t-test
Fluency	27	77.15	7.466	90.41	5.380	-10.825**
Flexibility	27	77.56	6.302	89.52	5.041	-11.256**
Originality	27	83.07	11.913	93.85	8.075	-5.570**
Overall (Standard Score)	27	79.30	8.222	91.30	5.915	-8.978**

**$p \leq 0.05$

MIM to manage questions in the TTCT that did not deal with mechanical concepts. Stating so, we considered this to be one of the limitations of the study.

Nevertheless, Table 1 also illustrates that the t-test results exhibited a significance difference between the pretest and posttest for all the creative thinking elements and the overall TTCT result. Generally, such results support the earlier hypothesis that the utilization of MIM could increase engineering students' creative thinking. However, since there were no control groups for comparison, with the sample being tested, it should be noted that we cannot exclude that the difference could have been due to a different variable in the environment other than the MIM such as the nature of the syllabus content which require students to solve case studies which could trigger students' critical and creative thinking or the dynamics of students characteristics namely learning styles or motivational factors.

Although previous studies in multimedia learning have not looked at creative thinking performance, there have been studies that have tested students' transfer performance. Mayer (2001) states that transfer occurs in learning once students are able to understand the new information and transfer it to novel situations. This resonates with the definition of creativity (Amabile, 1998). Studies conducted by Mayer and his colleagues on the principles of CTMD, which use transfer tests showed that students performed better in the transfer test when the multimedia principle (Mayer and Anderson, 1992), contiguity principle (Mayer and Anderson, 1991: 1992), coherence principle (Harp and Mayer, 1998), and interactivity principle (Mayer and Chandler, 2001; Mayer et al., 2003) were effectively applied to the design of the multimedia materials the students used for learning. It should be noted that all the transfer tests in all these studies covered or inquired about the information that had been included in the multimedia presentation. Therefore, since creativity has been commonly defined not only in terms of creative cognitive process, but also as the production of creative ideas and creative products, a means of assessing the creativity of the engineering students in future studies should include assessing the production of engineering products in order to look for the effective transfer of the information represented in the MIM to their constructed products.

The results presented in Table 1 were also supported by the data collected in the focus group interview sessions. In the interviews, most of the students indicated that watching the MIM had helped them to understand engineering concepts better, and to apply the mechanism concepts to create novel ideas and products. Examples of these comments are shown below:

> *S2: The MIM stimulates students' critical thinking about mechanism design, and improve my understanding about the concepts. It helps the students to visualize the motion of the part easily and 100% correct.*

S6: This multimedia file gives me a strong understanding, improve my skills, and give me new experience and new knowledge.

S10: I think the motion and graphics in the multimedia can help me to learn to create device which is new and more complicated.

This indicates that the design of the MIM based on four of the CTMD principles effectively elicited germane cognitive load, which in turn fostered students' understanding and learning. However, one student who was a high achieving student did not agree that the MIM had helped him to enhance his creative thinking; in fact, he stated that it could hinder students' imaginative skills.

S1: It can help the students to imagine the right motion and function of the mechanism, but I think it does not help the students to imagine on their own. It will prevent the students from generating their own imagination skills.

The student's comment indicates that it is worth considering that MIM could also hinder creativity. Some creativity theorists believe that imagination is one of the important factors in creative production (Rhodes, 1987) and generating creative ideas (Milgram, 1990). Some individuals depend on and form their ideas using their imaginative skills. In the case of S1, although the MIM has helped him to understand the mechanism concept, it had prevented him from imagining creatively. In future studies, as mentioned above, students like S1 could make use of their imaginative potential in creating new and novel products. However, since imagination effect is not the focus of this particular study, this phase of the issue will not be discussed further.

It is generally known that the mechanical engineering industry is dominated by males. At the location where the study was conducted, the ratio of the male students to female students was 4:1. Therefore, it would be interesting to find out whether there were differences in the TTCT scores between the genders. Table 2 presents the mean scores for the TTCT results for both pretest and posttest differentiating between the genders.

Generally, Table 2 indicates that 1) the pretest and posttest mean scores of male students were higher than for the female students, and 2) there was an increase in the posttest mean scores for both male and female students for all the creative thinking elements and the overall TTCT results. However, the mean score difference indicates that female students scored higher than the male students for fluency (F = -14.14, M = -12.95), originality (F = -11.43, M = -10.55) and the overall TTCT results (F = -12.42, M = -11.85) whereas it is only for the flexibility mean score (M = -12.15, F = -11.43) that male students scored higher than the female students. This indicates that the use of MIM has helped both male and female students to enhance their creative thinking in the different dimensions of

TABLE 2
Mean scores of the creative thinking elements and overall creative thinking score according to gender

Creative thinking	M Pretest		M Posttest	
	Female (n = 7)	Male (n = 20)	Female (n = 7)	Male (n = 20)
Fluency	73.86	78.30	88.00	91.25
Flexibility	75.86	78.15	87.29	90.30
Originality	79.14	84.45	90.57	95.00
Overall (Standard score)	76.29	80.35	88.71	92.20

creative thinking. The data appears to indicate that it has helped the female students more than the male students. However, there are limitations to the study that need to be considered: 1) the number of students in the sample, 2) the imbalance in numbers between the genders, and 3) the absence of a control group for the sample.

CONCLUSION

Generally, the findings of this study indicate that with appropriate design, the use of multimedia instructional materials may well help suppport creative thinking among engineering students. This in turn might help students to be creative in creating products or solving problems when the opportunities arise.

However, the study has highlighted a few limitations. These limitations and their implications for future studies are discussed below:

1) The design of this study involved only one experimental group of students with no control group for comparison. We suggest that control groups be included in future studies to test the engineering students' use of the MIM on their creative thinking.

2) The data gathered from this study is limited and relied solely on the TTCT results and students' interviews; therefore, we suggest that for future studies, these findings should be supported with transfer tests on the information represented in the MIM, or with the creation of products to measure product creativity. Since the MIM dealt with mechanism concepts, students could be asked to create products by utilizing the mechanism concepts learnt from the MIM.

In summarizing, it is possible that the design of MIM which considers appropriate load on the learner's cognitive system can ensure that new schemas are constructed, and therefore, allow cognitive interaction and manipulation between these new schemas and the existing schemas to produce novel and creative ideas.

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APPENDIX

Students' Interview Questions

The purpose of conducting the students' interview is to further understand their opinions on the use of multimedia instructional materials (MIM) and in what way have the MIMs helped them in their learning or the development of creativity

1. Do you know what creativity is? Can you define creativity?
2. What do you understand about creative thinking?
3. How frequently have you referred to the MIM during your lab session?
4. Can you generally describe your experience of using the MIM?
5. In your opinion, how have the MIM helped you with your learning and understanding?
6. Do you think using MIM has any positive impacts on your learning? Why? In what way has it affected you?
7. Do you think using MIM has any influences on your creativity? Why? In what way has it influenced you?
8. What are the characteristics of the MIM that has helped with your learning and your creativity?

Torrance Tests of Creative Thinking (TTCT) Sample Question

Unusual Uses (Tin Cans)

Most people throw away their tin cans, but they have thousands of interesting and unusual uses. List as many of these interesting and unusual uses as you can.