Tan, S. C. et al. (Eds.) (2013). Workshop Proceedings of the 21st International Conference on Computers in Education. Indonesia: Asia-Pacific Society for Computers in Education

Investigating Students' Sequence of Mathematical Topics in an Educational Game with a Curriculum Map

Hercy N.H. CHENG*, Charles Y.C. YEH, Hui-Wen WU, Calvin C.Y. LIAO, Andrew C.-C. LAO & Tak-Wai CHAN
Graduate Institute of Network Learning Technology, National Central University, Taiwan
*hercy@CL.ncu.edu.tw

Abstract: Spiral curriculum is suitable for students' ability development in a teacher-centered learning. In a sense, current textbooks adopt spiral curriculum because teachers need textbooks to teach their students. However, in a learner-centered learning, textbooks leave little space for students to monitor their own learning. For this reason, this study aims to design an educational game, Math Island, in which students may learn mathematics in their own paces according to their own ability. In the game, students play as a role of a city manager who needs to choose building plans and build their own building. When they build their city, actually they have to complete various learning tasks, which are designed from simple to complicated concepts. A preliminary finding suggests that students tended to carrying out learning tasks continuously instead of spirally. However, further investigation into students' learning behaviors on Math Island should be conducted.

Keywords: Curriculum map, spiral curriculum, self-paced learning, educational mathematical games

1. Introduction

In a conventional mathematical classroom, a teacher teaches mathematical concepts and assigns exercises to students, whose job is to follow the instructions and do the exercises. Almost all teachers use textbooks to teach students, because textbooks have a well-defined sequence of mathematical knowledge. With the examples and exercises in textbooks, teachers may easily prepare their teaching and tell students what to do in a class. By tests, teachers may assess whether students have learnt or not. However, although students learn the knowledge, they do not really know why they need to learn it and what they have to learn. In a sense, the domination of teachers in a classroom may hinder students from learning actively.

The major problem perhaps is the design of mathematical textbooks, which usually follows the official curriculum guideline. As the matter of fact, the curriculum guideline originated from spiral curriculum (Bruner, 1966). Furthermore, spiral curriculum provides increasing level of difficulty, which allows students to learn a new concept when they revisit a certain topic. For example, a student learns the addition of two 1-digit numbers in the first grade, and has to learn the concept of carries for adding two 2-digit numbers in the second grade. Later in the third grade, hi/she revisits the addition again and learns the addition of 3 or 4-digit numbers. Because of the property of spiral, the curriculum emphasizes the linkage between prior knowledge and the new concept. More specifically, teachers have to guide students to look back on knowledge previously learned, so that students can learn a new concept.

Nowadays, our textbooks, which embody the formation of spiral curriculum, hold the structure of mathematical knowledge, which teachers follows to lead students to learn the knowledge. However, textbooks leave little space for students to monitor their own learning, because textbooks are designed for teacher-centered learning. Teachers use textbooks to follow the standard pace of the curriculum, to demonstrate the examples, to instruct students, and to conduct exercises. In a sense, textbooks ignore the ability difference between students, which actually exists in a normal classroom. Some students who

learn well and fast can and should be allowed to learn more complicated concepts, while some students who learn badly and slowly should be taught in a careful way. In other words, students should have different learning paces depending on their unique ability.

For this reason, this study aims to design an educational game, Math Island, in which students may learn mathematics in their own paces according to their own ability. More specifically, the game allows students to explore mathematical concepts and their relationship with a curriculum map. Like spiral curriculum, the curriculum map guides students from simple concepts to complicated ones. However, the curriculum map does not force all students to follow the same pace. Instead, students may take their own paces and choose a path of the curriculum map in the game.

2. Design of Math Island

2.1 Curriculum Map

The design of curriculum map originates from curriculum tree (Chan, 1992). Curriculum tree provides a tree structure, which has several nodes and links. In a curriculum tree, each node represents certain knowledge (for example, the addition of two two-digit numbers with carries), while each link represents the linkage between two nodes of knowledge. Knowledge providers may easily add, delete, modify, and manage a curriculum. Furthermore, the feature of tree structure may visualize and organize a complex curriculum, so that teachers and students may easily make decision.

Like curriculum tree, curriculum map is also a visualized relationship between knowledge. The structure of map may allow students to explore concepts (Davenport, & Prusak, 2000). The well-structured knowledge may help students to retrieve, retain, and transfer knowledge (Davenport, de Long, & Beers, 1998). Furthermore, the structure organizes and links plenty of information visually, so that students may easily find the key information. Besides, the structure also helps them to evaluate how well they learn and adjust the way they learn.

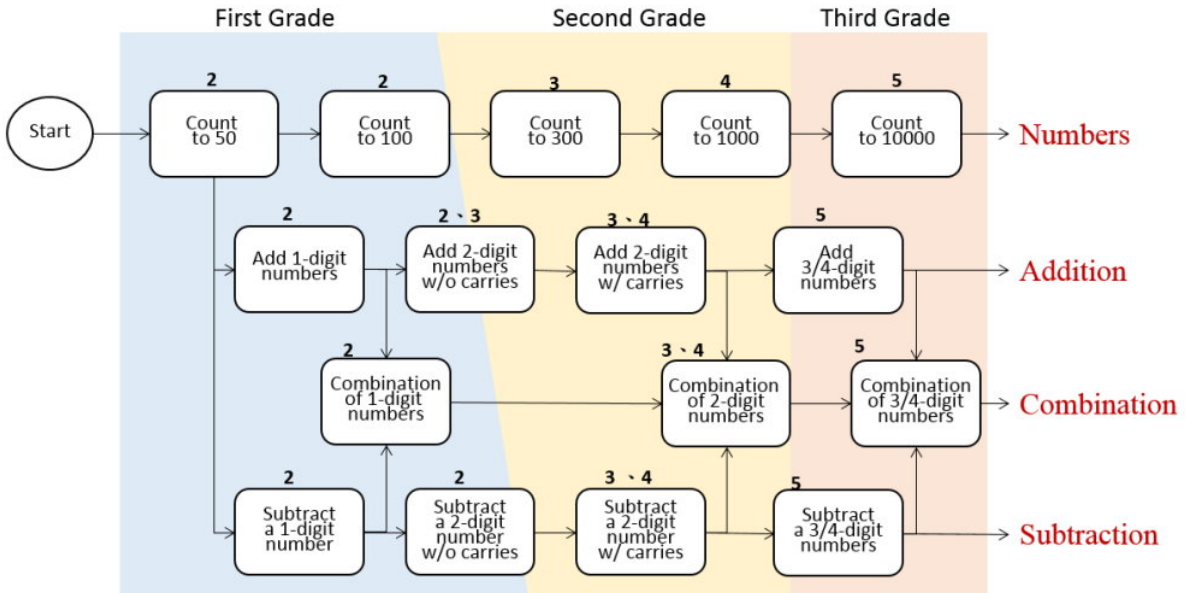


Figure 1. Curriculum Map

Figure 1 shows the design of curriculum map in the game. As shown in the figure, there are four topics of mathematical knowledge, i.e. numbers, addition, subtraction, and combination of addition and subtraction. For each topic, there are several concepts, illustrated as boxes with book numbers. For each concept, there are a series of learning tasks, which will be introduced in section 2.2 and 2.3. Take the topic of numbers for example. In the original textbook, the first grader have to learn how to count numbers to 100 in book 1 and 2 (this study only provide the concepts in book 2), while the second

grader learn how to count numbers to 1000 in book 3 and 4. However, in this curriculum map, students can learn how to count 1000 once they complete counting 100 (book 2) and 300 (book 3).

Furthermore, after they learn the concept of counting to 50, they can choose the concept of counting to 100, adding two 1-digit numbers, or subtracting a 1-digit numbers. The freedom of choice may increase learning interest. Most importantly, it encourages students to explore knowledge and to try to solve problems. Perhaps they may make mistakes, but making mistakes is also a form of learning.

2.2 Learning and Gaming Flow

Figure 2 illustrates the flow chart with three main steps for using Math Island in the perspective of learning and gaming. In the perspective of learning, students have to choose a learning task in the first step. For doing so, they first need to select a topic and a concept which they have not finished yet in the curriculum map. Then, they need to select an unfinished learning task in a specified concept. In the second step, they attempt to solve the selected learning task. There are two kinds of learning tasks: key learning tasks and practice learning tasks. A key learning task is designed for learning a new concept, while a practice learning task is designed for practicing a learnt concept. A learning task usually takes about 10 to 20 minutes. Furthermore, a learning task usually comprises several examples and exercises. If a student does an exercise wrongly, the learning task asks he/she do it again with hints if provided. In the third step, when finishing a learning task, they get feedbacks depending on their performance. Feedback may be positive or negative. Positive feedbacks help students build their sense of achievement and confidence, while negative feedbacks remind them to do it again.

In the perspective of gaming, students play as a role of a city manager. Their ultimate goal is to build a prosperous city. According to the aforementioned curriculum map, the ultimate goal is difficult for first graders, because it need taking at least two or three years. However, they can set a short-term goal when they attend a math class. More specifically, in the first step, they are required to choose a building plan, which is actually a learning task. Then in the second step they construct a part of the building by solving a learning task. Finally, when they finish the construction, they may get citizens with their taxes. Additionally, if they finish a certain number of learning tasks for a building plan, the building is enlarged and upgraded. The citizens and taxes can be used to plant more trees and to build more facilities for decorating their own cities.

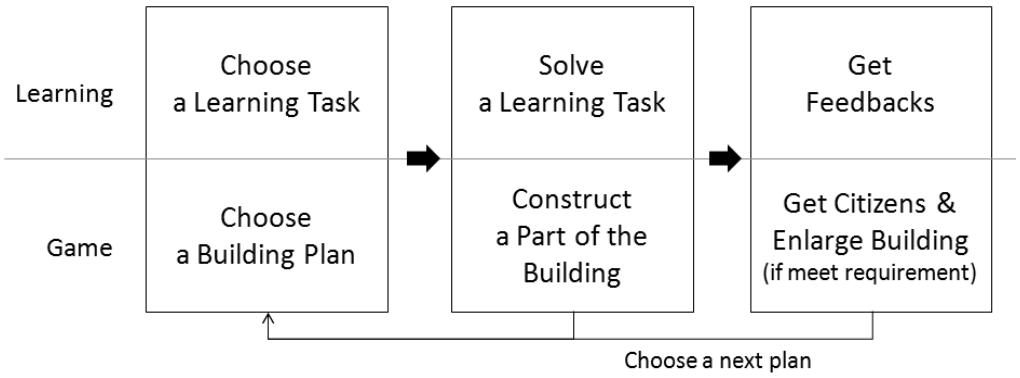


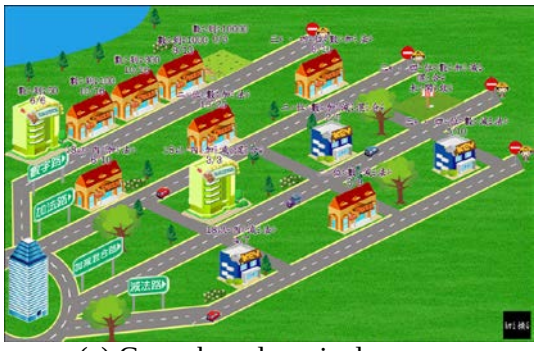
Figure 2. Learning and gaming flow

2.3 Game Design

Figure 3(a) shows the main interface of a Math Island for one student. As show in the figure, the Math Island is built according to the aforementioned curriculum map. Each topic is designed as a road. For example, from the top of the figure, there are a number road, an addition road, a combination road and a subtraction road, respectively. For a road of a topic, each concept is designed as a building, which is linked by roads. The buildings should be built according to the sequence of the curriculum map.

When students finish key learning tasks in a building, they are allowed to choose to build the next building. In other words, they may choose either exploring the next concept, or continuing constructing an existed building by finishing the practice learning tasks. If they decide to construct an existed building, they have chances to upgrade the building. Figure 3(b) illustrates the requirement for

upgrading buildings. In short, every time they finish one third of learning tasks in a building, the building meets the requirement and upgrades.



(a) Game-based curriculum map

(b) Building upgrade requirement

(c) Learning tasks for a concept

(d) A learning task

Figure 3. Math Island

When students choose a building of a concept, the game shows a list of learning tasks, as illustrated in Figure 3(c). The learning tasks with a "key" are key learning tasks (Figure 3(d)), while those without a key are practice learning tasks. Furthermore, as shown in the figure, some learning tasks are "locked" because the student has not finished the previous key learning tasks. In this case, the student has finished the first three learning tasks, but has not start doing the forth, fifth and sixed learning tasks. The seventh and the eighth learning tasks are locked because the student has not finished the sixed learning task, which is the key learning task.

3. Preliminary Evaluation

The research goal in this study is to investigate students' learning path on Math Island. More specifically, this study focuses on the sequence of mathematical topics. It would be interesting to find out whether students still learn as the spiral curriculum or as a continuous curriculum, given a complete curriculum on Math Island.

3.1 Setting

This study was conducted in a first-grade class of a primary school in Taiwan. In the class, there were 14 male and 12 female students. Each student used a tablet PC to use Math Island. Because not all students had used computers, they were taught how to use tablet PC before the study.

This study took about 12 weeks in the second semester of the first grade. In each week, students were allowed to play Math Island in at least two sessions of formal math classes and each session took about 40 minutes. Besides, they were also allowed to play the game in the rest time at school and at home. Although the teacher started to teach book 2 at that time, the Math Island provided a complete curriculum from book 2 to book 5 about numbers, addition and subtraction, as shown in Figure 1.

3.2 Sequential Analysis Approach

For investigating the sequence of mathematical topics, this study adopted sequential analysis approach (Jeong, 2005; Jeong & Davidson-Shivers, 2006), which could be used to analyzing the interaction and argumentation in an online discussion forum. This approach could reveal not only the frequencies of behaviors, but also their sequence (Kapur, 2011; Liao, Chen, Cheng, & Chan, 2012).

The study adopted sequential analysis approach to explore the sequence of students' learning behaviors, especially about how they choose mathematical topics on Math Island. For doing so, the students' behaviors on Math Island were coded in the following way. First, for each student, the sequence of learning tasks was recorded. Second, the learning tasks were categorized as four mathematical topics: numbers (N), addition (A), subtraction (S), and the combination of addition and subtraction (C). If students use Math Island as spiral curriculum, there should be significant sequences between one topic and another topic. Otherwise, there should be significant tendency for continuing the same topic.

3.3 A Preliminary Finding

Table 1 shows the frequencies of learning tasks for the first grade. As shown in the table, all students finished the learning tasks on numbers for the first grade. However, not all students finished the learning tasks on addition, subtraction, and combination. It should be noted that only 7 students started to carry out the learning tasks on combination.

Table 9. The frequencies of learning tasks for the first grade

Topic	Total Amount	Average Frequencies	Average Time (minutes)
Numbers	30	31.1	187.6
Addition	34	14.4	92.4
Subtraction	16	9.8	94.9
Combination	8	4.9	19.9

Figure 4 further illustrates the sequence of mathematical topics on Math Island. The figure shows that students tended to do the same topics after they finished a learning task (N→N: 0.88; A→A: 0.69; S→S: 0.61; C→C: 0.65). Although the current curriculum indicates students should learn mathematics via revisiting different topics spirally, this tendency suggests a more natural way that students learn mathematics continuously.

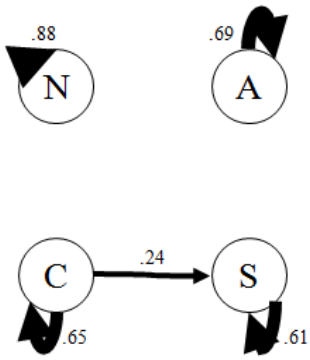


Figure 4. The sequence of mathematical topics on Math Island

Figure 4 also shows that the seven students, who started to carry out the learning tasks on the combination of addition and subtraction, tended to go back to completed learning tasks on subtraction (C→S: 0.24). This result may be due to the fact that when they started to do the exercises on combination, they found that the topic was too difficult for them and they may need to strengthen their

ability of subtraction. For this reason, they decided to complete their unfinished learning tasks on subtraction. However, this conjecture needs further investigation.

4. Concluding Remarks

The textbooks nowadays adopts spiral curriculum, which may be suitable for students' ability development in a teacher-centered learning. However, it cannot allow students to realize the relationship among knowledge in a macro view. For this reason, this paper designs and develops an educational game, Math Island, on the basis of a curriculum map. In this version, the game may help the first graders explore the curriculum map, which may build core mathematical concepts and their relationship. Furthermore, the game provides learning tasks of all concepts about numbers, addition, subtraction, and combination for the first to the third graders. In the game, the students need to choose a learning task, and to adjust their direction for self-paced learning. A preliminary finding suggests that students tended to carrying out learning tasks continuously instead of spirally. However, further investigation into students' learning behaviors on Math Island should be conducted.

Acknowledgements

The authors would like to thank the National Science Council of the Republic of China, Taiwan, for financial support (NSC-101-2631-S-011-002 、 NSC-101-2511-S-008-016-MY3 、 NSC-100-2511-S-008-013-MY3 、 NSC-99-2511-S-008-002-MY3、NSC-101-2811-S-008-009、NSC-101-2811-S-008-010), and Research Center for Science and Technology for Learning, National Central University, Taiwan.

References

Bruner, J. S. (1966). *Toward a Theory of Instruction*. Cambridge, Mass: Harvard University Press.

Chan, T. W. (1992). Curriculum tree: a knowledge-based architecture for intelligent tutoring systems. *Intelligent Tutoring Systems*, *608*, 140-147.

Davenport, T. H., de Long, D. W., & Beers, M. C. (1998). Successful knowledge management projects, *Sloan Management Review*, *39*(2), 43-57.

Davenport, T. H., & Prusak, L. (2000). *Working Knowledge: How Organizations Manage What They Know*. Cambridge, Mass: Harvard Business Press.

Jeong, A. (2005). A guide to analyzing message–response sequences and group interaction patterns in computer-mediated communication. *Distance Education, 26*(3), 367–383. doi:10.1080/01587910500291470

Jeong, A., & Davidson-Shivers, G. V. (2006). The effects of gender interaction patterns on student participation in computer-supported collaborative argumentation. *Educational Technology Research and Development, 54*(6), 543–568. doi:10.1007/s11423-006-0636-4

Kapur, M. (2011). Temporality matters: Advancing a method for analyzing problem-solving processes in a computer-supported collaborative environment. *Computer-Supported Collaborative Learning*, *6*(1), 39–56.

Liao, C. C. Y., Chen, Z. H., Cheng, H. N. H., & Chan, T. W. (2012). Unfolding learning behaviors: A sequential analysis approach in a game-based learning environment. *Research and Practice in Technology Enhanced Learning, 7*(1), 25-44.