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A-MathS Multimedia Courseware for Effective Mathematic Learning: Matching Instructions to Student's Learning Style

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Abstract: The objectives of this study were to design, develop and evaluate an adaptive multimedia courseware (A-MathS) for teaching mathematics, based on learning styles. The courseware consisted of diagnostic modules and instructional modules. The diagnostic modules provided data for adaptation of instructions based on user's learning style and knowledge level in the given topic of percentage. The instructional modules were designed based on four dominant learning styles; global-visual, global-verbal, analytical-visual and analytical-verbal. Methodology used was based on Robyler's Instructional Design (ID) model for computer-aided instruction. Evaluation of the courseware involved usability and the effectiveness aspects. The usability study on the courseware was a case study involving thirty five Form 1 secondary school students, using the quasi-experimental pre and post-tests approach, observation, as well as survey questionnaire. Findings indicated that samples using matching A-MathS modules showed a significant rise in their post-test achievement ($p = 0.000$). This experimental group obtained a significant mean gain score of 10.5 compared to the low mean gain score of 1.8 for the mismatched group. Results from the study indicated that matching students' learning styles to instructions using A-MathS multimedia courseware is effective in enhancing students' learning gains.

Key words: Cognitive style, educational technology, individual differences, computer-aided instruction

INTRODUCTION

Mathematics is an important subject for careers in the science and technological field but many children still have difficulties in mathematics learning. Failure to master basic mathematics concepts further contributes to inability in problem-solving activities in college subjects. As an example, analysis of Mathematic achievement in the Malaysian Examination Certificate (high school certificate) for 1999, showed that 29% of the total students failed, while another 30% obtained only passing grade (Ministry of Education Malaysia, 2000). Similar achievement patterns were also observed for the lower secondary national assessment in 2001, whereby a high percentage of students who passed obtained lower grades of C and D only (Arshad Khan, 2001). Furthermore, many students entering college in the US were reported to have weak skills in mathematics and the decrease in the number of college graduates in STEM disciplines (science, technology, engineering and math) is also said to be correlated with comparatively weak performance by US school children on international assessment of math and science (Thiel *et al*., 2008). Most observed failures and substandard performance in mathematics are due to insufficient teaching-learning environment. Even learning difficulties due to developmental delay of cognitive components are also reinforced and shaped by environmental influences such as insufficient measures taken by educational support system (Reusser, 2000). One way to help overcome this learning problem is to teach using various effective tools such as interactive multimedia software.

Teachers often adopt methods of teaching that reflect their own preferences in learning which may or may not accommodate student's learning style and students whose styles do not match the teacher's style may never understand the lesson. Furthermore, slow learners need to be taught at their own pace and ability level. Normal classroom practice of assuming students as having similar abilities and learning styles resulted in slow students never understanding concepts being taught. The proliferation of tuition centers in urban as well as rural Malaysia, for example indicates that there is high demand for individualized instructions. However, in practice, adapting instructions to individual traits is not always possible due to large classrooms size and limited teacher's time, but with the advancement of ICT, instructional software can be developed at a cheaper cost and used to help in tutoring students with learning problems. Since individual differs in cognitive ability, prior knowledge and learning styles (Dunn, 1992; Jonassen and Grabowski, 1993), adapting instructions to these differences can facilitate learning. Interactive multimedia courseware can be easily designed to provide individualized instructions for students who fail to learn through conventional means. They have been used effectively to teach various subjects (Chen and Paul, 2003; McAndrews *et al*., 2005; Ng and Yee, 2001; Scholten and Russel, 2000) including mathematics (Chang *et al*., 2006; Nor Azan, 2006; Sanchez *et al*., 2002; Weiss *et al*., 2006).

Individuals vary in their aptitudes for learning, their willingness to learn and the styles and preferences for learning. Traits that affect learning outcomes include intelligence, cognitive controls and cognitive styles, learning styles and prior knowledge. Intelligence (cognitive ability) form a foundation for cognitive controls and cognitive styles which in turn determine learning styles. Relationship between these traits can be shown in Fig. 1.

Cognitive style reflects an individual's habit and approaches in processing information. Many earlier researches investigated variables such as field dependence/independence, global/analytic, simultaneous/successive or left and right preference processing. Earlier research also found differences in brain function between left and right brain hemisphere and tendency of individual to prefer either left or right brain when processing information. Furthermore, models of human information processing (Reed, 2006) also shows the presence of a sensory or echoic store whereby sensory stimuli or information in different modalities of communication are first transferred and briefly stored in its original sensory form. This echoic store exist for each of the senses (or modality) of visual, auditory, verbal, tactile and kinesthetic (motor). Information in preferred modality is easily recognized, stored in working memory and easily remembered upon retrieval from storage in long term memory.

Human begin to concentrate, process and remember new information under very different conditions. In a learning environment, this different but consistent way an individual acquires, retains and retrieves information according to his cognitive style is defined as learning style. Learning style is defined as the preferred mode of receiving and processing information (Riding and Rayner, 1998; Dunn, 1992). Adapting instructions to students' learning styles has been found effective in improving learning, besides changing their attitudes to be more positive towards the subjects taught (Burke and Dunn, 2003; Dunn and De-Bello, 1999; Ford and Chen, 2001; Triantafillou *et al*., 2003).

Learning performance is affected by an interaction between cognitive style and the structure of instructional materials, its mode of presentation and type of content, thus different structural design of instructional material will facilitates different styles of learning and thus influences learning achievement (Riding and Rayner, 1998). Matching instruction to learner's learning style will facilitates acquisition and processing of information. If information is in the preferred mode then processing load is less. For some learners, additional processing load result in a longer time being required to learn the information or at worst the load may exceed capacity and the information will not be learned at all. Matching instructional styles to learning styles can significantly enhance academic achievement, student attitudes and student behaviors. Literature have shown many and varied learning style models, each with their own instrument used in different situations and population being studied. However, the basis for theoretical framework of learning style should be styles of cognitive processing since learning involves thinking. Modality of the information also influence learning since the preferred mode will facilitate information acquisitions and processing during learning. Therefore, in this study we defined learning style as consisting of cognitive style and modality preference, as shown in Fig. 2.

Other researchers also studied psychological traits in relation to mathematics problem-solving. In his study of Soviet school children, Krutetskii (1976) isolated different styles termed mathematical types (or cast of mind); analytic type (an analytic or mathematic cast of mind), geometric type (a geometric or mathematically pictorial cast of mind) and two modifications of a harmonic type

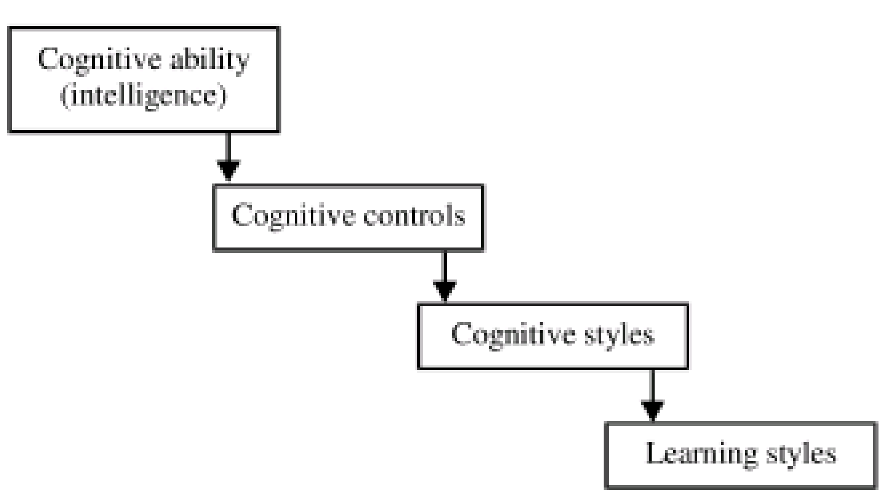

Fig. 1: Relationship between individual psychological traits

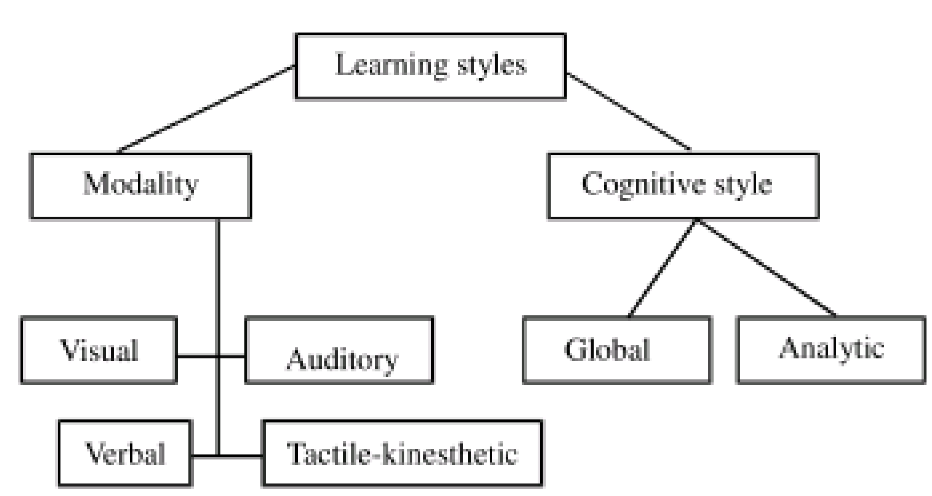

Fig. 2: Components of learning style

(abstract and image-bearing modification of a harmonic cast of mind). Most students tested belong to the harmonic type. The geometric type student had no difficulty in topics that require visualization, they were easily oriented in image-bearing material and did operations related to analysis of diagram, drawings and graphs more easily compared to operations related to analyses of concepts and definitions. Krutetskii's harmonic type is similar to Pask (1976)'s versatile style in which an individual shows versatility in using either global or analytical style based on the task being performed.

In this study, we designed an adaptive multimedia courseware based on different learning styles and then evaluated its effectiveness by matching and mismatching the instructional modules to learner's learning style, using a quasi-experimental case study approach.

MATERIALS AND METHODS

The method used in this study was a modification of Roblyer (1988) Instructional Design model for computer courseware and is shown in Fig. 3a-c. The model has three phases; analysis and design, pre-programming development and development and evaluation.

During the analysis and design phase, problems, students' characteristics, topic and learning outcomes, testing and instructional strategies were identified. Contextual instructional strategy and cognitive, constructivism learning theories were used in the lesson design, besides the different characteristics of cognitive learning style and visual-verbal modalities. The topic percentage was chosen based on results of document analysis of Education Ministry's major examination achievement reports (1993 to 2003) and further supported by questionnaire survey results of math's teachers and secondary school students. The courseware, A-MathS consist of diagnostic and instructional modules. The diagnostic modules provided data on user's learning styles and his knowledge about the topic, for automatic adaptation of instructional presentations. The instructional modules were designed based on four dominant learning styles; global-visual, global-verbal, analytical-visual and analytical-verbal. A-MathS was implemented and evaluated for effectiveness and usability in a an experimental, pre and post-test case study involving thirty five Form 1 (13 years old) secondary school students. The usability of the courseware prototype was evaluated using questionnaire given out to samples after using A-MathS. A paper and pencil pre-test were first administered before the diagnostic tests. After the diagnostic tests, samples were divided into experimental or control group at random. Samples in the experimental group were given instructional modules that matched their learning styles whereas samples in the control group were given mismatched instructional

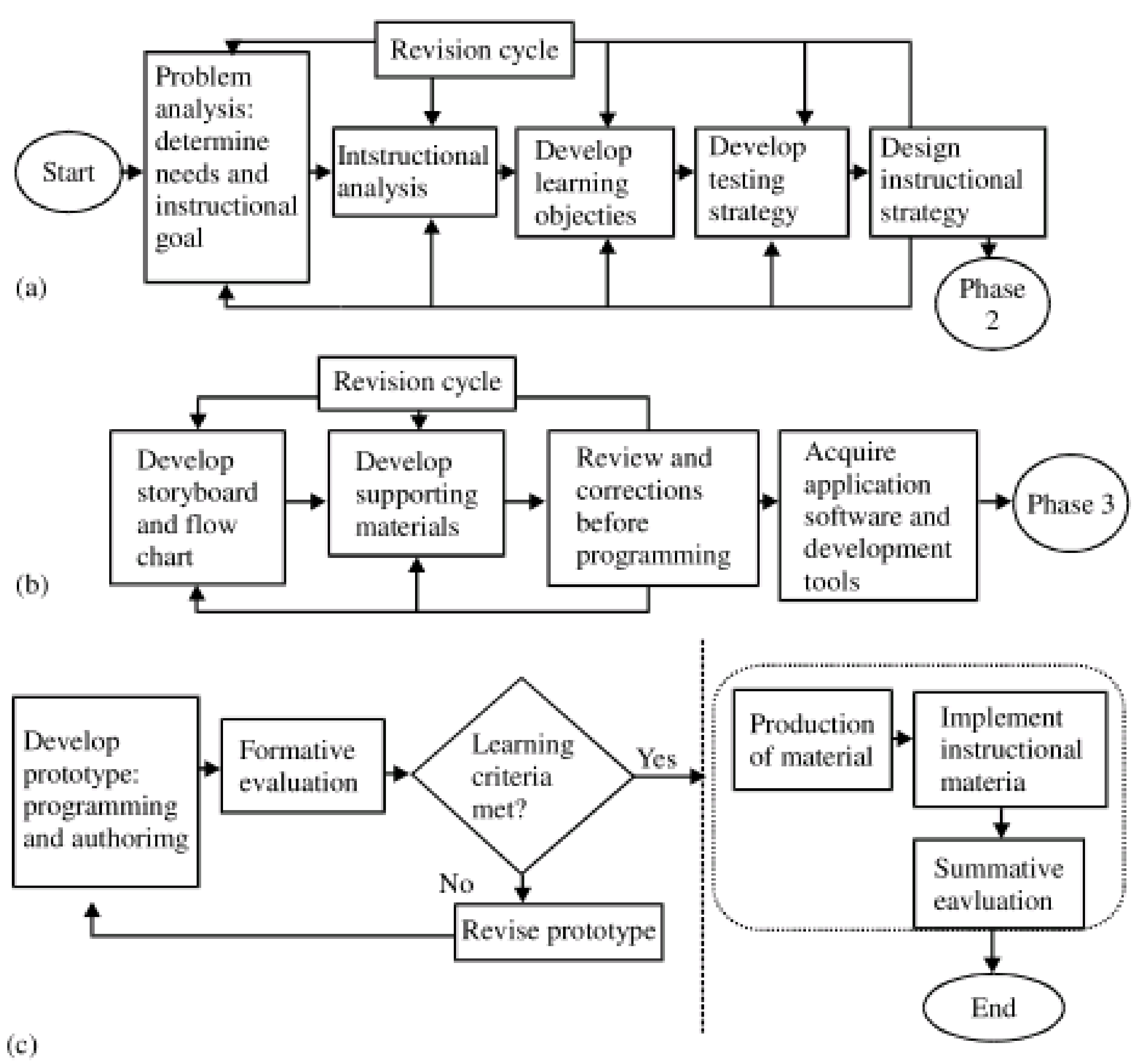

Fig. 3: (a) Analysis and design, (b) Pre-programming development and (c) Development and evaluation

modules. Samples were given instructions on how to use the courseware before they were assigned to a computer each in the computer laboratory. Samples spent an average of three to four hours on the lesson.

RESULTS AND DISCUSSION

A-MathS adaptive multimedia mathematics courseware: A-MathS was designed and developed based on four major learning styles of global-visual, global-verbal, analytical-visual and analytical-verbal. The courseware has a diagnostic module, to diagnose learner's learning styles and knowledge level in the topic of percentage and then to automatically adapt the presentation of contents to suit each learner. The structure of the courseware can be seen in Fig. 4.

The instructional module was designed based on four major learning style characteristics. Examples of cognitive learning style characteristics identified and applied in the design of A-MathS structure can be seen in Table 1 while the modality attributes can be seen in Table 2. The instructional module was developed using Macromedia Director 8.5 and Lingo scripting.

Typical examples of instructional modules interface for different learning styles can be seen in Fig. 5a-c.

Table 1: Cognitive (processing) style characteristics

Global learner	Analytical learner
Structured presentation; courseware controlled, limited navigation	Unstructured presentation; user controlled free navigation
Advance graphic organizer at beginning of lesson	Text menu
Icon indicates topics being accessed	Text of topics on the initial frame
Deductive approach	Inductive approach

Table 2: Modality characteristics

Visual learner	Non-visual (verbal, auditory, tactile, kinesthetic) learner
Use a lot of visual objects such as realistic graphics, animation, video	Repeating important points and verbalization of text, hands-on activities such as drawing, writing, typing
Written instructions	Verbal instruction
Use a lot of charts, graphs and maps	Use a lot of text

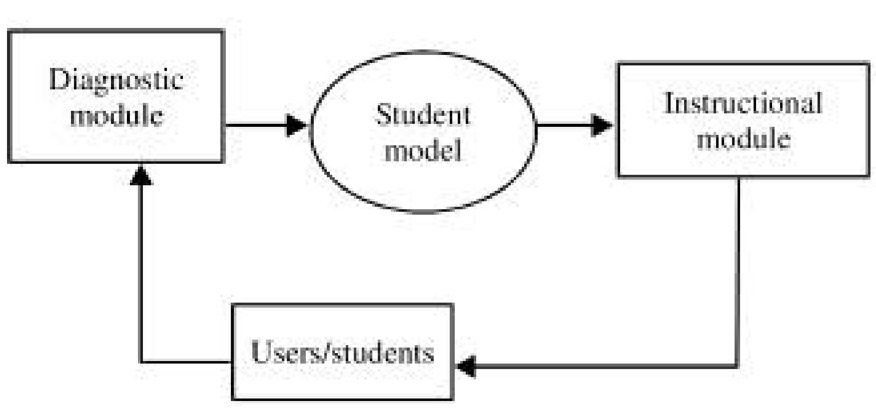

Fig. 4: Structure of A-MathS courseware

Diagnosing learners' learning style: The diagnostic module consists of three components; cognitive processing and modality learning styles tests which are self-reported questionnaire and mathematics pre-test questions developed using Visual Basic 6.0. Validation study (Nor Azan *et al*., 2004) of the learning style

Fig. 5: (a) Example of interface menu using lift metaphor for global-visual learner, (b) Example of 'quick review' module interface for visual learner and (c) Example of 'quick review' module interface for verbal learner

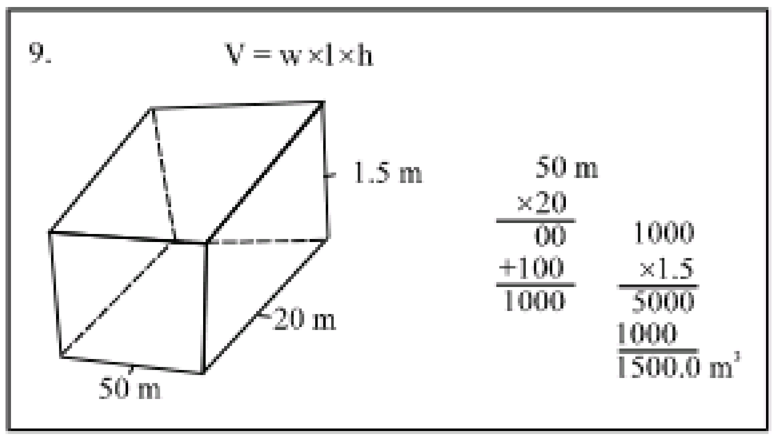

Fig. 6: Example of solution presented by a visual sample

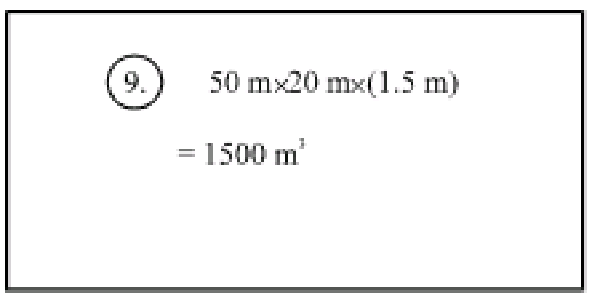

Fig. 7: Example of solution presented by a verbal sample

instrument showed that almost half of the total respondents have analytical styles while the other half were divided between global and versatile styles. Versatility in learning style may be due to individual's ability to adapt to differing teaching styles and structure of materials being learned throughout life such that an individual can process information globally or analytically depending on the situation or the materials presented. For the modality, verbal style rank first followed by visual style.

However, since self-reported learning style tests depend only on respondents perception, further test was carried out to identify individual's learning style based on observation and to answer questions of whether observed learning style is the same as learning style identified through these tests. The way students solved math problems which were carefully designed to be solved either visually or non-visually reflected his observed visual or verbal learning style.

The self-reported preferred modalities were verified with paper and pencil test of math's problem-solving (observed modality). Examples of solutions given by samples for a volume problem can be seen in Fig. 6 and 7. Results showed that there was a moderate correlation between the observed modality and the self-reported modality.

Evaluation results of A-MathS courseware: Data of mean scores for the two groups is shown in Table 3. Mean gain score (post-test-pre-test) for control group is much smaller than that of the experimental group.

Table 3: Summary of mean scores

Group	Pre-test mean score (pre)	Post-test mean score (post)	Mean gain score (postBpre)
Experimental	50.3	60.8	10.5
Control	55.0	59.0	1.8

Table 4: Results of Wilcoxon tests

Groups	N	N for test	Wilcoxon statistic	p-value	Approximated median
Gain score (experimental group)	19	18	166.5	0.000	12.25
Gain score (control group)	16	16	71.0	0.572	1.125

Table 5: Mann-Whitney test

Groups	N	Median (gain score)
Experimental group (matching instruction)	19	12.50
Control group (mismatched instruction)	16	2.00

W: 397.5, ETA1: ETA2 vs ETA1 > ETA2 is significant at 0.0343

Since, the sample number in this case study is small (19 for experimental group, 16 for control group), non-parametric Wilcoxon signed rank and Mann-Whitney tests were used. Results of these tests are shown in Table 4 and 5.

There is a significant difference (p = 0.000) between mean gain score for experimental group, meaning that the average mean score for post-test is significantly higher than average pre-test mean score (Table 4). On the other hand, Wilcoxon's test for the control group showed that the difference between mean pre-test score and mean post-test score is not significant (p = 0.275). In other words, matching instruction to learning style using A-MathS courseware designed based on student's learning style is significantly effective in enhancing learning gains.

To test whether the differences obtained using Wilcoxon test is significant or otherwise, Mann-Whitney test was carried out. Mann-Whitney test showed that there is a significant difference (p = 0.0343) in gain scores between the two groups after using the A-MathS courseware (Table 5). Samples who used courseware matching their learning styles showed better achievement in the post-test compared to those using mismatched courseware. This case study indicates that multimedia can be used to design instructions based on students' learning styles for teaching mathematics effectively. Findings from this study also concurred with similar previous studies (Predavec, 2001; Jeffries, 2001).

Usability evaluation of A-MathS: Dimensions of interface design (Perlman, 1998) evaluated are ease of use, screen design and navigation, information presentation, media integration and overall user's perception of A-MathS functionality. Five level Likert scale (1 = very unsatisfactory/very much disagree; 2 = not satisfactory/ disagree; 3 = medium/ neutral; 4 = good/ agree; 5 = very

Table 6: Results (%) of A-MathS usability evaluation by experimental and control groups

	Dimensions							
	1		2		3		4 and 5	
	1	2	1	2	1	2	1	2
Variables	Groups							
Ease of use	1	5	6	10	16	24	77	60
Screen design and navigation	-	8	5	6	18	18	76	67
Information presentation	2	4	5	7	14	17	80	72
Media integration	5	6	-	6	13	13	82	75
Perception of A-MathS functionality	-	3	1	5	14	27	84	66

good/agree very much) was used to rank items in the questionnaire. The interface evaluation by experimental (matching) group showed that A-MathS courseware has good interface design for all dimensions; ease of use (Mean = 4.06), screen design and navigation (Min = 4.19), information presentation (Mean = 4.20), media integration (Min = 4.13) and perception of overall functionality of A-MathS courseware (Mean = 4.32). Percentage of students from both groups, ranking various usability dimensions is shown in Table 6 (Level 4 and 5 were combined). Group 1 is the experimental group while 2 is the control group.

All dimensions of A-MathS courseware interface design were evaluated to be good (4) or very good (5) by majority of samples from both groups, even though the percentage is much lower for samples from the control group who use the mismatched A-MathS courseware. Since they were given A-MathS courseware that were mismatched to their learning styles, samples have some difficulty using the courseware, navigating and understanding the information presented, thus adding cognitive load to their learning effort. However, the A-MathS courseware has satisfied majority of samples whose learning styles were matched to the courseware design and was effective in increasing their learning gains, thus helped them better understand the mathematics lesson on percentage.

CONCLUSION

Matching instructions to learner's learning styles is effective in enhancing learning gains and A-MathS adaptive multimedia courseware facilitated this effort. This approach of teaching to learner's preference can help students with learning difficulty in mathematics or any other subjects learn on their own, topics not understood during normal classroom lessons. However, it is still time consuming to design presentation for each type of learning styles and teachers may not have the skills to use multimedia application software to create courseware. Therefore future research can look into the development of database of learning objects which can be automatically chosen and sequenced for presentation based on students' learning styles.

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