Wong, L.-H. et al. (Eds.) (2013). Proceedings of the 21st International Conference on Computers in Education. Indonesia: Asia-Pacific Society for Computers in Education

Aim-Math: an audio-based interactive media for learning mathematics

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Abstract: We propose, Aim-Math, an alternative approach to develop an interactive-enhanced mathematics learning system for blind and visually impaired (VI) students. By integrating the text-to-speech technology with the educational process, Aim-Math is able to read aloud the math expressions in Thai and to provide the interactive features that allow the students to study and practice on their own. With this interactive mathematics learning system, the blind and VI students can conveniently learn mathematics.

Keywords: Text-to-speech, blind and visually impaired learning, mathematics, interactive learning

1. Introduction

In the past few decades, text-to-speech (TTS) technologies have shown successfully in developing automatic math reader systems (Raman & Gries, 1995; Stevens, Edwards & Harling, 1997; Ferreira & Freitas, 2004; Soiffer, 2009) including i-Math (Wongkia, 2012). i-Math is proposed in 2012 as an assistive technology for Thai blind and visually impaired (VI) students in learning mathematics. Although TTS removes barriers to access math content and symbols for blind and VI students, it is inadequate to help the students to understand the subject matter. Being able to access the materials which are full of notations and symbols via the synthesis voice is rather difficult especially when the students continuously listen over the long periods.

In teaching and learning system, an interactive instruction that allows students to explore, search, and write is able to help them to gain a deeper understanding of concepts. With the interactive features, the teaching instruction will be more attractive and easy for the students to follow. Besides, the progress of computer technology makes it possible to combine TTS and interactive features to form a practical math learning tool. Therefore, we designed Aim-Math, an audio-based interactive system which integrate i-Math with the interactive features such as read aloud a typed-character, provide immediate feedback, and drop a hint.

2. Backgrounds

We begin this section with the development of i-Math, an automatic math reader system, which is able to read math expressions in Thai, and follow with the scaffolding process which is a traditional and popular technique for interaction in teaching and learning process between teachers and learners.

2.1 i-Math

i-Math, an intelligent accessible mathematics system, is a TTS system which is able to read both math expressions and Thai plain text aloud. The motivation for developing i-Math is the awareness of the need of technologies that enable Thai blind and VI students to have the same opportunities as the sighted students in studying, especially in math and science. i-Math takes math expressions and Thai plain text in Microsoft Word format as an input and generates speech output in Thai.

i-Math begins the process with extracting an eXtensible Markup Language (XML) format from the input document and adding the necessary words to convey the meaning of math expressions. Next, all English and Greek alphabets, math symbols, and numerals are mapped into their Thai

pronunciation patterns. Then i-Math applies a rules-based strategy to analyze a Thai syllable, a basic pronunciation unit of Thai sound. Finally, i-Math generates an output sounds by a concatenation technique. To accurately read exponents or powers, a^b, involving two components, the base '*a*' and the exponent '*b*'. i-Math reads the base '*a*' first and adds the word "ยกกำลัง (/yók-gam-lang/, to the power of)" follows with the exponent '*b*'. The expression, a^b, is then read in Thai as "*a* ยกกำลัง *b*". To identify the end of a base, i-Math adds the word "ทั้งหมด (/táng-mòt/, all)" when the base is not one character. The expression, $(a+b)^c$, is read as "*a* บวก *b* ทั้งหมด ยกกำลัง *c*". If the base is a kind of math expressions, e.g., a fraction, the word "ทั้งหมด" must be added as well. For example, the expression, $\left(\frac{a}{b}\right)^c$, is uttered "เศษ *a* ส่วน *b* ทั้งหมด ยกกำลัง *c*". The two underline words "เศษ (/sàyt/, numerator)" and "ส่วน (/sùan/, denominator)" are added into the utterance to identify the beginning of the numerator, the beginning of the denominator, the end of the fraction, and the beginning of the exponent respectively.

i-Math differs from other math reader systems in that its input and output are in Thai. The input format is in Microsoft Word since it is easy to use for most Thai teachers, blind and VI students. Importantly, to produce concise and clear Thai speech of the math expressions that convey the correct meaning, the relationships between notations appearing in the expressions, the locations, and the order of appearances of characters are taken into account. i-Math also retains the order of spoken words to serve the ease of communication between users and i-Math.

i-Math was evaluated in three aspects. First, the intelligibility results indicate that i-Math can generate understandable pronunciations for math text. Next, overall speech quality results show that the utterances produced by i-Math are good quality and understandable with slight effort. Finally, teachers and students have positive perceptions toward the use of i-Math.

2.2 Scaffolding in Technology-Enhanced Learning

Scaffolding is a teaching strategy used to support students in learning (Wood, Bruner & Ross, 1976) for helping students in performing a task. Up until now, the scaffolding still gains interesting from educators and researchers in several fields, e.g. science and math education and technology-enhanced learning. In technology-enhanced learning, the scaffolding has been designed to best support a student learning (Sharma & Hannafin, 2007). The computer-based scaffolding includes interaction between a teacher and students in learning process by providing, fading, and removing supports to students.

Jackson, Krajcik and Soloway (1998) proposed Guided Learner-Adaptable Scaffolding (GLAS) as a guideline for implementing scaffolding in designing educational tools. GLAS allows the students to control the changing and fading the scaffolding on their own. The scaffolding in GLAS is categorized into three parts: supportive, reflective, and intrinsic scaffolding. Firstly, supportive scaffolding is a support for doing the task by providing advices, e.g. examples, hints, explanation, during and alongside to reach the task. Next, reflective scaffolding is a support for thinking about the task. Students are provided opportunities to reflect what they are thinking (e.g., planning, predicting). Finally, intrinsic scaffolding is a support for changing the task itself. This scaffolding is provided for reducing the complexity of the task.

The success of i-Math in producing accurate audio of math expressions and the well-known learning strategy led us to the idea of combining i-Math with the scaffolding technique to design and develop an interactive learning tool, Aim-Math. The architecture of Aim-Math is described in the following section.

3. Aim-Math

Aim-Math was designed to be a supplementing math learning tool, not for replacing the classroom teacher. The instruction and exercise in Aim-Math are intended to provide motivation for blind and VI students in mathematics learning. The following issues were concerned in designing Aim-Math:

- The instruction and exercise should be in the interface suitable such as keyboard navigation.

- The instruction must synchronize between sound and text with pause and repeat sound playing.
- Text and picture should be allowed the size adjustment, for supporting the low vision students.
- The sound must be provided in concise and clear sound, avoiding a very long explanation.
- The math expressions must be read aloud in correct, concise, and clear.
- The exercise must be arranged from simplest to the most complex. The multiple choices should be avoided since the students have to continuously listen for a very long period.
- The immediate feedback should be provided to reflect what the students are doing.

The first two issues are for the students to select the content of the Aim-Math and to control the speech. The third through the fifth are to facilitate especially the blind and VI students. The last two items are designed to be an interactive learning system based on the scaffolding process. In this section, we describe math content, math reader feature, and interactive features available in Aim-Math.

3.1 Mathematical Content

To construct the math learning tools for blind and VI students, the exponent content is added in the initial state of the Aim-Math prototype. The reasons for including this content are: the exponent is a basic knowledge for learning Algebra in higher level and it is found in the beginning of the secondary school level. The instructions and exercises used in Aim-Math are based on the Mathematic Learning Standard, the Thai Basic Education Core Curriculum B.E. 2551 (A.D. 2008). Table 1 shows some examples of the exercises provided in Aim-Math and its English translations provided in the parentheses. In the first example, the students are asked to express "125" in the exponential notation while they are asked to compute the values of the exponential expressions in the 2nd–4th examples. The 5th and 6th examples are in math word problems. Each instruction is prepared in concise and clear explanation. The set of exercise is provided from simplest to the most complex. The students are asked to fill in short answers while the multiple choices are avoided.

Table 1: Some examples of exercise in Aim-Math.

No.	Examples of exercise
1	จงเขียน 125 ในรูปของเลขยกกำลัง (Write 125 in the exponential notation.)
2	$(-5)^2$ มีค่าเท่ากับจำนวนใด (What is the value of $(-5)^2$?)
3	จงหาว่า -10^2 แทนจำนวนใด (What is the value of -10^2 ?)
4	จงหาว่า $\left(\frac{1}{2}\right)^5$ แทนจำนวนใด (What is the value of $\left(\frac{1}{2}\right)^5$?)
5	จงหาว่า $(5^2 \times 5^7) \div 5^3$ มีค่าเท่ากับเลขยกกำลังใด (What is the value of $(5^2 \times 5^7) \div 5^3$?)
6	โรงเรียนมัธยมแห่งหนึ่งมีนักเรียนจำนวน 1,000 คน จงเขียนจำนวนดังกล่าวในรูปเลขยกกำลัง (A school has 1,000 students. Write the number of students in the exponential notation.)

3.2 Math Reader Features

To provide correct and understandable sound of math expressions, i-Math is used in the reader aloud module of Aim-Math. i-Math generates Thai speech of plain text and math expressions by adding extra words to convey correct meaning of such math expressions. The i-Math generations and English translations of the 2nd–5th examples (Table 1) are shown in the 2nd and 3rd columns (Table 2), respectively.

i-Math added the word "ยกกำลัง (/yók-gam-lang/, to the power of)" to convey the meaning of exponents shown in highlight marks (2nd column). The 3rd and 4th example present the different pronunciations of the expression "$(-5)^2$" and "-10^2" which convey the different meaning. i-Math generated "(ลบ 5) ทั้งหมด ยกกำลัง 2" for the expression "$(-5)^2$", while it generated "ลบ 10 ยกกำลัง 2"

for "-10^2". The word "ทั้งหมด (/táng-mòt/, all)" was added for ending the base of the exponents illustrated in bold text. In 5th example, the fraction was read by adding the words "เศษ (/sàyt/, numerator)" and "ส่วน (/sùan/, denominator)" as shown in the italic text. The minus, multiplication, and division signs were mapped into the corresponding Thai words "ลบ (/lóp/, minus)", "คูณ (/koon/, multiply)", and "หารด้วย (/hăan dûay/, divided by)", respectively as shown in the underline text. Moreover, before reading the Thai text, i-Math segmented the string into a sequence of words with the space in-between text since there is no end-word boundary in Thai. All Thai pronunciations were matched into their corresponding Thai sound and generated Thai speech.

Aim-Math extracts the output of i-Math both in Thai pronunciations and the corresponding sound of math expressions and displays on the user interface of Aim-Math.

Table 2:. Thai pronunciations generated by i-Math.

No	Input	i-Math generation	English translation
2	$(-5)^2$ มีค่าเท่ากับจำนวนใด	(ลบ 5) **ทั้ง หมด** ยก กำ ลัง 2 มี ค่า เท่า กับ จำนวน ใด	What is the value of minus 5 all to the power of 2?
3	จงหาว่า -10^2แทนจำนวนใด	จงหาว่า ลบ 10 ยก กำ ลัง 2 แทนจำนวนใด	What is the value of minus 10 to the power of 2?
4	จงหาว่า $\left(\frac{1}{2}\right)^5$ แทนจำนวนใด	จงหาว่า (*เศษ* 1 *ส่วน* 2) **ทั้ง หมด** ยก กำ ลัง 5 แทนจำนวนใด	What is the value of the denominator 1 the numerator 2 all to the power of 5?
5	จงหาว่า $(5^2 \times 5^7) \div 5^3$ มีค่าเท่ากับเลขยกกำลังใด	จงหาว่า (5 ยก กำ ลัง 2 คูณ 5 ยก กำ ลัง 7) หาร ด้วย 5 ยก กำ ลัง 3 มี ค่า เท่า กับ เลข ยก กำลัง ใด	What is the value of 5 to the power of 2 multiply by 5 to the power 7 divided by 5 to the power of 3?

3.3 Interactive Feature

To make Aim-Math an interactive learning system, we apply the scaffolding technique in designing the interactive features. Figure 1 illustrates the interactive features of Aim-Math. Sequence of math problems (*Sequence of Exercise*) is carefully selected from the simplest to the most complex. Each problem is presented in different forms, i.e. a graphic display, its corresponding Thai pronunciation (text) synchronizing with its audio in *Problem Posing* step. Aim-Math uses two transformed outputs, text and sound, of i-Math to post and play a math problem. Aim-Math is aimed to design especially for blind students but it is not limited to only blind students. Low vision and sighted students can fully utilize. Obviously, totally blind students cannot gain a benefit from that the graphic display on the screen, however, the students who are low vision are able to enlarge the size and read the problems. Moreover, teachers, parents or other assistants can use the graphic display and text during providing guidance.

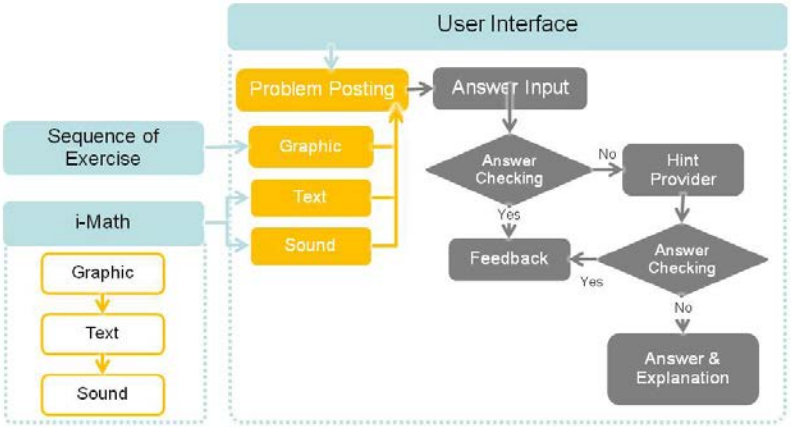

Figure 1. Interactive feature of Aim-Math

The *Answer Input* step accepts the typing answer input from users. Each typed-character is converted into audio played sound for the users to verify what they have typed. After typing the answer, the users press the Enter key on the keyboard to submit the answer. In Aim-Math, the star sign, '*', denotes the multiplication sign and the hat sign, '^', is the to-the-power-of sign. The answer will be checked to determine whether it is correct or not in the *Answer Checking* step. If the answer correct, the users will receive immediately the correct feedback (*Feedback)* and automatically go to the next problem. Otherwise, the users will receive a step-by-step hint from the *Hint Provider* step. The users can then try to input their new answers. After checking, if the new answer is still incorrect, the users will be provided the correct answer and explanation in the *Answer & Explanation* step.

The main interface of Aim-Math is depicted in Figure 2. The interface in this figure presented in English for easily reading but the developed interface of Aim-Math is in Thai. The sample math problem, "What is the value of 4^3?", is shown in the Problem part. The two buttons: Read and Pause allow users to control the audio during their listening. Aim-Math also provides the Help button or pressing Ctrl+H on the keyboard to describe keyboard controling both in text and sound. For example, Ctrl+R is for "Repeat " and Ctrl+P for "Pause". The Stop-providing-a-hint button is provided in the case that the users do not want any suggestion.

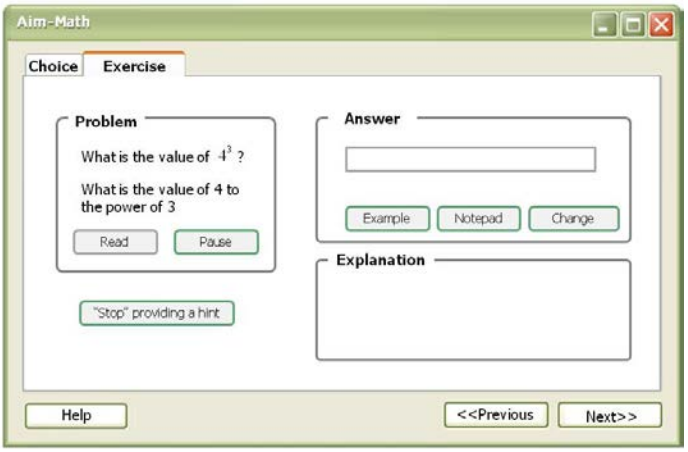

Figure 2. Aim-Math Interface

Table 3: scaffolding technique in designing interactive feature of Aim-Math.

Scaffolding	Implementation of Aim-Math	Fading
Supportive	Post the math problem in sequence from simple to complicate problem with text and sound synchronization, font size adjustment, and pause and repeat audio.	Automatically available.
	Provide hints after the first incorrect answering.	Option with the Stop-providing-a-hint button.
	Provide immediate feedback, solution, and explanation after entering answer such as reading aloud typed characters, correct or incorrect feedback, and dropping a hint.	Automatically available.
Reflective	Provide a notepad window with guided questions and editing field.	Option with the Notepad button.
Intrinsic	Give an example of the similar problem at the first time.	Option with Example button.
	Post the new math problem with association to the recent problem.	Option with the Change button.

In the Answer part, the users can type in their answer with the read-aloud-typed-character function. Three buttons provide in this part is the Example (Ctrl+E), Notepad (Ctrl+N), and Change (Ctrl+G) buttons. The Example button is provided to show a similar example at only the first time that the users meet this kind of problem. In the case that the users ignore the hint the Notepad and Example buttons are faded. Clicking the Notepad button will open the notepad window with the guideline, e.g. "4^3 can write in the multiplication form as…", that allows the user to fill what they

think in the editing fields. Moreover, the problem can change with the Change button, but the new problem remains the association with the recent one. For example, the math problem, What is the value of 5^2?, is posted after clicking the Change button.

After answer checking, the feedback, solution and explanation are provided in text format with sound synchronizing in the Explanation part. However, if the users fill in the incorrect answer, Aim-Math will provide the message "The answer is incorrect, do you need the suggestion?" even the users ignore the hint by pressing the Stop-providing-a-hint (Crlt+S) button.

The three scaffolding categories: supportive scaffolding, reflective scaffolding, and intrinsic scaffolding, and their designs and fading are described in Table 3. The supportive scaffoldings are provided through the sequence of posting problems, message synchronizing with audio of hints, feedback, solution, and explanation with the Stop-providing-a-hint button for fading. To explicit what the users think, the notepad window appears and fades with pressing the button or keyboard for reflective scaffolding. Options with the Example button and the Change button are intrinsic scaffolding to simplify the problem.

4. Conclusion and Future works

Aim-Math combines i-Math and the scaffolding technique in designing an interactive learning system. Aim-Math system has been implemented to be an interactive-enhanced math learning tool for Thai blind and VI students with math content, exponents, as an initial prototype. This system can be used by individual blind and VI students to learn math through the learning activities with short instructions and interactive exercises. The accurate utterances of math expressions are rendered to the students with the capability of i-Math. The interface is designed to be suitable for the users who are blind and VI with a number of the keyboard control options and sound synchronization. However, some options are provided only at the first time the problems appear and fade away if the students do not need them anymore. The students can choose or ignore the options they want to help them learn and meet the right answer of the posted problems.

The performance evaluation of Aim-Math will be carried out in two parts, i-Math accuracy and interactive features learning benefits. The first part, i-Math accuracy evaluation, was fully completed and its results. The second part, the interactive features learning benefits, will be conducted to determine whether Aim-Math can help the blind and VI students to enhance their mathematics learning. The success of this study will open an alternative gateway in learning math for blind and VI students.

Acknowledgements

This research project is supported by the grant from Mahidol University.

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