Application of Cognitive Load Theory in Programming Teaching

Xiaoqing Li
University of Illinois at Springfield

Modern e-learning tools offer great potential for instructors to develop innovative pedagogies. Based on the cognitive load theory, this research proposes an information technology supported pedagogy to teach mobile programming. With the proposed methodology, students record their hands-on programming exercises when learning from worked examples. As an effective approach to improve learning performance, this method can also be applied in other similar teaching scenarios.

INTRODUCTION

Teaching computer programming is always a difficult task. Many students are overwhelmed when they start to learn new terminologies, concepts, and development tools. Instructors have been trying various ways in the effective teaching of programming languages (Moons & De Backer, 2013). As one important application of the cognitive load theory, learning from worked examples is an effective approach in learning computer programming languages (Abdul-Rahman & du Boulay, 2014; Renkl & Atkinson, 2003). This pedagogy has been widely applied in class teaching. The worked example method enables students to quickly grasp major points of theories and learn basic skills. Compared with other methods, like problem solving, the use of worked examples is especially effective in the initial stage of learning (Renkl & Atkinson, 2003). For example, students are required to follow a step-by-step tutorial to enter, test, and run programming code in a computer lab, so they can quickly learn basic programming structures and master the use of development tools.

Instructors can easily apply worked example pedagogy, such as assigning hands-on exercises, in face-to-face classes. However, it is difficult for instructors to assign worked examples to students as their homework, since instructors cannot evaluate the learning performance if all students repeat the same procedure and get the same result. The method that this paper proposes allows instructors to evaluate students' efforts by watching recordings of their working process. The working process is recorded using an on-screen activity recording tool, Camtasia relay (www.techsmith.com). By watching submitted video clips, instructors can easily identify problems that students have in their working process, and provide more specific and effective advising to students. This proposed method is originally designed for the teaching of mobile programming, but it can be easily adapted to other online or on-campus teaching.

The paper is organized as follows. First, the principle of cognitive load theory and technology acceptance studies are reviewed. Second, the methodology of the proposed research is explained. Third, the collected data are analyzed. Finally, the results are discussed and recommendations are developed.

BACKGROUND KNOWLEDGE

Cognitive Load Theory and Applications

In human minds, working memory is the place where a learning activity occurs. According to the cognitive load theory (Sweller, 1994), the cognitive load of a learning task consists of two parts: the intrinsic cognitive load and the extraneous load. The intrinsic cognitive load is determined by the nature of learning materials, but the extraneous cognitive load is determined by the presentation of the learning. Further, the germane cognitive load is the cognitive effort that a learner can really spend on learning. Therefore, an effective teaching pedagogy should consider balancing various cognitive loads that a learning task demands to a person. Cognitive load theory provides guidelines to course design and instructions. The specific effects developed from cognitive load theory include goal-free effect, worked example effect, completion problem effect, split-attention effect, modality effects, redundancy effect, and variability effect (Sweller, Merrienboer, & Paas, 1998):

- **Goal-free effect:** the goal-free effect is opposite to conventional means-end analysis, in which the problem solver starts from the given state and searches all steps to reach a pre-determined goal. With the goal-free strategy, the learner starts from the given states and finds possible results without any specific goal in mind (Sweller et al., 1998).
- **Worked example effect:** studying worked examples is proved an effective method to facilitate knowledge learning in many domains. By studying worked examples, learners can quickly build schemas in their minds with less cognitive load since they do not need to study and search many steps in the problem solving process. (Sweller et al., 1998).
- **Completion problem effect:** with the completion problem, learners are given a partially completed solution and are required to work on missing parts. This method is especially effective for design issues, such as software design. The worked example is a special case of the completion problem, in which all solution steps are given (Sweller et al., 1998).
- **Split-attention effect:** if several sources of information are required in order to learn new knowledge, there exists a split-attention effect. Therefore, relevant information should be put close to each other in a worked example in order to reduce the extraneous work load (Sweller et al., 1998). For example, when using a diagram to demonstrate a solution of geometry, it is necessary to put annotations and explanations together with the diagram so readers can easily refer to them when learning (Sweller et al., 1998).
- **Modality effect:** the split-attention effect can be ameliorated by the modality effect, which indicates that the use of visual/audio presentation can increase the working memory and, hence, learning effectiveness. The modality effect is only valid when dealing with high element interactivity learning materials (Sweller et al., 1998).
- **Redundancy effect:** the redundancy effect means that one format of presentation is solely enough to deliver the information; the redundant format presentation with the same information from other sources will increase the cognitive work load. In other words, presenting the same information with multiple sources at the same time interferes with the learning process (Sweller et al., 1998).
- **Variability effect:** the variability effect can facilitate the knowledge transferring process, which enables learners to look over different problem situations, and, hence, improve their learning effectiveness. This process increases the learners' germane cognitive load, so they can process the materials more effectively if the total cognitive load is under the limit (Sweller et al., 1998).

The rapid development of information technologies enables the application of the cognitive load theory in teaching and learning. E-learning tools can help instructors design better courses to reduce students' cognitive load in learning (Alasraj, Freeman, & Chandler, 2011). With the support from information technologies, instructors can have many flexible ways to present information under the guidance of the cognitive load theory, and students also have more ways to show their works. Various e-learning tools are considered as an important approach to provide various possibilities based on the cognitive load theory (Alasraj et al., 2011).

As indicated by many researchers, studying worked examples is an effective approach in learning computer programming, especially for beginners. Instructors usually assign and demonstrate the "Hello World!" program in the first class, with which students quickly grasp the basic principles and build a framework in their minds. How to implement the worked example effect is not an easy task in all scenarios. When studying worked examples, students are expected to have the same result. It is difficult for instructors to assign worked examples to students as homework, since everyone will have the same result. However, information technologies can allow for more flexible multimedia formats of assignments, so students can record their working activities with audio and video information. By practicing worked examples, students can show their dynamically working process. In particular, the learning can be more effective if students actively and verbally explain (think aloud) their coding process when studying from worked example (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Renkl, 1997).

Acceptance of Information Technologies

Technology acceptance is a widely discussed issue when people try to introduce the use of new information technologies. The major research topic of technology acceptance is why people use a new information technology (Legris, Ingham, & Collerette, 2003). From the baseline model, the major constructs are "perceived usefulness" (PU), "perceived ease of use" (PEU) (Davis, 1989), and "usage intention" (UI) (Venkatesh, Morris, Davis, & Davis, 2003). More specifically, PU means "the degree to which a person believes that using a particular system would enhance his or her job performance" (Davis, 1989, p. 320), while PEU means "the degree to which a person believes that using a particular system would be free of effort" (Davis, 1989, p. 320). Another common construct is "personal innovativeness of information technology" (PIIT), which means "the willingness of an individual to try out any new information technology" (Agarwal & Prasad, 1998, p. 206). Depending on application areas, researchers include other constructs to handle each specific scenario.

Nowadays, education is becoming an increasingly important area of information technology application. Various information technologies and systems are supporting online and on-campus education. At the same time, researchers are conducting acceptance analysis of these technologies in teaching and learning (Agudo-Peregrina, Hernandez-Garcia, & Pascual-Miguel, 2014). For example, van Raaij and Schepers (2008) found that the PIIT plays a significant role in users' acceptance of online learning systems in addition to PEU and PU. Tarhini, Hone, and Liu (2013) found that students would more likely use online learning system (e.g., Blackboard) if this usage could help them save time, money, and effort. Agudo-Peregrina et al. (2014) found that the PIIT positively affects the PEU regarding e-learning systems. In an acceptance study about using podcast in education, Merhi (2015) indicated that personal and social factors also play important roles in students' adoption intention in addition to technical factors.

This study aims to compare the proposed methodology with previous studies in this area. Therefore, four commonly used constructs related to users' perceptions are included, i.e., PU, PEU, PIIT, and UI.

RESEARCH METHODOLOGY

Camtasia relay is a software tool that can record on-screen activities with audio/video information. When learning mobile programming, students were required to develop mobile applications by following step-by-step tutorials from a textbook, "Android Boot Camp for Developers Using Java" (Hoisington, 2015). The development package used in this research is Eclipse ADT (Android Developer Tools), which includes a set of tools for android programming (developer.android.com).

The direct way of applying worked example is to allow students explain and reflect worked programming codes (Abdul-Rahman & du Boulay, 2014). The instruction is as follows: "When recording, please tell your name in voice at the beginning of each chapter and narrate instructions during the process so others can follow your steps when learning." Therefore, students are required to narrate their working activities of each step and record their working process using Camtasia Relay simultaneously. At the end, students submit their recordings as the completion of assignments. Considering differences in personal innovativeness of information technology and programming backgrounds, students usually submit their recordings in different times, so many students can learn from early posted recordings. This creates a mutual leaning environment in the class. Different from regular assignments which mainly evaluate students' performance, the proposed methodology can also be used to evaluate students' learning process.

The following assignments demonstrate how to use the Camtasia relay to support the application of worked example effect and variability effect in teaching programming.

Assignment 1: Worked Example Effect

The textbook includes detailed instructions for one mobile project in each chapter. The first type of assignments is to develop a project by following step-by-step tutorials. However, differently from the worked example application in many other areas, repeating the same worked example of android mobile programming is not an easy task. If a learner cannot complete one step, he/she usually cannot continue to the next step. Students often need to do troubleshooting when following instructions, especially when doing the first one or two projects. During the learning process, students learn terminologies and concepts, get familiar with the ADT within Eclipse IDE, and understand procedures of mobile programming.

Assignment 2: Variability Effect

Repeating worked examples by following given procedures cannot guarantee complete understanding. Instructors can apply the variability effect of the cognitive load theory in teaching by gradually changing the problem situations and task dimensions (i.e., from low variability to high variability) (Sweller et al., 1998). According to Chi et al. (1989), solving an isomorphic project is one measure to assess students' understanding of the learned lessons. In the author's teaching, after completing chapter projects according to a tutorial, the students were required to complete a case project. There are no detailed instructions for case projects. These case projects have the same functions as previous chapter projects, but with different appearances. This is to apply the learned knowledge to a similar project. Students can complete a case project by referring to the original chapter project in the same chapter when they have any doubts.

DATA ANALYSIS

The proposed pedagogy is an information technology based methodology. Therefore, the researcher's first concern is whether or not the students would like to adopt and use it. This study first investigates students' general acceptance attitude towards this methodology and compare it with other education technologies. At the same time, this pedagogy is explored from the perspective of the cognitive load, interest, and satisfaction about using it. The related cognitive loads (cognitive load from the task and cognitive load from the method) are compared with those from using other education technologies. The survey questions are adapted from another research of using mobile devices to learn (Molina, Redondo, Lacave, & Ortega, 2014). Please check appendix A for the details of the questionnaire.

As a pilot study, 13 responses have been collected from students. Considering the small number of responses, a descriptive analysis is conducted below. The first part is to collect the demographic information of students. The average age of the respondents is 30.2 years. Ten of thirteen are male; three of thirteen are female. Two of thirteen are from computer science background, eight of thirteen are from information technologies/systems background, and the rest 3 are from the other background. The average computer programming experience is 4.2 years. The average Java programming experience is 1.3 years. The average mobile programming experience of using android is 0.3 years. The average mobile programming experience of using IOS is 0.1 years. No student has mobile programming experience using other platforms.

The second part of the questionnaire is to collect users' perceptions of technology acceptance. As Table 1 indicates, the average values of PEU, PU and UI are between 5 and 6. This is above the medium value 4. Therefore, the general attitude of this method is positive. The average values of PIIT are also between 5 and 6.

The third part of the questionnaire is to collect users' perceptions of cognitive loads. As Table 2 shows, the average values of the task cognitive load are between 3 and 4. This is below the medium value 4. The average values of the method cognitive load are between 3 and 5. This is at the medium value 4.

TABLE 1
TECHNOLOGY ACCEPTANCE

	Perceived Easy of Use			Perceived Usefulness			Usage Intention			Personal Innovativeness		
	PEU1	PEU2	PEU3	PU1	PU2	PU3	UI1	UI2	UI3	PIIT1	PIIT2	PIIT3
Avg.	5.54	5.15	5.31	5.54	5.08	5.38	5.00	5.15	5.00	5.69	5.92	5.38
Std.	1.63	1.47	1.63	1.59	1.75	1.59	1.54	1.53	1.44	1.72	1.76	1.52

TABLE 2
COGNITIVE LOAD MEASUREMENT

	Task Demand			Method Demand	
	TD1	TD2	TD3	MD1	MD2
Avg.	4.08	3.54	3.62	5.08	3.69
Std.	1.44	1.38	2.06	1.65	1.56

The fourth part of the questionnaire is to collect users' motivation, interest, pressure, and satisfaction. As Table 3 illustrates, the average values of interest and motivation are between 5 and 6. This is above the medium value 4. The average value of pressure is at the middle level. The average values of satisfaction are between 5 and 6. This is above the medium value 4.

TABLE 3
INTRINSTIC MOTIVATION AND PERFORMANCE SUBJECTIVE RATING

	Interest		Motivation	Pressure	Perceived Satisfaction			
	INT1	INT2	MOT1	PRE1	PS1	PS2	PS3	PS4
Avg.	5.00	5.15	5.46	4.23	5.31	5.38	5.23	5.08
Std.	1.67	1.89	1.79	1.57	1.80	1.82	1.82	1.66

In the following, the results of this research are compared with other similar studies regarding educational technology acceptance and the cognitive load theory. Evidence shows that these our results (mean, std.) are comparable with or higher than other studies in major acceptance factors, PEU, PU, PIIT, and UI (see table 4). The PIIT value of this research is higher than that in other two studies, and this leads to higher values in other factors, such as PU and then UI (van Raaij & Schepers, 2008). The studies used for comparison are all about widely accepted technologies, such as Blackboard and podcast. Therefore, the author's methodology is comparable with other educational technologies and is well accepted by students.

All values (mean, std.) regarding task cognitive load, method cognitive load, pressure, interest, and motivation are higher than those in Molina et al.'s (2014) research (see table 5). This reflects the fact that the author's research data are from challenging tasks, i.e., computer programming. However, the averages of interest, motivation, and satisfaction are all higher than 5. The students have very positive attitudes towards using this method.

In this research, the method demand cognitive load (MD: 4.38) is higher than the task demand cognitive load (TD: 3.74). This means that the tools used cause higher cognitive load than the task itself. In this study, there are two tools involved in assignments. One is the Camtasia relay, which is used to record the desktop activity; the other is the Eclipse ADT. Based on the author's observations, the major method demand cognitive load is from the Eclipse ADT. If other easy-to-use development tools are adopted, the total cognitive load can be reduced significantly. Therefore, there is a great potential to improve the acceptance of this method and students' learning effectiveness in the future.

TABLE 4
COMPARISON WITH OTHER ACCEPTANCE STUDIES

	Perceived Ease of Use	Perceived Usefulness	Personal Innovativeness	Usage Intention
This research	**5.33(1.08)**	**5.33(1.34)**	**5.67(1.18)**	**5.05(1.32)**
Molina et al. (PC)	3.97(0.73)	3.83(0.85)		3.75(0.86)
Molina et al. (Tablet)	3.5(0.96)	3.07(0.78)		3.05(0.98)
Tarhinia et al.	5.38(1.31)	5.24(1.27)		5.67(1.28)
Agudo-Peregrina et al.	5.05(1.24)	4.81(1.41)	5.09(1.51)	4.89(1.58)
Merhi	3.78(1.3)	3.96(1.31)		4.14(1.10)
van Raaij and Schepers*	6.20(0.85)	6.68(0.62)	4.55(1.60)	5.05(0.99)
	6.00(1.20)	5.90(0.96)	4.23(1.67)	4.90(1.01)
	5.98(1.12)	5.88(1.02)	5.05(1.75)	5.23(1.00)
	6.25(1.08)	5.75(1.41)	5.25(1.65)	

* The values of mean and std. of each indicator are listed separately.
* Numbers in one row do not have the corresponding relationship.

TABLE 5
COMPARISON WITH OTHER COGNITIVE LOAD STUDIES

	TD	MD	INT	MOT	PRE	PS
This research	**3.74(1.63)**	**4.38(1.50)**	**5.08(1.55)**	**5.46(1.61)**	**4.23(1.30)**	**5.25(1.22)**
Molina et al. (PC)	2.50 (0.28)	1.40 (0.39	3.95 (0.83)	3.50 (0.85)	2.50 (1.08)	3.90 (0.91)
Molina et al. (Tablet)	2.47 (0.39)	2.55 (0.98)	4.00 (0.88)	3.70 (0.95)	2.50 (1.18)	3.40 (0.93)

DISCUSSION AND RECOMMENDATIONS

In addition to the worked example effect, this pedagogy also involves the application of other effects from the cognitive load theory. When students work on programming based on step-by-step instructions from the textbook, there is a split-attention effect occurring, since they have to frequently switch from reading the instructions, looking at diagrams on the textbook, and working on the computer. This causes an extra cognitive load in learning. However, after one student posts a recording clip, other students can watch and listen posted works simultaneously. Due to the modality effect, including both visual and audio presentations can increase students' working memory and improve their learning effectiveness (Sweller et al., 1998). Therefore, earlier posted works may greatly help other students overcome the split-attention effects when learning. After students complete chapter projects by following tutorials, they are offered to complete two case projects based on the learned knowledge. The case projects are similar to the previous chapter projects, but with some changes. The variability effect increases the students' germane cognitive load, so they can learn better (Sweller et al., 1998). In practice, some students also try their own way autonomously to reduce the cognitive load, although they may not be aware of the cognitive load theory behind. Some students use an online version of the textbook, which allows them to easily read the instructions on the same screen when they are doing programming.

The proposed pedagogy also helps instructors in teaching and advising. The recordings show the learning process of students. Therefore, even if some students cannot complete a project perfectly, they can submit what they have done, and then instructors can understand what challenges students are facing and give specific instructions. This method is applicable when the learning task is procedural, so it can be used in other procedure-based assignments, such as running statistical tests using SPSS. With this methodology, students can quickly understand new concepts and build schemas in their minds.

REFERENCES

Abdul-Rahman, S.-S., & du Boulay, B. (2014). Learning programming via worked-examples: relation of learning styles to cognitive load. *Computers in Human Behavior,* 30, 286–298.

Agarwal, R., & Prasad, J. (1998). A conceptual and operational definition of personal innovativeness in the domain of information technology. *Information Systems Research*, *9* (2)*,* 204–215.

Agudo-Peregrina, A. F., Hernandez-Garcia, A., & Pascual-Miguel, F. J. (2014). Behavioral intention, use behavior and the acceptance of electronic learning systems: differences between higher education and lifelong learning. *Computers in Human Behavior*, 34, 301–314.

Alasraj, A., Freeman, M., & Chandler, P. (2011). Considering cognitive load theory within e-learning environments. In *Proceedings of Pacific Asia Conference on Information Systems (PACIS)* (pp. 1-13). Queensland: Queensland University of Technology.

Chi, M. T. H, Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-explanations: how students study and use examples in learning to solve problems. *Cognitive Science*, *13*(2), 145-182.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319-340.

Hoisington, C. (2015). *Android boot camp for developers using Java, 2nd Edition*. Boston, MA: Cengage Learning.

Legris, P., Ingham, J., & Collerette, P. (2003). Why do people use information technology? A critical review of the technology acceptance model. *Information & Management*, *40*(3), 191–204.

Merhi, M. I. (2015). Factors influencing higher education students to adopt podcast: an empirical study. *Computers & Education*, *83*(4), 32-43.

Molina, A. I., Redondo, M. A., Lacave, C., & Ortega, M. (2014). Assessing the effectiveness of new devices for accessing learning materials: an empirical analysis based on eye tracking and learner subjective perception. *Computers in Human Behavior, 31*(2), 475-490.

Moons, J., & De Backer, C. (2013). The design and pilot evaluation of an interactive learning environment for introductory programming influenced by cognitive load theory and constructivism. *Computers & Education*, *60*(1), 368-384.

Reder, L. M., Charney, D. H., & Morgan, K. I. (1986). The role of elaborations in learning a skill from an instructional text. *Memory & Cognition*, *14*(1), 64-78.

Renkl, A. (1997). Learning from worked-out examples: A study on individual differences. *Cognitive Science, 21*(1)*,* 1–29.

Renkl, A., & Atkinson, R. K. (2003). Structuring the transition from example study to problem solving in cognitive skill acquisition: a cognitive load perspective. *Educational Psychologist*, *38*(1), 15–22.
Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction*, *4*(4), 295-312.
Sweller, J., van Merrienboer, J.J.G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251-296.
Tarhini, A., Honea, K., & Liu, X. (2013). User acceptance towards web-based learning systems: Investigating the role of social, organizational and individual factors in European higher education. *Procedia Computer Science, 17*, 189 – 197.
van Raaij, E. M., & Schepers, J. J. L. (2008). The acceptance and use of a virtual learning environment in China. *Computers & Education*, *50*(3), 838–852.
Venkatesh, V., Morris, M. G., Davis, G., & Davis, F.D. (2003). User acceptance of information technology: toward a unified view. *MIS Quarterly, 27*(3)*,* 425-478.

APPENDIX A: SURVEY QUESTIONNAIRE OF USING WORKED EXAMPLE

PART A: DEMOGRAPHIC INFORMATION

Age (subjects must be at least 18 years old): _____________
Gender: Male Female

Education Background (Undergraduate major):
1. Computer Science; 2. Information Systems/Technologies; 3. Others.

Experiences of computer programming (years): _________________

Experiences of Java programming (years): _________________

Experiences of mobile programming (years): Android; IOS; Windows Phone; Others.

PART B: ACCEPTANCE, COGNITIVE EFFORTS, AND LEARNING ACHIEVEMENTS

Teachnology Acceptance

Perceived Easy of Use: (Adapted from Molina, Redondo, Lacave & Ortega, 2014)
PEU1: Learning mobile programming using this method is easy for me.
PEU2: My interaction with this method has been flexible, direct and fluid.
PEU3: Overall, I believe that this learning method is easy to use.

Perceived Usefulness: (Adapted from Molina, Redondo, Lacave & Ortega, 2014)
PU1: I think that the use of this method could help me in my learning tasks.
PU2: Using this method enables me to accomplish study tasks more quickly.
PU3: Overall, I find that using this method is a useful studying method**.**

Usage Intention: (Adapted from Molina, Redondo, Lacave & Ortega, 2014)
UI1: I intend to use this method for studying in the future.
UI2: I would recommend the use of this method for studying.
UI3: I intend to use this method for learning as often as needed.

Personal Innovativeness of Information Technology: (Adapted from Agarwal & Prasad, 1998)
PIIT1: I like to experiment with new information technology.
PIIT2: If I heard about a new information technology, I would look for ways to experiment with it.
PIIT3: Among my peers, I am usually the first to try out new information technology.

Cognitive Load Measurement (Adapted from Molina, *Redondo, Lacave & Ortega*, 2014**)**

Task Demand (Indication of Intrisnic Load)
TD1: The learning task was difficult.
TD2: The learning content was difficult for me.
TD3: The learning task required a lot of mental activity/ effort.

Method Demand (Indication of Extraneous Load of Recording the Work)
MD1: I have made an effort to visualize the learning materials (scroll, navigation, links).
MD2: It was difficult to learn the learning materials using this method.

Intrinstic Motivation and Performance Subjective Rating (Adapted from Molina, *Redondo, Lacave & Ortega*, 2014**)**

Interest
INT1: This method was fun to do.
INT2: I thought it was an interesting activity

Motivation
MOT1: I felt motivated during the activity.

Pressure
PRE1: I felt nervous while doing the activity.

Perceived Satisfaction
PS1: I am satisfied with accessing learning contents using this method.
PS2: I am satisfied with the interaction with this method for studying.
PS3: I think that using this method for learning could be motivating.
PS4: I like using this method for studying.

COMMENTS ABOUT USING THE PROPOSED METHOD IN LEARNING:

* Measured using a 7-point, Likert-type scale, ranging from 1 (strongly disagree) to 7 (strongly agree).