

THE DEVELOPMENT OF A VIRTUAL MATHEMATICS TEACHING AID BASED ON COGNITIVE LOAD THEORY¹

Sugiman, R. Rosnawati, Endah Retnowati and Ilham Rizkianto²

Yogyakarta State University

Abstract

Manual mathematics teaching aids are available in all Mathematics Education Laboratory in Indonesia. These aids are used to assist students in doing abstraction and finding concepts and principals in mathematics. Because they are manual, students need to work directly with the teaching aids. This activity makes sure that the numbers of students are the same as the number of the aids. Moreover, the manual teaching aids require many ingredients and variation, for instance the scale and the things which want to weigh. Thus, mathematics teaching aids need to be virtualized so that they become more interactive and practical in utilizing.

The development of a virtual mathematics teaching aid can be done by conducting a developmental research (research and development) utilizing 4-D Model consisting of define, design, develop, and disseminate phases. Those four D in the 4D-Model are phases or syntaxes in developing virtual mathematics education laboratory that will take 3 years. In the year 2013, three phases, define, design, and develop, have been done.

The result acquired from the study is the prototype of a virtual mathematics teaching aid used to rounding topic. It consists of rounding to the nearest ones, tens, and hundreds. The prototype of a virtual teaching aid applying a cognitive load theory is called "Mari Menimbang". In order to see the validity of the prototype developed, it is assessed by three media experts and 10 practitioners. Those 10 practitioners are junior high school teachers with a lot of experiences in conducting mathematics learning activities. The result of experts' assessment to intrinsic cognitive, extra cognitive, didactic term, construction term, and technical term is 3.17, 3.10, 3.17, 3.08, 3.40, 3.33, and 3.19 respectively and each of all falls into good category. Meanwhile the result of practitioners' assessment to those aspects is 3.73, 3.53, 3.58, 3.60, 3.54, 3.73, and 3.60 respectively and each of all falls into good category. Over all, the expert assessment to the virtual mathematics education laboratory is 3.19 which is good category while the practitioners give 3.6 which is also included in good category. According to the second assessment from assessor group to be concluded that the products resulted in this study are appropriate to be tested in mathematics learning classrooms aiming at the practicability and the efficiency. The trial is planned to be conducted in the second year of the study.

Keywords: Cognitive Load Theory, Mathematics Education Laboratory

INTRODUCTION

Dewi Padmo, et al (2004: 246) found that teachers usually teach mathematics started by giving information followed by examples and some problems which are similar to those

¹ Bagian dari Penelitian Pengembangan Laboratorium Pendidikan Matematika

² Dosen-dosen Jurusan Pendidikan Matematika FMIPA UNY

examples. Until today, there are no fundamental changes of teachers' technique in teaching. Talk and chalk are the main tools for teachers in teaching the concepts and principals in mathematics. While the teaching aids are rarely used by the teachers when they teach mathematics; if they use it, those teaching aids are served as demonstration tools to explain a concept or mathematics principles not being used by the students to do mathematical exploration. Ausubel (Bell, 1978: 130-132) also affirmed that the poor learning process in involving students and the essential content learnt will cause students do not get total and comprehensive understanding, thus students are easy to forget.

Mathematics teaching aids which have been used physically can be developed into multimedia form in adaptive e-learning platform as well as what exists in UNSW (see www.smartsparrow.com). The distinction with other multimedia is the platforms developed give possibility to students to do simulation, experiment or manipulation of the teaching aids provided, for example using the physical teaching aids. Moreover, students can do any experiment on the teaching aids functions which usually cannot be held in physic laboratory because of the limitation of the teaching aids. Every student can learn based on his or her cognitive development because the platform developed could provide a learning path and feedback suitable with what a student needs. Besides that, student' activity can be recorded so that the teacher can do authentic assessment of student' cognitive development. Different from two years ago, which was around 2011, now the smart sparrow portal cannot be accessed freely but on the opposite a user should pay and be the member of it. Because of that, there is a need to make a similar portal that can be accessed freely for students and teachers in Indonesia.

The used of ICT for learning by the teachers and students nowadays has developed. Through ICT there will be a learning environment which is interactive so that students can get feedback effectively and directly from what they have been doing. Many studies had been proved the advantages of using multimedia in ICT; for instance multimedia is useful in supporting students develop their intellectual ability. Suitable computer software provides students a unique opportunity to learn through exploration and creative problem solving.

Implementing Cognitive Load Theory (CLT) in making virtual visual aids through ICT expected can produce an effective learning facility. According to CLT, the effectiveness of a learning instruction is determined by three aspects of cognitive load, namely intrinsic cognitive load, extraneous cognitive load, and germane cognitive load (Brunning Scaw, Norby dan Ronning, 2004; Paas and Merrienboer, 1993; Sweller, 2004, 2010). Since our cognitive ability to process complex material is limited, CLT suggests that presenting material should minimize the intrinsic and extraneous cognitive load, but stimulate germane cognitive load. Intrinsic cognitive load is related to the complexity level of material influenced by students' starting point. Extraneous cognitive load is related to the way how to present the information during learning process, including loading a picture, a text, an animation or sounds which does not cause excessive cognitive process. Presenting information can be done through media, teachers, friends, or students' environment. While germane cognitive load is related to the new knowledge construction process Brunning Scaw, Norby dan Ronning, 2004; Sweler & Chandler, 1994).

Utilizing an example of an associated picture and a text, (oral or written) from many studies had showed the effectiveness in learning (Chandler & Sweller, 1992, Retnowati, Sweller & Ayres, 2010; Moreno & Mayer, 1999; Tarmizi & Sweller, 1988; Tindall-Ford, Chandler, & Sweller, 1997; Van Gog, Paas, & Van Merrienboer, 2006). However, integrating two associated pictures and illustrations has to ignore a repeating effect. This effect appears if a picture implicitly loads an illustration about the picture (self-explained figure). Moreover, this repeating effect also happens if teachers explain information which students have already known (Chandler & Sweller, 1992). In this case, the repeating effect happens because of excessive information, information and knowledge have the same idea.

Constructive cognitive process happens automatically if there is content in an empty worker's mind as a result of the minimum intrinsic and extrinsic cognitive load. However, it can be influenced by motivation and students' behavior about the learnt material. Without motivation and fine behavior through the learning process, even if the material is well managed, the result of learning probably cannot be maximal.

Cognitive load theory concerning with doing study tasks is controlled by two strategies. First, intrinsic is controlled by organizing study task in class; the tasks are developed from easy to difficult. For the easy study tasks in class, element and interaction amongst elements have to be processed at the same time in working memory. The more complex tasks are given, the numbers of elements and the process of interactions amongst unsure increase. Second, cognitive load is run by giving a big amount of support and guidance to the first study task in class. Because supportive information usually has high interactivity element, it is better not to tell students when they work at study task. Doing task and learning information at the same time will cause excessive cognitive load. On the other hand, supportive information is better served before students work on the task. Using this strategy, cognitive scheme can be built in a long term memory and then can be activated in memory during the task. Taking this cognitive scheme is expected to reduce the cognitive load better than activate complex information which is served in a working memory during the task.

Implication of cognitive load theory in designing virtual mathematical teaching aids are: (1) need to understand the complexity level of materials which will be learnt or the amount of presented information; (2) need to know the level of students' starting point who will learn the material; (3) minimize the number of intrinsic and extrinsic cognitive load; and (4) facilitate the process of enhancing germane cognitive load, namely accusation and knowledge scheme construction; also (5) build a better scheme composition and facilitate automatic scheme.

PROBLEMS FORMULATION

The problems studied in the first year of this present research are:

1. How to develop a better adaptive virtual teaching aid based on Cognitive Load Theory?
2. How high is the validity level of an adaptive virtual teaching aid developed based on Cognitive Load Theory?

RESEARCH METHOD

Akker and Plomp (1993: 2) stated that quality of developmental research depend on two things, namely: (1) how the quality of the process and the result of developing a product's prototype is and (2) how the implementation of developmental method start from the planning phase into the last evaluation phase of a product is. Furthermore Nieven (1999: 127-128) said that the quality, the design, the development, and the evaluation program of a product have to fulfill some criteria, such as valid, practical, and effective.

Development model of a virtual mathematical teaching aid in this present research refers to development model by Thiagarajan, Semmel & Semmel (1974: 5-9) which is known as 4-D Model. 4-D Model consists of defines, design, develop, and disseminate phases. Product development in this study is in the third phase.

This study involves experts (ICT experts, material experts, and pedagogic experts), practitioners from school, and students as users. The experts' role is to give validation to the assessment paper and to assess product validity. The practitioners' role from school is only to assess product validity. Besides that, developing a virtual mathematics teaching aid process involves a class of grade four elementary school students and a class of grade seven junior high students. The goal is to see whether the program designed for the virtual teaching aid works

well or there is still deficiency. Not only giving feedback, but students also give argument about the product of the virtual teaching aid they use.

As for the categorization of assessment result given by experts and practitioners about the product, researchers use categorization by Syaifuddin Azwar (2010: 163) which is used ideal average value (X_i) and ideal standard deviation (SB_i). There are 5 categories, namely Not good (if score $< X_i - 2SB_i$), not good enough (if $X_i - 2SB_i \leq \text{score} < X_i - SB_i$), enough (if $X_i - SB_i \leq \text{score} < X_i + SB_i$), good (if $X_i + SB_i \leq \text{score} < X_i + 2SB_i$), and very good (if $X_i + 2SB_i \leq \text{score}$).

RESEARCH RESULT AND ANALYSIS

This part consists of defining, designing, and assessing validity level by experts and practitioners. Moreover, there is a prototype product of the virtual teaching aid.

Defining Phase through Need Assessment

Need assessment was conducted by observing the classroom, observing students' reasoning during mathematics lesson, interviewing mathematics teacher, studying curriculum, studying text books, studying lesson plans used by the teachers, and studying the references. The results stated as follows:

1. The obstacle faced by some teachers in teaching mathematics happens when most students find various strategies to answer the question. Each student's answer needs a fast response so that if a student does a mistake, it will not affect all of his or her work. Teachers' obstacles are (1) difficult in differentiating the right or the wrong answer; (2) lack of affectivity in managing various answer to promote the discussion; (3) serving students based on their own level of understanding. Therefore, there is a need for medi to give fast responses according to the variety of students' answers.
2. From observation result found that there is a diversity of students' capability in transforming from concrete level, to semi concrete, and to abstract level at the end. The heterogeneity of students' intellectuality is the main cause. This problem is still difficult to handle by the teacher when it appears during the lesson.
3. Teachers tend to teach as soon as possible the formal mathematics even though the learning starts from giving the contextual problem or sometimes it start directly in formal phase. Teachers' ability in arranging materials is the primary cause.
4. From interview result, there are some teachers who do not master all mathematics materials which they should teach. Consequently, those materials are left by the teachers and students are asked to learn by themselves or to find the information of the materials using internet. If that so, there is a need of learning resources which can be used by the students. Those materials, for example, are division procedure of fraction, permutation and combination concept, and rounding numbers.
5. From studying the text books used at school, there is an indication only few numbers of books encouraging students in doing inquiry. The knowledge attained by the students because they read the concepts or principles of mathematics; not because they reinvent them through inquiry process.
6. Many schools have computers facility which can be used in learning mathematics. Moreover, many students have their own computer or phone cells equipped by internet feature. Those schools have not had their own mathematics education laboratory yet. They only have limited simple teaching aids.

According to these findings, there is a need to build a mathematics education laboratory which can be used by many schools and to develop adaptive virtual teaching aids.

Designing Phase

Through this phase, there has been developed a prototype of a virtual teaching aid based on cognitive load theory which is put on cyberspace and a website of a virtual mathematics

education laboratory (laditiv). It will be filled by virtual media. The products and the results of it will be described as follows:

1. The development of a virtual teaching aid has been done by considering some components which are based on cognitive load theory and an adaptive e-learning. In this first year the developed prototype consists of rounding numbers to ones, tens, and hundreds. The rounding teaching aid is called "Mari Menimbang". The steps of designing the rounding teaching aid are: (1) Determining that mathematics content in the virtual teaching aid is the essential content for students, but the available learning media have not facilitated students in exploring the mathematics content yet; (2) Finding relevant contexts in the virtual teaching aid so that students can enhance their understanding not only about the concept, but also the mathematics procedure in abstract way; (3) Designing the virtual teaching aid media which can encourage students to maximize germane cognitive load, maximizing students' minds in building schemas of concepts and mathematics principals which is contained by virtual teaching aid; when designing it there was consideration of giving scaffolding or helps when students need; (4) Producing a virtual teaching aid using computer programs which has facility needed; one of the programs is macromedia flash; (5) Discussing the embryo of a virtual teaching aid in discussing forum, namely Forum Group Discussion (FGD); (6) Testing the virtual teaching aid to the students in order to detect its weakness and then fix it; the trial was done one or two times, but it also can be done as many as the necessity; students' comments on the virtual teaching aid prototype "Mari Menimbang" are very positive, as can be seen in Figure 1, and (7) Assessing the virtual teaching aid to the experts and practitioners and also asking for the suggestions to make it better. Through the seven steps, the prototype of a visual teaching aid has been successfully built.

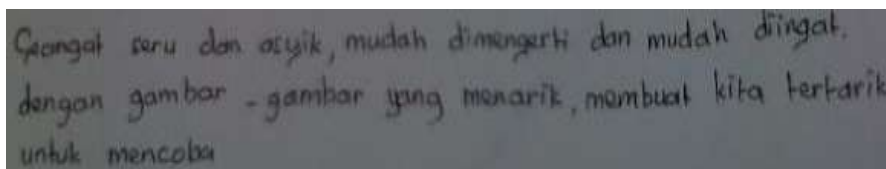


Figure 1. Example of a student's comment

2. Assessment about the virtual teaching aid was done by three experts (media/technology expert, material expert, and mathematics education expert) and ten practitioners namely experience mathematics teachers. The result of the assessment can be seen in Table 1.

Table 1. Assessment result of the virtual teaching aid by the experts and the practitioners

Assesing Components	Experts		Practitioners	
	Score	Criteria	Score	Criteria
Intrinsic Cognitive	3,17	Good	3,73	Very Good
Extra Cognitive	3,10	Good	3,53	Very Good
Quality of Materials	3,17	Good	3,58	Very Good
Didactic Requirement	3,08	Good	3,60	Very Good
Construction Requirement	3,40	Good	3,54	Very Good
Technical Requirement	3,33	Good	3,73	Very Good
All Components	3,19	Good	3,60	Very Good

The assessment given by the experts for every component and as a whole contained in

the virtual teaching aid prototype includes in a good category. This shows that the teaching aid is feasible to be used by the students in the classroom or at home. The feasibility is also supported by teachers' assessment results who are given a very good criteria for all components of the virtual teaching aid.

The product of The Virtual Mathematics Teaching Aid Prototype: Mari Menimbang”

The validity of the virtual teaching aid of a rounding material which has been developed and assessed can be seen in Figure 2 below:



Figure 2. The Rounding Virtual Teaching Aid

The procedures of the teaching aid are as follows:

1. Choose one of the three things (fish, banana, or papaya) to be placed on the scale,
2. The scale will show the weight of the thing. In Figure 2, the weight of papaya is 2007.06 gram,
3. Students fill the box on a Rounding command to the nearest ones. If the answer is right then the green circle will appear and so will the second command "Round to the nearest tens". If the answer is wrong, the red cross will appear and students are asked to fill the box again. If it is still wrong, scaffolding will be given in the form of guidance and students are asked to fill it again. And if there is the third wrong answer, the answer key will be given. This process also works for rounding to the nearest tens and hundreds.
4. Students do the rounding exercises consisting of some contexts, namely the distance from house to school, the number population in a village, reading a price tag, and determining two people's weights. If all the answers are true, students will be given the next problems with other contexts, such as determining perimeter of a frame and determining the number of possible marbles.

CONCLUSIONS

1. The virtual teaching aid based on cognitive load theory is developed through some steps, namely: (1) determining the mathematics content; (2) determining the contexts; (3) designing by considering the cognitive load theory; (4) rounding; (5) reviewing via FGD; (6) testing to students, and (7) assessing by the experts and practitioners.
2. The result of experts' assessment on the virtual teaching aid prototype is in a good criterion, while the practitioners give a very good. Thus, the prototype can be implemented to students and can be a reference for other virtual teaching aids development.

REFERENCES

- Akker, J.V. & Plomp. (1993). *Development research in curriculum propositions and experiences*. Diakses jam 09.00, tanggal 10 Desember 2012, dari http://leerplanevaluatie.slo.nl/Taakhulp/vandenAkker_Plomp_1993.pdf/
- Bell, F.H. (1978). *Teaching and learning mathematics (In secondary school)*. Moines: Wm. C. Brown Company.
- Brunning Scaw, Norby dan Ronning. (2004) Cognitive load theory, learning difficulty and instructional design. *Learning and Instruction*, 4 , 295-312.
- Chandler, P., & Sweller, J. (1992). The split-attention effect as a factor in the design of instruction. *British Journal of Educational Psychology*, 62(2), 233-246.
- Dewi Padmo, Siti Juliaha, Kristina A, Puspitasari & Nurdin Ibrahim (Ed). 2004. *Teknologi Pembelajaran: Peningkatan Kualitas Belajar melalui Teknologi Pembelajaran*. Jakarta: Pusat Teknologi Komunikasi dan Informasi Pendidikan
- Moreno, R., & Mayer, R. (1999). Cognitive Principles of Multimedia Learning: The Role of Modality and Contiguity. *Journal of Educational Psychology*, 91(2), 358-368.
- Nieveen, N. (1999). Prototyping to Reach Product Quality dalam Plomp, T; Nieveen, N., Gustafson, K., Branch, R. M., & van den Akker, J (eds). *Design approaches and tools in education and training*. London: Kluwer Academic Publisher.
- Paas, F. G. W. C., and van Merriënboer, J. J. G. (1993). The efficiency of instructional conditions: An approach to combine mental-effort and performance measures. *Human Factors*, 35(4), 737-743.
- Retnowati, E., Sweller, J. & Ayres, P. 2010. Worked Example Effects in Individual and Group Work Settings. *Educational Psychology*, 30(3), 349-367.
- Sweller, J. (2004). Instructional Design Consequences of an Analogy between Evolution by Natural Selection and Human Cognitive Architecture. *Instructional Science*, 32(1-2), 9-31.
- Sweller, J. (2010). Element Interactivity and Intrinsic, Extraneous, and Germane Cognitive Load. *Educational Psychology Review*, 22(2), 123-138.
- Sweller, J., & Chandler, P. (1994). Why Some Material is Difficult to Learn? *Cognition and Instruction*, 12(3), 185-233.
- Syaifuddin Azwar. (2010). *Tes prestasi (fungsi pengembangan pengukuran prestasi belajar)*. Yogyakarta: Pustaka Pelajar.
- Tarmizi, R. A., & Sweller, J. (1988). Guidance Suring mathematical Problem Solving. *Journal of Educational Psychology*, 80(4), 424-436.
- Thiagarajan S., Semmel D. S., Semmel M. I. (1974). *Instructional development for training teachers of exceptional children: A sourcebook*. Minnesota: Central for Innovation on Teaching the Handicapped.

- Tindall-Ford, S., Chandler, P., & Sweller, J. (1997). When Two Sensory Modes Are Better Than One. *Journal of Experimental Psychology: Applied*, 3 No. 4, 257 - 287.
- Van Gog, T., Paas, F., & Van Merriënboer, J. (2006). Effects of Process-Oriented Worked Examples on Troubleshooting Transfer Performance. *Learning and Instruction*, 16(2), 154-164.