I-MATH: AN ALTERNATIVE GATEWAY TO MATHEMATICS FOR THAI VISUALLY IMPAIRED

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ABSTRACT

Although blind and visually impaired (VI) students can access math documents/materials via many channels, e.g., a human reader, math Braille codes, and audio (talking) books, these channels have limited availability. We, therefore, propose an intelligent accessibility mathematics approach called *i-Math*. *i-Math* synthesizes speech output from math text input by (1) extracting an XML format from the Microsoft Word document input, (2) adding necessary words required in reading math expressions, (3) mapping all foreign alphabets with their Thai pronunciation, and (4) generating corresponding speech.

The *i-Math* system, an educational tool for blind and VI students, was implemented based on the *i-Math* approach. It was designed to facilitate access to math materials. The *i-Math* system can serve as a math learning and teaching tool for both students and teachers. The students can enjoy their newfound ability to read and practice math anytime and anywhere with *i-Math* while their teachers can prepare their classroom handouts, assignments and exercises in audio versions.

The evaluations of the *i-Math* system were conducted with blind and VI students and their teachers regarding three aspects: (1) intelligibility, (2) overall speech quality, and (3) user satisfaction. The intelligibility results indicate that the *i-Math* system can generate understandable pronunciations for math text. Overall speech quality results show that the utterances produced by the *i-Math* system are good quality and understandable with slight effort. It can be concluded from the user satisfaction questionnaire that teachers and students have positive perceptions toward the use of *i-Math* because math materials are easily accessible to blind and VI students through *i-Math*, and they can independently and comfortably study and practice their mathematics.

KEY WORDS: MATH EXPRESSION / TEXT-TO-SPEECH / BLIND AND VISUALLY IMPAIRED LEARNING / ASSISTIVE TECHNOLOGY

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ระบบอ่านออกเสียงภาษาคณิตศาสตร์สำหรับนักเรียนที่บกพร่องทางการมองเห็น
I-MATH: AN ALTERNATIVE GATEWAY TO MATHEMATICS FOR THAI VISUALLY IMPAIRED

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บทคัดย่อ

ปัจจุบัน แม้ว่านักเรียนที่มีความบกพร่องทางสายตาสามารถเข้าถึงเอกสารทางคณิตศาสตร์ได้ในหลายช่องทาง อาทิ ผู้ช่วยอ่าน อักษรเบรลล์ และหนังสือเสียง แต่ช่องทางดังกล่าวเหล่านั้นต่างมีความสามารถที่จำกัด ดังนั้นระเบียนวิธี *i-Math* จึงได้ถูกนำเสนอในวิทยานิพนธ์นี้เพื่อสังเคราะห์เสียงจากข้อความและสัญลักษณ์คณิตศาสตร์อย่างอัตโนมัติ โดย (1) ดึงรูปแบบ XML จากเอกสารที่อยู่ในรูปของ Microsoft Word (2) เพิ่มคำที่มีความจำเป็นในการอ่านสัญลักษณ์ทางคณิตศาสตร์ในตำแหน่งที่ถูกต้อง (3) จับคู่ทุกๆ อักษรภาษาต่างประเทศกับคำอ่านในภาษาไทย และ (4) สังเคราะห์เสียงที่สอดคล้องกับคำอ่านนั้น

ระเบียบวิธี *i-Math* ถูกใช้ในการพัฒนาระบบอ่านภาษาคณิตศาสตร์ ซึ่งเรียกว่า ระบบ *i-Math* ระบบนี้เป็นเครื่องมือทางการศึกษาสำหรับนักเรียนที่มีความบกพร่องทางการมองเห็น ระบบนี้ถูกออกแบบให้อำนวยความสะดวกในการเข้าถึงเอกสารต่างๆ ทางคณิตศาสตร์ และที่สำคัญคือเป็นเครื่องมือช่วยในการเรียนการสอนคณิตศาสตร์สำหรับทั้งนักเรียนที่มีความบกพร่องทางการมองเห็นและครูผู้สอนได้ นักเรียนสามารถสนุกสนานกับความสามารถที่ค้นพบใหม่ในการอ่านและฝึกฝนคณิตศาสตร์ได้ทุกที่ทุกเวลากับ *i-Math* ในขณะที่ครูผู้สอนสามารถจัดเตรียมเอกสารที่ใช้ในชั้นเรียน แบบฝึกหัด และแบบทดสอบในรูปของเสียงได้อย่างสะดวก

ระบบ *i-Math* ถูกทดสอบและประเมินจากนักเรียนที่มีความบกพร่องทางการมองเห็นและครูผู้สอนในสามประเด็น คือ (1) ความถูกต้องในการสร้างคำอ่านจากเอกสารคณิตศาสตร์ (2) คุณภาพเสียง และ (3) ความพึงพอใจในการใช้งานระบบ *i-Math* ผลการประเมินชี้ให้เห็นว่าระบบ *i-Math* สามารถสังเคราะห์คำอ่านจากเอกสารคณิตศาสตร์เป็นที่เข้าใจได้ สำหรับคุณภาพเสียงที่สังเคราะห์โดยระบบ *i-Math* นั้นให้คุณภาพเสียงที่ดีและสามารถเข้าใจได้โดยใช้ความพยายามเพียงเล็กน้อย ผู้ประเมินทั้งนักเรียนและครูผู้สอนมีความพึงพอใจในเชิงบวกต่อการใช้ระบบ *i-Math* ทั้งนี้เป็นเพราะผู้ประเมินสามารถเข้าถึงเอกสารต่างๆ ทางคณิตศาสตร์ได้ง่ายขึ้น อีกทั้งสามารถเรียนรู้และฝึกฝนคณิตศาสตร์ได้อย่างอิสระในเวลาที่ต้องการและสะดวกอีกด้วย

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LIST OF ABBREVIATIONS

CAI	=	Computer Assisted Instruction
CRSLP	=	Centre for Research in Speech and Language Processing
DAISY	=	Digital Accessible Information System
DTB	=	Digital Talking Book
GCD	=	Greatest Common Divisor
HTML	=	HyperText Markup Language
IE	=	Microsoft Internet Explorer
LCM	=	Least Common Multiple
LES	=	Listening Effort Scale
MathEx	=	Mathematical expressions
MathML	=	Mathematical Markup Language
MOS	=	Mean Opinion Score
MS Word	=	Microsoft Word
NECTEC	=	National Electronics and Computer Technology Center
OpenXML	=	Office Open XML
TD-PSOLA	=	Time-Domain Pitch-Synchronous Overlap and Add
TTS	=	Text-to-Speech
VI	=	Visually Impaired
W3C	=	World Wide Web Consortium
XML	=	eXensible Markup Language
XPath	=	XML Path Language
XSLT	=	eXensible Stylesheet Language Transformations

CHAPTER I

INTRODUCTION

1.1 Thesis Statement

Reading and understanding math expressions, suitably displayed, are commonplace for most people. Blind and visually impaired (VI) people, however, are challenged in these activities. Hence, people with vision loss need assistive technologies to accommodate their mathematics learning (Educational Media for People with Disabilities section, 2005). Text–to–speech (TTS) technology allows people who are blind and VI to access the valuable knowledge through a hearing channel. To open an alternative gateway to mathematics for blind and VI people, we therefore propose '*i-Math*', an **i**ntelligent accessible **math**ematics approach. *i-Math* is able to read math text, both math expressions and plain text aloud. To do this, we must investigate the math expression structures, learn how to read math expressions in Thai and examine the differences between normal text and math expressions. The *i-Math* system prototype was implemented to demonstrate the ability of our framework as an educational tool for blind and VI students. With *i-Math*, students can independently and comfortably study and practice mathematics and science.

1.2 Motivation

Learning mathematics is essential to students at all levels. To develop math skills, practice in solving math problem is an alternative suggestion. Unfortunately, blind and VI students face the difficulties at the first step due to their limitations in writing and reading math formulas especially. Although a large number of math problems are available both in printed materials and digital forms, blind and

VI students barely benefit from them. The students lose opportunities to practice on their own that will finally result in losing opportunities to develop their math skills.

Generally, blind and VI students can access materials/documents of math courses with the help of human readers; however, having human readers at their side at all times is impractical because of the cost and the limited availability of the trained personnel. Braille is the more convenient way for blind and VI students to access the documents. Unfortunately, not many documents are available in Braille since the production of math documents in Braille is rather difficult and complicated (Moço & Archambault, 2004). Moreover, most blind and VI students found that reading Braille math code is quite tedious and ambiguous due to the additional meanings of the cells, even for some who are comfortable reading literary Braille transcriptions. The sound–based material is another access channel to information for the blind and VI students. DAISY books and talking books, for example, are the alternative audio materials that teachers can provide for their students; however, these books are less prepared for math and scientific expressions. With a hearing channel, a text–to–speech (TTS) engine has been widely used by blind and VI students to read electronic text through computers. A TTS engine is a system that can convert digital text into synthetic speech. Presently, TTS has recently become more suitable to individual needs. Screen reader and TTS technologies have made it possible to build reading aid devices for blind and VI readers. Unfortunately, most available TTS systems can read only plain text. They cannot be any assistance when it comes to math and scientific e–books, i.e., physics, chemistry, and engineering which are full of equations and formulas with math symbols.

Many researchers realized that enhancing the accessibility to the math materials for blind and VI students was very important. They, therefore, attempted to develop TTS based systems to read math expressions, e.g., A_ST_ER, MathTalk, and MathPlayer in English (Raman & Gries, 1995; Soiffer, 2005; Stevens & Edwards, 1994); AudioMath in Portuguese (Fereira & Freitas, 2005); and Math Genie in English, French, and German (Gillan, Barraza, Karshmer & Pazuchanics, 2004; Karshmer, Bledsoe & Stanley, 2004). A_ST_ER, MathPlayer, and Math Genie add extra words or phrases to read math expressions. For example, the expression "$I =$

$\int_0^\infty e^{-x}\,dx$" is read "i equals x *where x is the integral …*" or "i equals *limit*-integral with lower-limit zero and upper-limit infinity *expression something* d x. *Something is* …". The italic words and phrases are added to complete the reading. The rendered audio is very long and listeners may not be able to catch the main point of the expression if they listen for a long continuous period. The prosody, e.g., pitch change and duration, was introduced in MathTalk and AudioMath to convey the meaning of the expressions. However, the pitch change alone does not help clarify the meaning of the math expression in Thai since Thai language is a tonal language. Each syllable has a choice between five distinct tones: low, mid, rise, high, and falling. Different tones result in different words with different meanings. For example, the five different tones /see/, /sèe/, /sêe/, /sée/, and /sěe/ correspond to an English alphabet 'c', a number '4', a classifier[1] of "rib" or "tooth", a verb "die", and a noun "color", respectively.

Moreover, these automatic math accessible systems take inputs prepared in Latex or some markup languages. Unfortunately, most Thai teachers, blind, and VI students found that these document preparation systems are not easy to use, unlike Microsoft Word (MS Word). Some math accessible systems scope their capabilities for algebraic expressions and some cover only math expressions appearing at the secondary school level in Thailand. We first focus on secondary mathematics and then extend to several topics of high-school level including sequences and series, exponential and logarithm functions, and vectors.

Some math accessible systems present their outputs in both audio and Braille e.g., TRIANGLE, REMathEx, and LAMBDA (Gardner, Lundquist & Sahyun, 1998; Gaura, 2002; Schweikhardt, Bernareggi, Jessel, Encelle & Gut, 2006). Also, the multimodality accessibility of math expressions was proposed to support individual preferences. This multimodality provided output in audio, tactile, and visual forms (Awde, Bellik & Tadj, 2008; Tsonos, Kaccori & Kouroupetroglou, 2009) to support all desires of blind and VI people. However, the tool which provides only one form of output received more researcher attention partly because it is easier to develop and maintain.

[1] In Thai, a classifier is used to express a quantity of a countable noun; different nouns require different classifiers (Naruedomkul, 2000).

In Thailand, TTS has gained the researchers' interest since 1980. A number of the TTS systems, for example, CU–TTS (Luksaneeyanawin, 1993), VAJA (Mittrapiyanuruk, Hansakunbuntheung, Tesprasit & Sornlertlamvanich, 2000b), PPA Tatip (PPA Innovation, 2005), and a stochastic knowledge–based Thai TTS system (Narupiyakul, Khamya, Sirinaovakul & Cercone, 2005) were developed. These systems are able to synthesize Thai speech from Thai plain text only, not from math expressions however.

We are aware 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 studying mathematics and science. Therefore, we designed the *i-Math* (an **i**ntelligent accessible **math**ematics) approach with the capability to convert both text and math expressions into unambiguous speech automatically as they are displayed on the screen. *i-Math* is a practical tool that enables blind and VI students to independently and comfortably study mathematics and science anytime and anywhere.

1.3 Objectives

We aim to discover an alternative approach to converting both text and math expressions into Thai speech automatically. A second objective is to implement the suggested approach: a complete TTS system that demonstrates the feasibility and applicability of our approach. This prototype is intended for blind and VI students to use in learning mathematics.

To reach our objectives, the three main tasks must be completed: the reading analysis of Thai plain text and math expressions, the design and implementation of system prototype based on our approach, and the evaluations of the approach and the system prototype.

Part I: Analysis. The reading of Thai plain text and math expressions are analyzed in the following three aspects.

- Analyzing the writing and reading systems of Thai plain text and math expressions. The analysis result is used in designing algorithms to correctly utter the Thai text and math expressions.
- Analyzing the writing system of math expressions in terms of syntax and semantics. The components, relationships, patterns, and arrangements within the expressions are carefully explored. The relationships between notations appearing in the expressions, the locations, and order of appearances are learned to form the MathEx rules. These rules are used to determine whether and which extra words are required not only to retain the meaning of the original expressions but also to reduce the reading ambiguities.
- Investigating how math expressions are read in Thai. We investigate the way people read each expression to serve the ease of communication between users and the *i-Math* system.

Part II: Design and implementation. In designing and implementing *i-Math*, we aim at generating an accurate Thai speech output and supporting the available math documents in electronic form. The tasks involved in this part include:

- Selecting an electronic form file format of an input. Among a number of document preparation systems, MS Word is chosen since it is widely used and easily converted into other formats.
- Developing a set of MathEx rules. These rules are used to add the extra words (if necessary) to the right location of the expression pronunciation which is in the form of eXtensible Stylesheet Language Transformations (XSLT).
- Developing the Math-Thai lexicon to be used in mapping English and Greek letters, and math symbols into Thai pronunciation patterns.
- Inventing Thai sound in syllable units to be used in synthesizing speech for the generated pronunciation.

- Designing the user interface for the system prototype. The design should allow the blind and VI students to simply interact with the system. The functions must be designed to support the educational purpose.

Part III: Evaluation. In this thesis, the evaluation consists of three main parts: intelligibility, overall speech quality, and user satisfaction evaluation. For intelligibility, a listening test is performed to determine whether listeners understood the math text read by *i-Math*. To evaluate the overall speech quality, we analyze the Mean Opinion Score (MOS) and Listening Effort Scale (LES) rating by the listeners after they have heard the text producing by *i-Math*. To evaluate the user satisfaction, the interview is conducted.

1.4 Contributions

The two main contributions of this thesis are: the *i-Math* approach and *i-Math* system prototype. One contributes to computer science and the other one contributes to education for blind and VI students.

Part I: Computer science: the *i-Math* approach contributes to computer science as follows:

- We propose the approach, called intelligent mathematics accessibility (*i-Math*) approach, to converting math expressions into Thai speech. We designed and constructed the set of rules for adding the necessary words in the correct positions not only to complete the reading of the math expressions in Thai but also to retain the correct meaning of the original input expressions as they appear on the screen. The *i-Math* approach was different comparing to other available TTS approaches. We focused on designing the approach which conveys the correct meaning of math text and produces high accuracy of the pronunciations while other TTSs are aimed to improve naturalness of the speech quality. Moreover, *i-Math* differs from math expressions reader approaches. In developing the rules, we also treated the relationships between notations appearing in the expressions, the locations, and the order of appearances of characters to produce the correct, concise, and clear Thai speech. Regarding the content coverage, *i-Math* includes all topics of secondary schooling and some parts of high schooling levels e.g., exponential and logarithm functions; summations; limits; and integrals.

- We implemented our approach for an educational tool: the *i-Math* system. *i-Math* is an automatic mathematics accessible system for the students with blindness and visual impairment. *i-Math* enables them to access to math documents conveniently. Each step performed by *i-Math* is straightforward and simple. *i-Math* begins the process with extracting a XML file from a MS Word document. Next, the required words are added to the correct locations of the expressions. Then, all notations, characters, and symbols used in the expressions are mapped into their Thai pronunciations. Finally their speech are synthesized and played to the users. Unlike other mathematics accessible systems, *i-Math* supported MS Word documents as an input.

- We annotated the evaluation of an automatic mathematics reader system by examining the three aspects: *intelligibility*, *overall speech quality*, and *user satisfaction.* The intelligibility was conducted to determine whether *i-Math* generates a correct pronunciation in each word. The pronunciations generated by *i-Math* were compared against the math problem input which is in text form. The listening test was also performed by asking participants to transcribe what they have heard. For the overall speech quality, the Mean Opinion Score (MOS) was used to determine whether the speech output is acceptable while the Listening Effort Scale (LES) was used to measure the listener's effort in understanding the meaning of utterance. The listeners were asked to rate the speech quality and speech understanding efforts required with the scores. At the end of the evaluation, the listeners were asked to respond to questionnaires about perceived usefulness and ease of use.

Part II: Education: *i-Math* is intended to be an assistive learning tool for blind and VI students. The better tool they employ the better chance they learn.

We provide *i-Math*, the system to enable the blind and VI students to have the same opportunities as the sighted students in studying, especially in mathematics which is full of math symbols, expressions, and formulas. *i-Math* allows the students to learn and practice more independently and conveniently.

- The interface of *i-Math* was designed to serve the blind and VI students' needs.
- The practical use of *i-Math* could be demonstrated by augmenting it with some educational tools, for example, intelligent tutoring systems, computer assisted-learning (CAI), or other web-service for assistive learning mathematics. Meanwhile, *i-Math* can be applied to promote an assistive technology in mathematics classroom.

1.5 An Outline of the Thesis

This thesis is organized as follows: in chapter 2, an introduction to the educational technologies for blind and VI that facilitate their mathematics learning is provided. Tactile representations, audio aids, TTS technologies, and their applications to read math expressions are described.

Chapter 3 surveys what the blind and VI students require from a text-to-speech (TTS) system in accessing to mathematics. Their requirements are taken into account during the development of the intelligent accessible mathematics (*i-Math*) in this research.

Chapter 4 examines the nature of math expressions and Thai text. We describe the differences between their readings and also the reading of math expressions in Thai.

The technologies used in developing *i-Math* are summarized in chapter 5, including an eXtensible Markup Language (XML), an Office Open XML (OpenXML), an eXtensible Stylesheet Language Transformations (XSLT), and an XML Path Language (XPath).

The *i-Math* architecture and its implementation are presented in chapter 6, including the details of four modules: XML Extraction, MathEx Structure Analysis, Math-Thai Mapping, and Speech Synthesis. The knowledge and rules used in *i-Math* are explained as well.

The roles of *i-Math* in education and the usages of *i-Math* are described in chapter 7.

The explanations of the system evaluation are presented in chapter 8. Three main evaluations are conducted: (i) the intelligibility evaluation, (ii) the overall speech quality evaluation, and (iii) the user satisfaction evaluation. The design of the experiments is presented in this chapter. The experimental results and the performance of *i-Math* are discussed.

Chapter 9 concludes our contributions and suggests the possible improvements of *i-Math*. The further works are introduced at the end of this chapter.

Appendices are provided to illustrate related researches of Thai TTS; interview questions for the students' requirement; English and Greek alphabets, and math notations mapping table; XML representations and their syntax; MathEx rules in an XSLT format; full forms of abbreviations; the intelligibility evaluation; and the user satisfaction evaluation.

Our research presents in this thesis were published in a well-recognized referred journal and conference proceedings. Blind and VI students' requirements (Chapter 3) can be founded in Wongkia, Naruedomkul & Cercone (2010). The differences between reading Thai text and math expressions, the main part of chapter 4, will appear in Wongkia, Naruedomkul & Cercone (2009; 2010).

CHAPTER II

BACKGROUND

We begin this chapter with an education of the students with blindness and visual impairment, follow with educational tools for the blind and visually impaired (VI) students in section 2.2. An overview of the text-to-speech (TTS) technology is summarized in section 2.3. Some existing math expression reader systems are described in section 2.4 and the advantages and disadvantages of the existing systems are discussed in section 2.5.

2.1 An Education of the Students with Blindness and Visual Impairment in Thailand

The terms "blindness" and "visual impairment" describe vision abilities that denote the vision loss, rather than the eye defection. The term "blind" students refer to the students who cannot completely see while the term "visually impaired" students mean the students who are still able to see some extent. However, both blind and VI students have difficulties in learning or doing any daily activity.

Presently in Thailand, the educations for the students who are blind and visually impaired are organized in four system types (Thai Disabled Development Foundation, 2010): (1) early education, (2) mainstreaming education, (3) integrated education, and (4) informal education systems. Firstly, the early education system is a provision of the education for the blind and VI children before the primary education (Grade 1 – 6). The early school is provided for stimulating the childish development that includes the skill practices becoming ready for learning. Secondly, the mainstreaming education system is an education for the students with blindness and visual impairment. This education provides teaching, learning, and instructing to support the specific needs of the students who are blind and VI. There are eleven mainstreaming schools for the blind and VI students across Thailand, since kindergarten either to Grade 6 or to Grade 9. Thirdly, the integrated education system provides the same opportunities and the educational experiences for the blind and VI students as the normal education system which provides for the sighted students since kindergarten either to college or university supported by the well-prepared specialists in the educations of the blind. Finally, the informal education system is an education outside a standard school setting including the vocational practice center for the blind and VI people, and the individuals or the groups who choose to engage with their interests.

2.2 Educational Tools for the Blind and Visually Impaired Students

Current technologies allow the blind and VI students to access to printed text via various means. With these technologies, the blind and VI students can maintain their independence while they are studying and practicing. Karshmer and Bledsoe (2002) categorized the technologies to assist the blind and VI students in studying mathematics into five approaches: (1) tactile representations such as Braille and other raised representations; (2) audio aids by generating the voice of math equations and formulas; (3) tonal representations of graphs; (4) haptic or forced feedback devices in allowing a user to feel the shapes of objects and curves; and (5) integrated approaches. However, tactile representations and audio aids are the most popular and suitable for accessing math documents containing the math expressions. Details of the tactile representations and the audio aids are discussed below.

2.2.1 Tactile Representations

Tactile representations are created in the spatial patterns by raised dots. Blind and VI people can touch the raised parts to access the represented information. The first and most well–known amongst other tactile approaches is Braille. Braille is a printing form that is widely used amongst the blind and VI people, to read and to write. With raised parts, the blind and VI people can read by touching the paper with their fingers. Braille has been adapted for reading and writing in many languages, including Thai. Figure 2.1 shows the Braille representation of English alphabets, Thai alphabets, and math symbols. To represent text, the Braille codes, the six–bit cells (a three rows and two columns matrix) are mapped with a character set, only 64 different characters. Different Braille codes are required for different languages. The 64 different characters are inadequate for representing Thai alphabets (44 consonant alphabets, 15 vowel alphabets, and four tone markers). Thus, some Thai alphabets are represented by two matrices, for example ฃ, ฅ, and ฆ in Figure 2.1b.

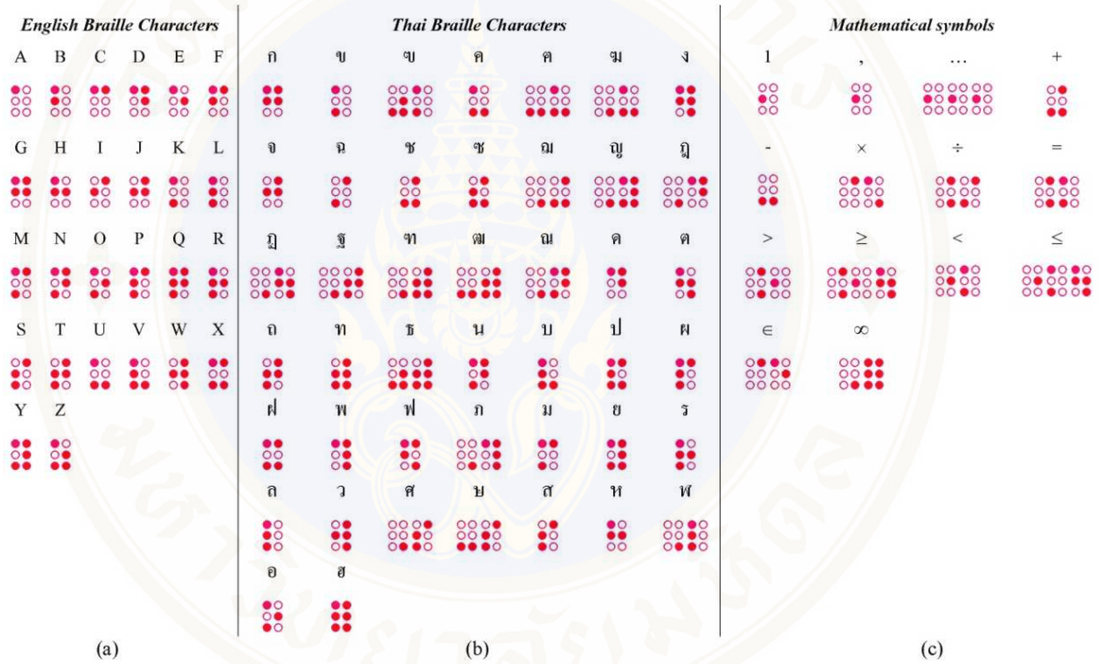

Figure 2.1 English Braille characters (a), Thai consonant Braille characters (b), and some Nemeth Braille codes for math symbols (c).

To represent the math notations, other Braille systems were introduced. A well–known Braille code for representing math and scientific notations is the Nemeth code, named after Dr. Abraham Nemeth, (Figure 2.1c). It is used for transcribing the math and scientific expressions (AAWE-AEVH-NBA Advisory Council to the Braille Authority, 1979). The Nemeth code is used in the United States for the elementary math textbooks as well as the highly technical material. Similarly, one matrix set is insufficient for all math symbols so that two or more matrices are used, for example '×', '=', and '≥' in Figure 2.1c. Moreover, there are other Braille math codes used in other countries. Therefore, in reading a math document, the blind and VI students need to know which the coding system was used in producing the document.

The productions of Braille math documents on a computer are divided into two methods: (1) directly input Braille code and (2) translate files which are prepared with the normal character set. The former, direct input Braille code requires the specific software to change the normal computer keyboard into the Braille keyboard and the set of rules used in representing the math notations. The latter needs the document preparation with the normal character set. And then, the prepared document is translated into Braille using the translation software, e.g., Duxbury and Megadots (Moço & Archambault, 2004). Currently, the math Braille translation systems can produce math documents.

In Thailand, Petkleang and Tandayya (2005); and Lalitrojwong (2005) proposed the Braille translation systems that translate Thai text into Thai Braille. Furthermore, Niyomphol, Tandayya, Nantachaipitak and Intasoi (2008) began to develop the Braille translation system that can translate Thai, English, math, scientific, and musical notations into Braille.

The preparation of Braille documents seems difficult for people who do not know Braille well. Thus, not many documents are available in Braille, particularly math and scientific Braille documents. Moreover, teachers who are able to teach mathematics to blind and VI students have limited since they do not know Braille so well. Producing a math document in Nemeth seems very hard but reading the document is even more difficult. Although most blind and VI people have been familiar with Braille, other math Braille code systems are used to represent the math notations or expressions. The blind and VI people require more efforts to memorize, recognize, and distinguish all the codes. Examples of the math expressions in Braille are illustrated below.

- The expression, $\frac{a+b}{c+d}$, would become ⠷⠁⠬⠃⠾⠸⠌⠷⠉⠬⠙⠾.
- The expression, $\sqrt{x+y+z}$, would become ⠜⠭⠬⠽⠬⠵⠻.
- The expression, a^b, would become ⠁⠘⠃.

In addition, the blind and VI students must be aware that some Nemeth and Braille text are similar. Thus, the blind and VI students must read the whole sentence to avoid the ambiguities.

2.2.2 Audio Aids

Audio aids, e.g. Daisy books and talking books, are alternative materials to provide for the blind and VI people. Certainly, speech technologies have become one of successful approaches for the blind and VI students. Many researchers have attempted to develop speech technologies for the blind and VI students to access the printed, written, and visual information (Freitas & Kouroupetroglou, 2008). The details of digital talking books and text-to-speech engines are discussed below.

Digital Talking Books: A digital talking book (DTB) is a book that has been recorded onto tapes, CDs, or DVDs for the blind and VI people. They can use an audio–based device with the basic functionalities such as play, stop, fast–forward, and rewind (Pittman, 2002). However, the development of DTB was aimed to increasingly facilitate the users by adding the functionalities of search, navigation, and bookmark to access the book contents. The DAISY (Digital Accessible Information System) standard is a standard used in creating the accessible DTB of a printed book with a human voice production (DAISY Consortium, 2008) by using speech synthesis technologies. The DAISY Consortium extended the DAISY standard to support Mathematical Markup Language (MathML) when reading the math expressions to provide the mathematics within DAISY books. MathML is an application of eXtensible Markup Language (XML) for representing the math expressions on the Internet browsers (Carlisle, Ion, Miner & Poppelier, 2003). DaisyReader is presented for interactive voice reading of math formulas, lists, and tables based on the DAISY standard in Polish and English languages.

In Thailand, the Thailand National Committee on DAISY Production and Services joined the DAISY Consortium to produce Thai digital talking books in the DAISY format for Thai people both who are blind and who cannot access normal printing. A number of Thai organizations, i.e. Ratchasuda College and the National

Electronics and Computer Technology Center (NECTEC), attempted to promote and develop DAISY books for Thai blind and disabled people as well.

The DTB production process is not simple (Kerscher, 1999) and time consuming. Also, most books that were translated into DAISY and DTB are in the form of text only, e.g., Thai Junior Encyclopedia books (Thailand National Committee on DAISY Production and Services, 2008). Very few math and scientific books are in the form of DTB.

Text-to-speech Engines: A text–to–speech (TTS) engine is computer software that can read aloud text within electronic text formats such as Internet Explorer (IE), Microsoft Word (MS Word), Outlook, and Adobe Reader. This engine often works with the screen reader software to have a more comfortable employment for the blind and VI people. The TTS system is widely used by the blind and VI people to read the electronic text through a computer since the sound–based representation plays an important channel to access information for the blind and VI people. The TTS system makes accessible books for the blind and VI people and is suitable for individual needs. Unlike the DTB and DAISY books, TTS can generate the corresponding audio of an unseen document in real-time. The TTS system allows the user to immediately listen to the audio version after inputting.

Groups of researchers in Thailand have attempted to research and develop Thai TTS systems since the 1980s. Until recently, most Thai TTS systems generate Thai speech from Thai text with high accuracy of pronunciations and high quality of natural sound (Wutiwiwatchai & Furui, 2007). However, the important problems in developing Thai TTS systems are the ambiguities of segmentations and pronunciations, and the unnatural sounds of continuous synthetic speech. More details of the TTS technology will be described in section 2.3.

At present, to enhance the access to the educational math materials, a number of researchers successfully developed the TTS-based systems with the capability to read math expressions in many languages, such as A_ST_ER, MathTalk, and MathPlayer in English, AudioMath in European Portuguese, and Math Genie in English, French, and German. The details of the automatic math expressions reader systems can be found in section 2.4. However, none of the TTS systems has the capability to read math expressions in Thai.

2.3 Text-to-Speech Technologies

Text–to–speech (TTS) is the process of automatically converting text in written form into human–like speech. The basic TTS procedure consists of four main phases: *text analysis*, *phonetic analysis*, *prosody analysis*, and *speech synthesis* shown in Figure 2.2 (Huang, Acero & Hon, 2001, pp. 6).

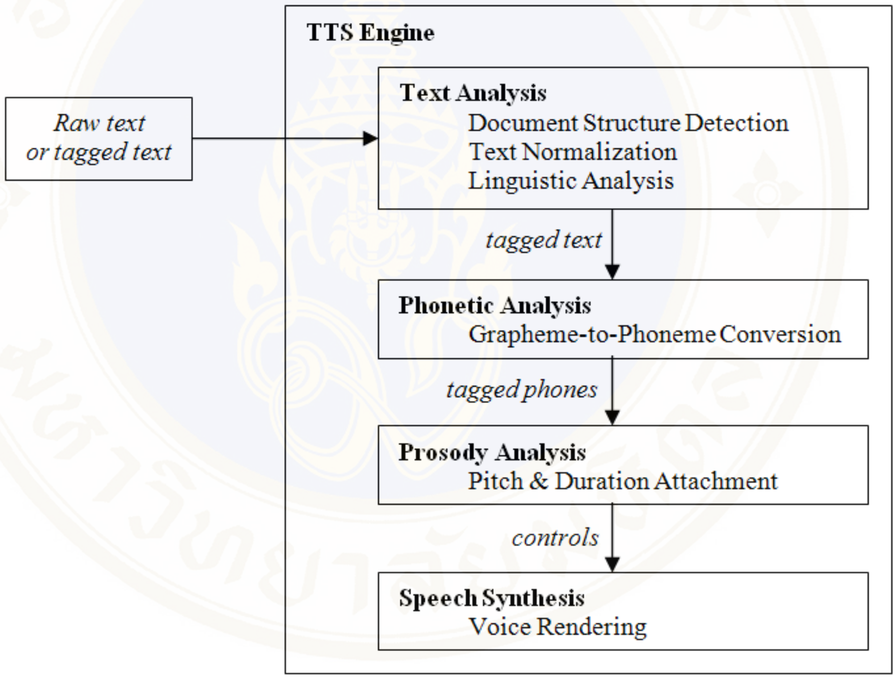

Figure 2.2 Basic system architecture of the TTS system.

2.3.1 Tasks Required in Developing Text-to-Speech

The structure of the input text is determined in text analysis module (Figure 2.2). This module begins the process by segmenting the input text for any language which has no boundary, next, converting symbols (e.g. $, %, &), numbers (e.g. 10, 02-123-4567, 19-11-2008), and abbreviations (e.g. Mr., Mrs., cm.) in each segmented sentence (if any) into the speakable forms, then, analyzing each sentence in the term of both syntax and semantic. Phonetic analysis module converts the analyzed input text into phonetic representations. Prosody analysis module adds all information required to make the synthetic speech more natural. With all this information, the speech of the input is synthesized at the end of the process.

Text Analysis: In English, punctuations (. , ? and !) are used to identify a sentence boundary and space at the end of a word while some Asian languages, i.e. Chinese, Japanese, and Thai, have no word or sentence boundary in the writing systems. Therefore, the document structure detection plays an important step for Asian languages to determine a word and sentence breaking. The output of this step provides the necessary information such as rhythm and pause in reading or speaking aloud like-human speech for ongoing next step.

Table 2.1 Some examples for symbols, abbreviations, and numerals.

Expressions	*Examples*	*Pronunciations*
Symbols	%	Percent
	$	Dollar
Abbreviations	cm.	Centimeter
	Mr.	Mister
Numerals	081–234–5678	O eight one two three four five six seven eight
	25/09/51	September twenty fifth two thousands and eight
	12:13:20	Twelve hours thirteen minutes and twenty seconds
	200 $	Two hundred dollars

An input text is the sequence of characters and it may contain symbols, abbreviations, graphs, figures, charts, tables, and numerals. Table 2.1 shows examples of symbols, abbreviations, numerals, and their pronunciations. Abbreviations and symbols are converted into their pronunciations for retaining their meanings. Numerals can occur in various formats, for example, phone numbers, dates, times, and money. To process the number formats, the corresponding pronunciations are assigned in the number representation step. Each part of the input text must be carefully concerned for developing a more accurate TTS system. The text normalization is a process for converting the writing forms into the appropriate forms that can be pronounced. The output of the text normalization step is a full set of interpretations with the added information, for suitable pronunciation in the next steps. The syntactic and semantic information can be used in selecting the accurate pronunciation.

Phonetic Analysis*:* The main task of phonetic analysis module, grapheme-to-phoneme conversion, is to generate phonetic representations or phonemes which are the basic units of sound. The phonetic analysis is a non-trivial task because of the problems in the homograph, the syllabification, and the word boundary ambiguity in many languages. Such problems are carefully considered. A linguistic analysis is utilized to provide more accurate phonetic pronunciations.

Prosody Analysis*:* The prosody plays an important role in supporting the understanding of the listeners. The pause between the words in a sentence and the stress of the word affect the meaning on utterance. Therefore, to generate a good prosody, the word and sentence boundary, the word identity, and the word part-of-speech must be concerned as well. Huang et al. (2001) stated that the prosody consists of pause, duration, pitch, and loudness features. A set of the prosody features is provided for each syllable or word because these features not only influence on the naturalness of the synthetic speech, but also result in conveying the meaning of the utterances. Furthermore, the duration and pitch values can control the speaking rates, the voice changes, and the stressed/unstressed voices.

Speech Synthesis*:* The speech synthesis can be classified into three types depending on the speech generation methods (Huang et al., 2001): (1) the articulatory synthesis: a physical model of the human speech production system, (2) the formant synthesis: the model which uses the pole frequencies of speech signal or transfer function of vocal tract based on a source-filter model, and (3) the concatenative synthesis: the concatenating speech segments were used to generate speech.

The speech synthesis is used to generate the speech waveform from the phonetic representations and the prosody parameter. The popular technique amongst the speech synthesis methods is the concatenative synthesis by concatenating the small speech units that are stored in the sound unit inventory. To improve the naturalness of the speech, the prosodic modification techniques are used to change the amplitude, the duration, and the pitch of the speech.

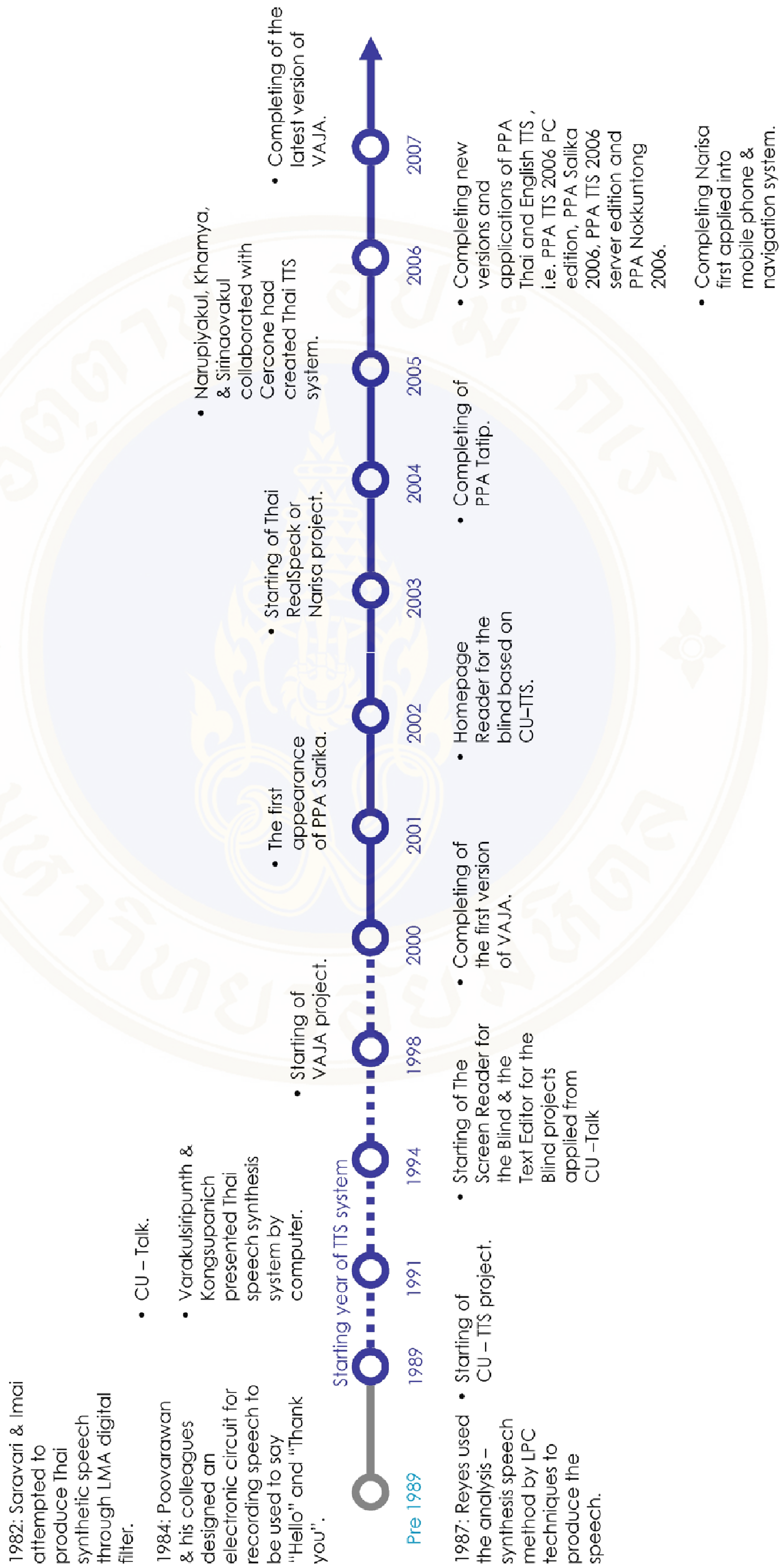

Figure 2.3 Brief history of the Thai text–to–speech systema.

2.3.2 History of Thai Text-to-Speech

The history of Thai TTS systems dates back to 1980s until the twentieth century shown in Figure 2.3. The ideas of the conversion of a Thai text format into a Thai speech signal began to gain interesting since 1989 at Chulalongkorn University by Sudaporn Luksaneeyanawin**.** Luksaneeyanawin and her colleagues started the project of the Chulalongkorn University Thai TTS (CU–TTS) system which was granted from NECTEC, Thailand and Chulalongkorn University for three years (1990 – 1992)**.** The CU–TTS system was the first Thai TTS system that was available since 1991. The CU–TTS system performs three steps to generate the Thai speech output: (1) converting the string of Thai text into the phonological syllables, and then combining the phonological syllables into the string of words; (2) representing the string of words and phrases with their phonological representation by dictionary looking up; and (3) concatenating the waveforms of the string of phrase used demisyllable units. This system used the concatenative synthesis technique which is the most common types of Thai synthetic speech.

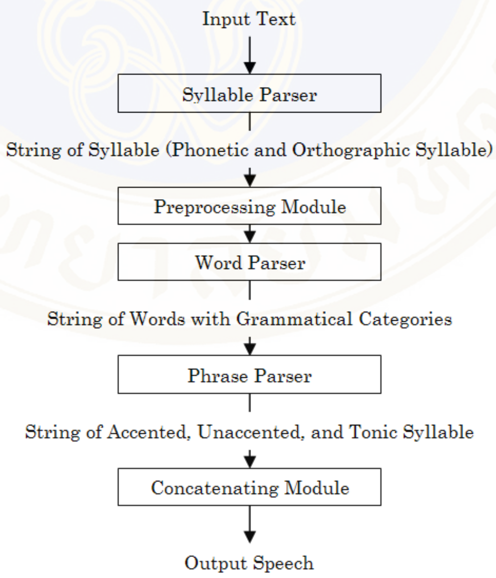

Figure 2.4 Architecture of the CU–TTS system.

The architecture of CU–TTS is illustrated in Figure 2.4 (Center for Research in Speech and Language Processing [CRSLP], 2002; Luksaneeyanawin, 1993; Luksaneeyanawin & Niyomphol, 1997; Mittrapiyanuruk, et al. 2000b). It had been developed into the first commercial Thai TTS system, called CU–Talk, with the support of Chulalongkorn University and the Rachasuda Foundation (CRSLP, 2002; Wutiwiwatchai & Furui, 2007). CU–Talk was a speech synthesizer for the blinds which could plug in a computer to separate the memory of the speech synthesizer from the memory of the computer because the computer at that time had limited the memory.

In 1991, two researchers, Ruttikorn Varakulsiripunth and Sa-nga Kongsupanich, at King Mongkut's Institute of Technology Ladkrabang, Thailand presented a Thai speech synthesis system (Varakulsiripunth & Kongsupanich, 1991). This system consisted of three main steps. Thai input sentence was first segmented into words by using the longest word mapping technique with dictionary. Next, the corresponding phoneme was generated from a Thai word. Then, the speech was synthesized by using the analysis-synthesis method based on the phoneme units.

To facilitate the blind people who used computer, the Screen Reader and the Text Editor for the Blind projects were designed to capture the text on the screen and sent to CU–Talk for the Thai speech. The users would hear the speech during the typing and the writing. Both systems were the applications of the TTS system in accessing and providing the information of the blinds (Luksaneeyanawin & Niyomphol**,** 1997). The director of these two projects was Sudaporn Luksaneeyanawin granted from Chulalongkorn University since 1994 to 1996.

A few years later, in 1998**,** NECTEC established the first VAJA project, the other commercial Thai TTS software which was aimed to create the synthesized Thai speech with the natural sound (National Electronic and Computer Technology Center [NECTEC], 2007)**.** The first version of VAJA using the concatenative rules with the demisyllable speech units was published in 2000 (Mittrapiyanuruk, et al., 2000b). VAJA is composed of three main parts: (1) segmenting the text into sentences or phrases and transcribing the segmented phrases into the phonetic symbols; (2) determining the prosody information, i.e. syllable duration and F0 contours, to improve the naturalness of the synthetic speech; and (3) concatenating the waveform by the phonetic symbols with the prosody information of each syllable to produce the speech output. Afterwards, NECTEC researchers aimed to improve the quality of the speech of VAJA by emphasizing the improvement not only in speech synthesis module (i.e., the use of the demisyllable concatenation and the signal processing) but also in the prosody analysis module (i.e., the detection of both sentence boundary and phrase break). The latest version of VAJA appeared in 2007 (Thangthai, Saychum, Rugchatjaroen, Thatphithakkul, & Wutiwiwauchai, 2007).

In the early 2000s, in 2004 Puttipan Ponyanun of PPA Innovation Co., Ltd. had been supported by the grant of Her Royal Highness Princess Maha Chakri Sirindhorn for developing a Thai TTS system, named PPA Tatip. This system was the Thai and English bilingual TTS system for the blinds to provide a good chance to commonly use a computer like the sighted people. At this time, Thailand Association of the Blind owns the copyright to this program (PPA Innovation, 2005; Thailand Association of the Blinds, 2008). The PPA Tatip software was free for the blind people who need it. Moreover, Puttipan Ponyanun received the Second Prize of Thailand Innovation Awards from PPA Sarika. It is both Thai and English commercial TTS system. Also, he created the new versions and applications of the PPA Thai and English TTS such as PPA TTS 2006 PC edition, PPA Salika 2006, PPA TTS 2006 server edition, and PPA Nokkuntong 2006. All versions and applications were completed in 2006 and sold under the copyright of PPA Innovation Co., Ltd.

Besides, the research team from IBM Thailand collaborated with CRSLP of Chulalongkorn University under the control of Sudaporn Luksaneeyanawin who was the director of CRSLP. In 2002, the Homepage Reader for the blinds based on the CU–TTS system was developed. A year after, CRSLP of Chulalongkorn University co-operated with Nuance Communications Inc., USA developed a Thai TTS system named Thai RealSpeak and called in Thai, Narisa, in 2003. This system was first applied to mobile phone and navigation system three years later, in 2006 (CRSLP, 2002).

In 2005, Lalita Narupiyakul, Apinya Khamya, and Booncharoen Sirinao-vakul of King Mongkut's University of Technology Thonburi, Thailand collaborated with Nick Cercone of Dalhousie University, Canada had created the Thai TTS system. The process of this system is divided into two steps: (1) converting the Thai letters into the phonetic symbols by using a rule-based approach and (2) producing the speech waveform by using the concatenative synthesis (Narupiyakul, et al., 2005).

In conclusion, a Thai TTS system is composed of text analysis, phonetic analysis, prosody analysis, and speech synthesis. To construct a professional and potential Thai TTS system, a number of researchers attempted to discover the best method in overcoming all problems of Thai TTS systems. The evidences which indicate the attempts of the researchers can be found in Appendix A. Existing Thai TTS systems, however, can generate the Thai speech from plain text alone. Those systems are unable to generate the speech from the math expressions. All existing technologies are inadequate for assisting the blind and VI students to access the math documents.

2.4 Text-to-Speech with the Capability to Read the Math Expressions

People with vision loss need an assistive technology to work with the documents which are full of math expressions. The TTS technology is the gateway to the valuable knowledge for the people who are blind and visually impaired. The TTS system with the capability to read math expressions has continuously been developed and researched to assist blind and VI people in accessing the math documents as the same as the sighted people. In this section, we will discuss in more details of the existing systems including A_ST_ER, MathTalk, Math Genie, AudioMath, and MathPlayer and will present some examples of the multimodal systems.

2.4.1 A_ST_ER (Audio System for Technical Readings)

A_ST_ER was developed by T.V. Raman. He was motivated by a desire to facilitate his own reading for his studies to read the technical documents. A_ST_ER accepts a (La)TeX document as an input and produces the English audio as an output (Raman & Gries, 1995).

A_ST_ER begins with conversing a (La)TeX document into the suitable form to provide the structural document (e.g. title, abstract, section, paragraph, math expression, and table). Then, A_ST_ER applies two sets of rules: lexical cues and prosodic cues. Firstly, the lexical cues are a set of words to delimit the structures such as parentheses, fractions, superscript, and trigonometry, for reading math expressions. The expressions are parsed into the tree structures and are analyzed for identifying which expressions are simple, or which expressions are complex. To read the complex expressions, A_ST_ER gives the user an overview of what an expression is by rendering the name of the expression (e.g. equation, fraction, superscript, and integral). Afterwards, all contents within the expressions are rendered for more details. Then, the prosodic cues consist of the statements for setting the voice in speaking and for changing the various parameters of voice such as pitch, volume, and tones. The variable substitution technique is used for the complex expressions to easier understand by listeners as shown in the following example,

$$I = \int_0^\infty e^{-x^2} dx, \quad (1)$$

the identifier *x* is substituted for the entire right-hand side of the equation to produce

"i equals x where x is the integral...".

A_ST_ER allows the users to create a new style for the different representations in hearing the same object. In audio browsing, users are allowed to navigate through the math expressions. The users can either skip from one term to the next within an equation or search into any selected structure for greater detail by the following actions: go to next sibling; go to previous sibling; go to parent; go to leftmost child; go to rightmost child; mark current node; and return to marked node. However, A_ST_ER never rearranged the spoken words (Hayes, 1996). For example, A_ST_ER read the expression, $\log_a x$, as "log base *a* of *x*".

2.4.2 MathTalk

Stevens, Edwards and Harling (1997) proposed MathTalk for (1) only reading algebra expressions on secondary schooling level (e.g. numbers, radicals, fractions, and superscript); and (2) controlling information flow. Once, Mathtalk uses (La)TeX formats as an input and generates English speech output.

Steven and his colleagues agreed with Raman and Gries (1994) to first identify the complexity of the expressions before rendering the audio. In reading the simple expressions, lexical cues become unnecessary because they make the verbose utterance while the complex expressions have to use the special words or phrases without unambiguity. The same prosodic cues as A_ST_ER are used in developing Mathtalk as well. To extend the prosodic rules, the pause, pitch, speed, and volume of voice parameters are used into the utterance of the math expressions to reduce unnecessary words that distract the listeners. For example in this following algebraic expression,

$$ax^2 + bx + c = 0, \quad (2)$$

the expression is represented in terms of timing, pitch change, and amplitude as,

“↑ **a** x super **two** . ↑ plus **b** x . ↑ plus **c** . **equals zero** ”,

where the arrows show the trend of the pitch change; the periods indicate the pauses; the italic typefaces indicate the increased speed; and the boldfaces indicate the increased amplitude.

In addition, MathTalk allows the users to control reading by flowing and shifting the attention to any part of an expression. Browsing functions were used to access a part of an expression. The action words (i.e., speak, current, next, previous, into, out-of, beginning, and end) and the target words (i.e., expression, term, item, superscript, quantity, fraction, numerator, and denominator) are combined for accessing the expression and reducing a long reading of the whole expression.

2.4.3 Math Genie

Karshmer & Bledsoe (2002) proposed an audio browser design for browsing the complex math expressions via the audio and implemented its application, called Math Genie in 2004 (Gillan et al., 2004). Math Genie supports a MathML format and an XML file as an input. An output is the English audio speech with options to move around parts of the expression. Functions and arrow keys on the keyboard are used to navigate the expression. The properties of Math Genie include the following features:

(1) Read an expression from left to right, one by one element at the time.

(2) Allow the users to go back to the beginning of the expression.

(3) Allow the users to return to the self-define points.

(4) Allow the users to substitute the expression with its outcome.

(5) Allow the users to scan the expression to provide an overview of the structure of the expression.

The expression input is parsed into the parsed tree. This tree can be used for viewing the structure of the corresponding expression as navigation. The user will be able to move up, down, left, or right around the tree. As the complex expression, like A_ST_ER, Math Genie first provides the users to hear the overview of the structure of the expression. For example, in the Equation (1), Math Genie will render the speech output as:

"i equals
limit-integral with lower-limit zero and upper-limit infinity
expression something d x ".

The speech word "something" replaces the omitted sub-expression. The depth of the tree is considered for omitting conditions. In this example, the content of the nodes below the depth of three nodes is replaced by the word "something".Math Genie also was extended to produce French and German audio output, offered a refreshable Braille output, and specialized video output.

2.4.4 AudioMath

AudioMath (Ferreira & Freitas, 2004) converts a MathML format into an European Portuguese audio format in four modules: Text Analysis; Parsing MathML; MathML Interpretation and Conversion; and Speaking Mathematical Content. The Text Analysis module converts numbers, abbreviations, acronyms, network, math expressions, and auto discoveries into the full plain text form. The Parsing MathML parses a MathML format by using XML::Parser. The MathML Interpretation and Conversion generates the European Portuguese text based on two dictionaries: (1) MathML entities to Unicode and (2) Unicode to European Portuguese. Finally, the Speaking Mathematical Content produces the audio. The prosodic rules are introduced to read the math expressions. The waveform is added the corresponding parameters (e.g., pauses and pitches) which according to the following rules (Ferreira & Freitas, 2005):

(1) Rising tone is used when a lower hierarchical level is starting.
(2) Falling and rising tones are used to mark the smaller separating pause.
(3) Falling tone is used at the end of the level.
(4) Emphatic falling tone is used at the end of the expression that is the end of the higher hierarchical level.
(5) Long pause (LP) is used when a lower hierarchical level is starting.
(6) Short pause (SP) is used before some operators and between the arguments.

For example in this following expression,

$$\sqrt{a^2 + b^2}, \quad (3)$$

AudioMath generates the European Portuguese plain text with pauses and some prosodic information:

"Raiz quadrada de (LP, rising) á ao quadrado (SP, falling and rising) mais bê ao quadrado (LP, falling) fim de radicando (emphatic falling)",

which refers to

"Square root of (LP, rising) a squared (SP, falling and rising) plus b squared (LP, falling) end of radicand (emphatic falling)".

2.4.5 MathPlayer

MathPlayer is a plug-in to Microsoft Internet Explorer (IE) to display a MathML format embedded on a web page (Soiffer, 2005). The conversion of math expressions into English speech is added to extend the ability of MathPlayer. Then, MathPlayer is also translated for Spanish and Chinese (Soiffer, 2009).

MathPlayer uses a set of rules to read the math expressions. The reading rules apply to the simple expressions are different from those apply to the complicated expressions. The speech word "over" is always used for a simple fraction, e.g., $\frac{x}{y}$ will be rendered "x over y", while "begin fraction", "over" and "end fraction" are spoken for complicated fractions to reduce ambiguous math speech. Pauses, pitch rates, and any prosody information are utilized in better understanding. MathPlayer allows users to browse expressions using the text-based navigation and the tree-based navigation. In the text-based navigation, the users can move around an expression, e.g., stepping through or repeating parts of an expression. The tree-based navigation allows the users to skip or listen to any sub-expressions.

2.4.6 Some Multimodal Systems

A multimodal accessibility of math expressions was proposed to support the users' individual preferences. These multimodality systems provide output in many formats e.g. audio, tactile, and visual formats to serve the different needs of the users. Table 2.2 illustrates some multimodality.

Table 2.2 Some examples of multimodal systems.

System	*Input*	*Output*
TRIANGLE (Gardner, et al., 1998)	Keyboard	• Visual display • English audio • 8-dot or 6-dot GS* Braille codes
REMathEx (Gaura, 2002)	MathML	• English audio • Nemeth Braille code
LAMBDA (Schweikhardt, et al., 2006)	MathML	• English speech • LAMBDA code**
Multimodal Adapter (Tsonos, et al., 2009)	MathML	• Visual display • English audio • Nemeth Braille code

*A GS Braille code had been developed by Prof. John Gradner and Prof. Norberto Salinas, University of Kansas. This code includes symbols for thousands of characters commonly used in mathematics, science, engineering, and other technical fields.

** A LAMBDA code which has been developed within the project is the new math notations based on 8-dot Braille.

2.5 Discussion of Some Existing Text-to-Speech Systems with the Capability to Read the Math Expressions

There are advantages and disadvantages of each approach. A_ST_ER and Math Genie add extra words or phrases in reading the math expressions. Some words and phrases were utilized to provide the overview of the whole math expressions. However, the rendered audio is very long and the listeners have difficulty to obtain the main point of the expression if they listen for a long period. The prosody, e.g. pitch change and duration, was introduced in MathTalk and AudioMath to convey the meaning of the expressions. However, the pitch change does not help in clarifying the meaning of the math expression in Thai since Thai language is a tonal language. Each syllable has a choice between five distinct tones: low, mid, rise, high, and falling. Different tones result in different words with different meanings. For example, the five different tones /see/, /sèe/, /sêe/, /sée/ and /sěe/ correspond to an English alphabet ‘c’, a number ‘4’, a classifier[1] of “rib” or “tooth”, a verb “die”, and a noun “color”, respectively. The pause and duration cannot reduce the ambiguities in reading math expressions in Thai either.

Moreover, these automatic math reader systems take the prepared inputs in (La)TeX or some markup languages. Unfortunately, most Thai teachers, blind, and VI students found that these document preparation systems are not easy to use, unlike Microsoft Word. Some systems scope their capabilities for algebraic expressions and some cover only math expressions appearing in secondary school level in Thailand. We concentrated on secondary mathematics and extended to several topics at the high-school level including sequences and series, exponentials, logarithms, and vectors.

Our goal is to overcome the shortcomings of the earlier techniques, to complete reading math expressions in Thai and to retain the meaning of the math expressions. *i-Math* is our proposed solution. The *i-Math* approach takes into account the relationships between notations appearing in the expressions, the locations, and the order of appearances of characters to produce concise and clear Thai speech of the math expressions that convey the correct meaning, unlike A_ST_ER and Math Genie. *i-Math* also treats the order of spoken words to serve the ease of communication between users and the *i-Math* system, unlike A_ST_ER. Unlike other systems, *i-Math* supports MS Word documents as an input according to the survey of blind and VI students’ requirement described in chapter 3. Similar to A_ST_ER and Math Genie, *i-Math* builds the rules to read complex math expressions such as summations, integrals, and limits. The central idea behind *i-Math* is discussed in chapter 6.

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[1] In Thai, a classifier is used to express a quantity of a countable noun; different nouns require different classifiers (Naruedomkul, 2000).

CHAPTER III

ACCESS REQUIREMENTS TO MATHEMATICS VIA TEXT-TO-SPEECH

Our survey examined the views of blind and visually impaired (VI) students toward the text-to-speech (TTS) technology as an access to mathematics. A verbal interview was conducted to determine the students' experiences of using a computer, experiences of using TTS for accessing mathematics, requirements of assistive tools in studying mathematics, and requirements for an automatic mathematics accessible system. The details of the survey are described in this chapter.

3.1 Experimental Design on Requirements of Text-to-Speech as an Access to Mathematics

The purpose of this experiment is to determine whether the blind and VI students have experienced of using computer, whether the students have experienced of using existing available TTS as an access to mathematics, whether the students need the assistive tools in studying mathematics, and whether the students need to use TTS with the capability to read the math documents in Thai. An interview was conducted in this experiment. Twenty students from two secondary schools[2] in the central part of Thailand participated in this study. The students were in Grade 7-9 and ranged in age from 14 to 20 years old. Ten students were blind (seven males and three females) and ten students were visually impaired (five males and females). The interview is consisted of two parts (see Appendix B). *Part 1* contains the students' background characteristics: personal information and their ability in using the computer including

[2] There are approximately twenty schools for the blind across Thailand and 150 students in Grade 7-9 (Educational Media for People with Disabilities section, 2005).

their experiences with computer software and aspects of using the Internet. *Part 2* covers the students' experiences in using the existing TTS systems to read math expressions, the students' requirements of assistive tools in studying mathematics, and the students' requirements for using the TTS systems with capability to read math expressions in their mathematics study. The participants were interviewed at their schools during February – March, 2009. The 10 – 15 minutes verbal interview of each student was recorded.

3.2 Experimental Results

A verbal interview was conducted as mentioned in the previous section. In this section, the interview responses were analyzed and discussed. The students' responses were grouped and discussed in four main parts. The first part in section 3.2.1 is the participants' background of using computer. The students' experiences in using the existing TTS systems to read the math expressions and the students' requirements of studying mathematics are discussed in section 3.2.2 and 3.2.3, respectively. The students' requirements for using TTS with the capability to read math the expressions in Thai in their mathematic study are presented in section 3.2.4.

3.2.1 Students' Experiences of Using a Computer

Most participants had the extensive experiences of using a computer, while two students who are blind had slightly experienced working with the computer and joined their partners in accessing the computer. All students had used Microsoft Windows as a computer platform both in school and at home. All blind students and most VI students also used a screen reader with a Thai speech synthesizer to work with the computer. Some VI students had mentioned about other devices and the assistive tools such as a magnifying glass, a Braille display, and an enlarged visual display to work with the computer.

The majority of the blind and VI students had used the Internet for more than a year. Two students who joined their partners in accessing the computer had accessed the Internet with their partners. Most students used the Internet for retrieving the academic information and entertaining themselves. Some students had used the Internet to obtain information; exchange the ideas, news, and information; and communicate with other people.

For software, all blind and VI students were provided a list of software that could be used on a computer. All students were quite familiar with Microsoft Word. The students also had experienced the use of other software as shown in Figure 3.1. None of students had used the software for writing or editing the math expressions e.g., Microsoft Word Equation Editor or Math Type Editor. Most students had used PPA Tatip[3]. None of them used VAJA[4]. Some sound–player software, e.g., Winam and Window Media Player, were useful in providing the information and their entertainment. Furthermore, a few students stated that they had used TAB Player[5].

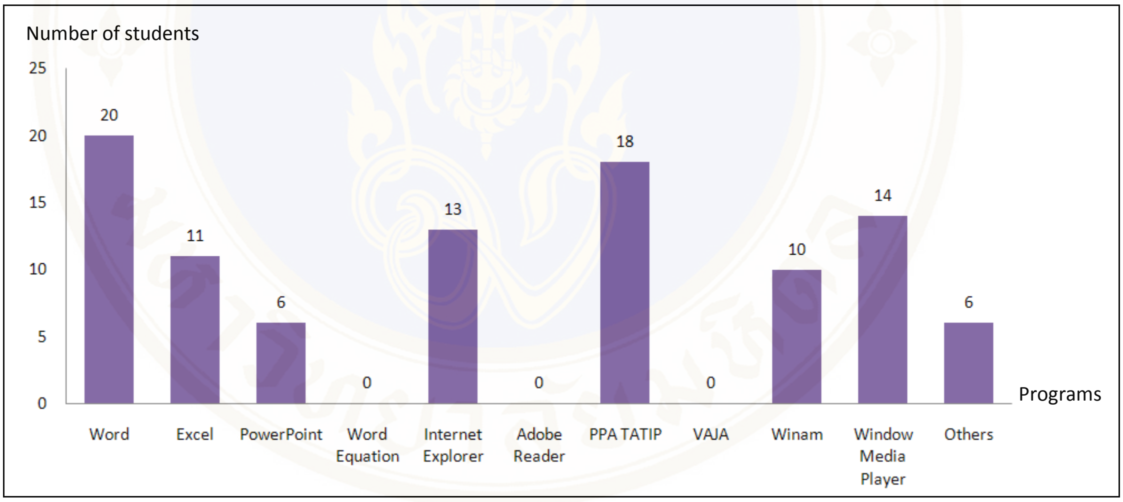

Figure 3.1 Students' experiences of using the computer software.

According to these results, all participants used Microsoft Window platform both at school and at home. Thus, the developed software should run on this platform. Most blind and VI students had basic skills and knowledge in using computers. They ever used some standard software such as MS Word, Window Media Player, and Internet Explorer. In addition, the students are familiar with PPA Tatip.

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[3] PPA Tatip is a Thai and English TTS system to work together with Microsoft Speech and Speech Synthesizer. PPA Tatip is available for the Thai blind and VI people (Thailand Association of the Blinds, 2008).

[4] VAJA is another Thai TTS system developed by NECTEC (NECTEC, 2007).

[5] TAB Player is a free media software player supports the DAISY books for Thai and English.

We then can conclude that if new computer technologies are provided, the students tend to use them and they are interested in these computer technologies. With the students' ability to use computers, they have adequate skills and knowledge to reach the computer technologies. In addition, since the students could use the Internet, they can retrieve the available knowledge in the electronic formats.

3.2.2 Students' Experiences of Using Text-to-Speech to Read the Math Expressions

All blind and VI students stated that they have ever used a Thai TTS system during the time they used computers. Some students used a TTS system to read the numbers and some simple math notations, e.g., the plus sign '+', the minus sign '-', and the percent sign '%'. Some students also mentioned that the TTS system they used read the math notations with an English accent which they hardly understood. A few VI students noted that those systems do not work with the more complicated math expressions, e.g., fractions and superscripts. Most students have never used an automatic math expressions reader system to read the math expressions. Only one student has heard the synthetic sound of the math expressions in Spanish.

The survey results showed that most students have experienced with the available TTS systems to read the math expressions. However, such systems have their own limitations in reading mathematics. For example, the systems can read only the plus sign '+', the minus sign '–', or some simple symbols that do not cover the mathematics domains, and the systems produce the English accent speech or the speech that is difficult to understand for the students. These problems became the barrier for the students in accessing to mathematics. However, if there is a TTS system that is able to read the math expressions in larger domain with an understandable speech, the students will certainly use the system in their study.

3.2.3 Students' Requirements of Assistive Tools in Studying Mathematics

Thirteen students participated in this experiments have attended an integrated school[6]. The students have problems in reading the printed materials or documents from their classroom because those documents were written in a normal character system. Most students said that they need an assistant at their side for practicing or doing homework, especially in mathematics.

Furthermore, a few students preferred to read such documents in Braille. However, the Braille printing devices and the Braille reading displays are not individually provided to students. The students also mentioned that the production of such documents in Braille is time consuming because the documents is supposed to send to other organization for producing and send back to the students later. They also noted that, recently the translation from math notations into Thai Braille was incomplete. Moreover, it is even more difficult for the students to read the math Braille system because the particular coding is used to represent numbers and special characters. The students also stated that most math materials contain graphs, tables, figures, and notations, so it is rather difficult for them to study and practice mathematics.

Similar to the students in the inclusive schools, the other seven students who attended a mainstream school[7] faced the reading problems in the math Braille codes as well. All students usually read the documents and the books, take notes, do exercises, homework, and exams in Braille. The students must memorize all special codes for studying mathematics.

This survey result indicates that there are two methods the students use to access the math documents. First, the students have the assistants to read the documents for them, but this is impractical since the assistants cannot be with them all the time. Second, the students use the Braille documents; however there are problems in production, reading, and writing. It is, therefore, necessary to find another solution

[6] A school encourages the blind students and the sighted students in the same class and in the same treatments.
[7] A school provides teaching, learning, and instructing for the students with special needs, for example a school for the blind and VI students.

to accommodate the student in studying mathematics. Thus, an assistive tool that allows them to individually access mathematics anytime and anywhere they want, to easily produce, prepare, and use; should be provided for the blind and VI students. Our solution is a TTS system with the capability to read the math expressions in Thai that enable the students independently and comfortably study and practice mathematics.

3.2.4 Students' Requirements of Using Text-to-Speech with the Capability to Read the Math Expressions in Thai

The blind and VI students were asked to express their opinions on the needs of TTS system with the capability to read the math expressions in Thai. Many students stated that if the math documents could be read aloud in Thai, they could do mathematics better than before. The students also said that they could practice exercises, do homework and perform exams by themselves anywhere and anytime that they wanted. The students' comments included: "It is easy and convenient for me to do math by myself" and "we can quickly prepare and study all by ourselves before class". Some VI students reported that the reading for a very long continuous period exhausted their eyes.

The VI students also said that it will be more comfortable if they have the computer software to read the documents aloud. Furthermore, a few students mentioned that the documents from the classroom are in printed text form, not in electronic file format.

Most students said that they dream of a TTS system with the capability to read the math expressions in Thai. They want to use this TTS system to help them in studying mathematics. They also commented that this TTS system could possibly enhance their mathematics learning. However, one student was not interested in this TTS system at all because he cannot catch the main idea when he listens for a very long length of time. He prefers to read the math documents in Braille.

The students were asked for the suggested design. If they have a chance to use TTS with the capability to read the math expressions, what they want it to be. They suggested that the system should be able to produce the correct pronunciations in more natural-like speech and be able to read all math expressions aloud including scientific notations. The volume should be adjustable. The students want the system to be able to solve the math problems and guide them to solve the problems. In addition, the system should be available for free and as a standalone system.

In conclusion, most students want the TTS that can read the math expressions in Thai because they thought that the tool would benefit them in studying mathematics. When they were asked what they want the system looks like, they need the natural-like pronunciation, the understandable speech, and the adjustable volume.

3.3 Summary

Blind and VI students have difficulties in learning mathematics not excluding the Thai blind and VI students. We surveyed the blind and VI students' requirements for using TTS to access mathematics. The results show that the students have the basic skills and knowledge in using the computer and some standard software. They could accept an assistive computer technology if it was provided. However, the computer technology should be designed and developed to support the platform and the standard software they are familiar with. Most students have ever used the existing available TTS systems to read the math expressions but such systems do not work well in reading the math expressions in Thai. The students tend to use a TTS system to read the math expressions if it could read the math expressions covering all math domains they want in the understandable accent. Moreover, the students require the tool that could independently and comfortably access, study, and practice mathematics in anytime and anywhere. The students also thought that this tool could benefit them in studying mathematics. They need this tool to produce the correct pronunciations and the understandable speech. The tool should be easily controlled when they what it to do.

One alternative solution to assist the students is the TTS technologies with the capability to read the math expressions out loud in Thai. Therefore, we design *i-Math*, a tool to enable the Thai blind and VI students independently and comfortably study and practice mathematics. We developed *i-Math* to work on the Window platform since the students are most familiar with and to support a MS Word document since the students can easily prepare the input document. *i-Math* is designed to produce the Thai speech that conveys the correct meaning of the original expressions input appeared on the screen. In addition, *i-Math* is designed to cover the secondary schooling math domains and some parts of the high schooling. Moreover the designed interface allows the users to adjust the speed rate and the volume of speech output.

CHAPTER IV

MATHEMATICAL EXPRESSIONS AND THAI

Converting the math expressions and the plain text into the speech are different. The differences are considered in developing the TTS system with the capability to read the math expressions. The math expressions are in various forms and each form needs the different reading rules, so that each form must be investigated to develop the reading rules. To synthesize the correct Thai speech for the math expressions, a number of issues must be concerned. One important issue is that the same speech can lead to different expressions. For example, the speech

“a plus b over c”

could be transcribed into either

“$a + \frac{b}{c}$” or “$\frac{a+b}{c}$”.

Another example, the speech

“square root of a squared plus b squared”

could refer to four different expressions:

“$\sqrt{a^2 + b^2}$”, “$\sqrt{a^{2+b^2}}$”, “$\sqrt{(a^2+b)^2}$” or “$\sqrt{(a^{2+b})^2}$”.

All different expressions carry the different meanings. Thus, the synthesizing algorithm should be carefully designed to generate an unambiguous speech which corresponds to exactly one expression. In this chapter, math expressions in various forms are analyzed to discover reading rules and to generate corresponding the Thai pronunciations for such math expression. The differences between Thai and mathematics are summarized in the next section. The details of the reading math expressions in Thai are described in section 4.2.

4.1 Differences between Thai and Mathematics

Converting math expressions into speech is different from converting plain text due to the differences in alphabets/symbols and structures used. Also, the location where alphabets appear is significant since it indicates an audio form of the alphabets. The differences between the Thai plain text and the math expressions are discussed in this section. A math expression differs from Thai plain text in alphabets/symbols, writing, and reading systems as listed below:

1) Alphabets and symbols: The Thai alphabet system contains 44 consonants (e.g. ก, ฎ, ป, ฌ, ญ), fifteen vowels (e.g. อู[8], อา, อี, โอ), and four tone markers (e.g. อ่, อ้, อ๊, อ๋) while math expressions uses normal English letters in upper case and lower case (e.g. a, b, A, B), digits (e.g. 0, 1, 2, 3); Greek letters (e.g. α, δ, ε, θ, π) and math symbols (e.g. +, –, ÷, <, =).

2) Displays: Thai text and math expressions are written in non-linear form. Thai text is written in four levels. The word "ที่ (/têe/, that, at, place)[9]" shown in Figure 4.1 presents in three levels. Three alphabets, an initial consonant 'ท', a vowel "อี", and a tone marker "อ่" appear in level 2, 3, and 4 respectively. Another word "รู้ (/róo/, know)" is composed of three alphabet symbols as well, an initial consonant 'ร', a vowel "อู", and a tone marker "อ้" appearing in levels 2, 1 and 3 respectively. Unlike Thai text, a math expression is a multi-level system as shown in Figure 4.2. In Figure 4.2a, x_1 to the power of $x^{x^{x^x}}$ appears in six levels. Figure 4.2b illustrates a fraction where the numerator appears in three levels and the denominator in three levels.

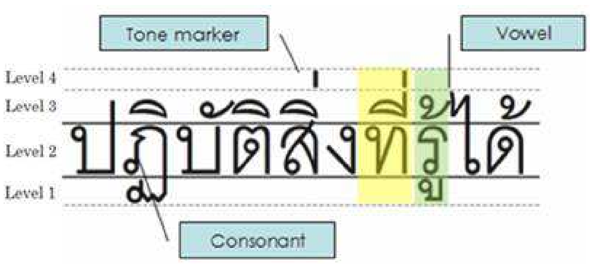

Figure 4.1 Four levels of the Thai characters.

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[8] Consonant position is indicated by 'อ'.

[9] In the parenthesis following a Thai word, the first is the phonetic transcription inside / /. Thai phonetic transcriptions provided from the online Thai-English dictionary (Thai2English, n.d.). The next are all possible meanings.

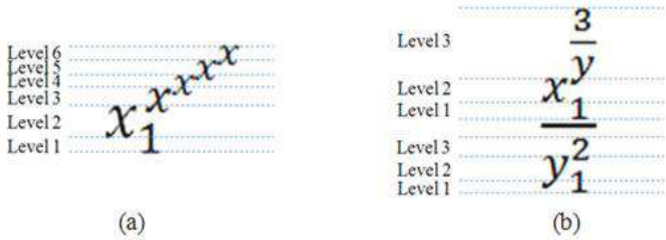


Figure 4.2 A multi-level of math expressions.

Special math symbols are a group of symbols including a vinculum or a fraction bar "—", a summation operator " $\sum$ ", a product operator " $\prod$ ", an integration sign " $\int$ ", a limit notation " lim ", and a radical sign "$\sqrt{}$". Some examples are shown in Figure 4.3.

$$\sum_{i=1}^{n} i^2 + 2i - 3 \qquad \lim_{x \to 0} \sum_{i=1}^{10} \frac{i - \sqrt{2}}{i + \sqrt{2}}$$

(a) (b)

Figure 4.3 Examples of special symbols in math expressions.

Table 4.1 The locations of '3' and '*x*' in eight different expressions.

Expression	*Thai*	*Pronunciation*	*Description*
x_3	เอ็กซ์ สาม	/èk săam/	The third term of x
$3x$	สาม คูณ เอ็กซ์ or สาม เอ็กซ์	/săam koon èk/ or /săam èk/	Three times x
x^3	เอ็กซ์ ยกกำลัง สาม	/èk yók-gam-lang săam/	The third power of x
$\sqrt[3]{x}$	รากที่ สาม ของ เอ็กซ์	/râak-têe săam kŏng èk/	The third root of x
$\frac{x}{3}$	เศษ เอ็กซ์ ส่วน สาม	/sàyt èk sùan săam/	x divided by three
$\frac{3}{x}$	เศษ สาม ส่วน เอ็กซ์	/sàyt săam sùan èk/	Three divided by x
$(x + y)^3$	เอ็กซ์ บวก วาย ทั้งหมด ยกกำลัง สาม	/èk bùak waai táng-mòt yók-gam-lang săam/	x plus y all to the power of three
$\log_3 x$	ล็อก ฐาน สาม เอ็กซ์	/lók tăan săam èk/	Log x to base three

3) Location and order: The location and the order of the character appearances determine whether and which extra words are required to convey the meaning of the expression. Table 4.1 illustrates the locations of '3' and '*x*' in eight different expressions. To correctly read these expressions, the different extra words are required in the different expressions. No extra word is needed in the first expression. In 2nd row, the word "คูณ (/koon/, multiply)" may or may not be added into the reading, it does not affect the meaning of the expression. The word "ยกกำลัง (/yók-gam-lang/, to the power of)" is required in reading the 3rd expression. The word "เศษ (/sàyt/, numerator)" and "ส่วน (/sùan/, denominator)" are added to identify the numerator and denominator of the fraction in the 5th expression. The word "ทั้งหมด (/táng-mòt/, all)" is added to indicate the numerator boundary. In the 6th expression, the word "ทั้งหมด (/táng-mòt/, all)" is added to indicate that the 3rd power is for "$x + y$". A logarithm is written in a subscript form, $\log_3 x$, composing the base '3' and the expression 'x' in the last row. The word "ล็อก (/lók/, log)" is the transliterated word of the symbol "log" while the word "ฐาน (/tăan /, base)" refer to "to base".

4) Characters-Thai sound mapping: A single character in a math expression can be mapped to one or more sounds, e.g. the Greek letter 'π' is mapped to one sound /paai/ while the notation '<' is mapped to two sounds /nói-gwàa/. But in the opposite, one sound in Thai text can correspond to two or more alphabets, e.g. a three-alphabet symbol "มาก" is mapped to one sound /mâak/ while a two-alphabet symbol "รถ" is mapped to one sound /rót/.

5) Homograph: The correct pronunciation of a Thai homograph depends on its context. For example the word "สระ" can be pronounced as "(/sà-rà/, vowel)" or "(/sà/, pool)". A kind of the homograph appears in mathematics as well. The correct reading of a math expression depends on where it appears. For example, the expression "1-12" either refers to "one to twelve /nèung tĕung sìp-sŏng/" or "one minus twelve /nèung lóp sìp-sŏng/". The dot '.' that comes after the number "7." is not a part of math expression. It is read as "item seven /kôr jèt/" while the dot '.' that lies between two number "12.5" indicates that "12.5" is a decimal so it is read "twelve point five /sìp-sŏng jùt hâa/". Furthermore, the dot that comes after "ซม." (cm: centimeter) is left unsounded, it is a part of the abbreviation.

One surface form of a math expression carries only one meaning (in mathematics). For example, if we see the expression, $\frac{a+b}{c}$, we will read it as "a plus b

over c". However, if we heard such expression, we could interpret it as either "$\frac{a+b}{c}$" or "$a+\frac{b}{c}$".

4.2 Reading the Math Expressions in Thai

To accurately read the math expressions in Thai, each structure of expressions needs to be analyzed. The different expressions need the different Thai words and the rules to complete the accurate reading. We consider several math expressions which include basics (e.g. decimals, 3x + 3y = 12, and 5 × 9 ÷ 3 ≠ 10), fractions, powers, radicals, vectors, trigonometric functions, logarithms, summations, limits, and integrals.

1) Basic expressions: The basic expression does not need an extra word to complete the reading. English and Greek letters and math symbols (see Appendix C) would be directly read from left to right, one by one at the time. In Figure 4.4., the math expression is read as Thai sentence on the right-hand side. The numerals (3, 4, and 12), English alphabets (x and y), and math notations (+ and =) are matched into their Thai words. For each word, its pronunciation and meaning are respectively presented inside the parentheses. As following, we discuss in details of the numbers and decimals reading.

3x + 4y = 12	สาม เอ๊กซ์ บวก สี่ วาย เท่ากับ สิบสอง (/sǎam/, three) (/èk/, x) (/bùak/, plus) (/sèe/, four) (/waai/, y) (/tâo-gàp/, equal) (/sìp-sǒng/, twelve).

Figure 4.4 An example of reading a basic math expression.

- **Numbers**: To read the numbers, it starts with reading each digit. A digit is read in Thai as illustrated in Figure 4.5. If a number is in the range 10 to 99, there are a number of rules to read the numbers in Thai as lists below:
  - If the first digit is '1', one must be read as "สิบ (/sìp/, ten)" to replace "หนึ่ง (/nèung/, one)". For example, "15" should be read as "สิบ ห้า (/sìp-hâa/, fifteen)" and "19" as "สิบ เก้า

(/sìp-gâo/, nineteen)". In particularly, the numeral "10" is read only "สิบ (/sìp/, ten)".

- If the first digit is '2', the number must be read as "ยี่ (/yêe/, two)" to replace "สอง (/sŏng/, two)". For example, "20" should be read as "ยี่ สิบ (/yêe-sìp/, twenty)" and "26" as "ยี่ สิบ หก (/yêe-sìp-hòk/, twenty-six)".
- If the final digit is '0', the number must be read "สิบ (/sìp/, ten)" to replace "ศูนย์ (/sŏon/, zero)". For example, "30" must be read as "สาม สิบ (/săam-sìp/, thirty)" and "70" as "เจ็ด สิบ (/jèt-sìp/, seventy)".
- If the final digit is '1', one must be read "เอ็ด (/èt/, one)" to replace "หนึ่ง (/nèung/, one)". For example, "11" should be read as "สิบ เอ็ด (/sìp-èt/, eleven)", "21" as "ยี่ สิบ เอ็ด (/yêe-sìp-èt/, twenty-six)", and "51" as "ห้า สิบ เอ็ด (/hâa-sìp-èt/, twenty-six)".

0	1	2	3	4	5	6	7	8	9
ศูนย์	หนึ่ง	สอง	สาม	สี่	ห้า	หก	เจ็ด	แปด	เก้า
/sŏon/	/nèung/	/sŏng/	/săam/	/sèe/	/hâa/	/hòk/	/jèt/	/bpàet/	/gâo/

Figure 4.5 Reading digits in Thai.

Otherwise, the numbers are read based on the place value, which is a positional system of the digit. Figure 4.6 illustrates the numeral "324,567,098" and the name of the places for each digit in the numeral. '8' is in the ones (หน่วย, /nùay/) place. It also means that there are eight ones-แปด (/bpàet/). '9' is in the tens (สิบ, /sìp/) place. It also means that there are nine tens-เก้า สิบ (/gâo-sìp/) while '0' is in the hundreds (ร้อย, /rói/) place and means zero hundred (does not read aloud). In the same way, there are seven thousands-เจ็ด พัน (/jèt-pan/), sixty thousands-หก หมื่น (/hòk-mèun/), and five hundred thousand-ห้า แสน (/hâa-săen/). All underline phrases are stated together and rearranged from left to right, and then we read all straightforward as:

ห้า แสน หก หมื่น เจ็ด พัน เก้า สิบ แปด

/hâa-săen hòk-mèun jèt-pan gâo-sìp bpàet/.

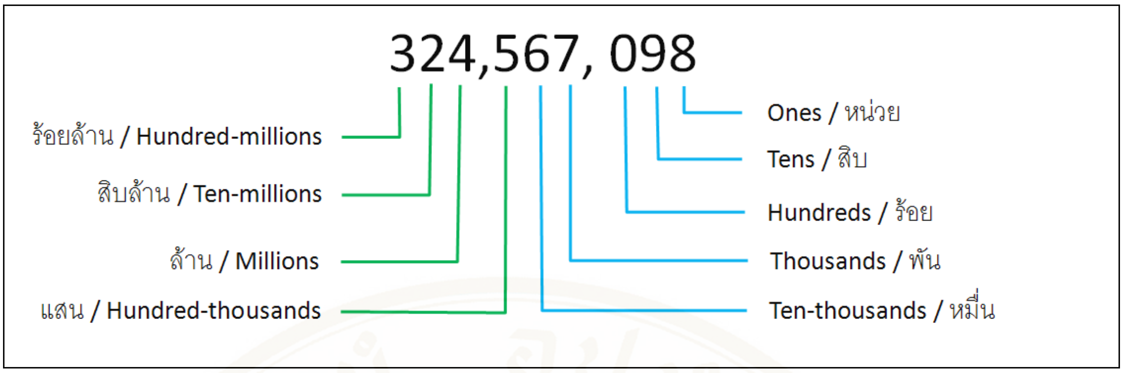


Figure 4.6 The Thai and English place values.

In millions place and more, the digits are grouped as the millions (/láan/, ล้าน) value. Generally, it is unnecessary to read the word “millions (/láan/, ล้าน)” in many times. We always read the numeral ‘324’ first, and then the word “ล้าน (/láan/)” from left to right. ‘3’, ‘2’, and ‘4’ are the hundred-millions (/rói-láan/, ร้อย–ล้าน), the ten-millions (/sìp-láan/, สิบ–ล้าน), and the millions (/láan/, ล้าน), respectively. Therefore, we read three hundreds–<u>สาม ร้อย</u> (/săam-rói/), twenty–<u>ยี่ สิบ</u> (/yêe-sìp/), and four millions–<u>สี่ ล้าน</u> (/sèe láan/) as three hundred twenty four millions-<u>สาม ร้อย ยี่ สิบ สี่ ล้าน</u>. Again, putting all together, the whole number can be read as:

<u>สาม ร้อย ยี่ สิบ สี่ ล้าน ห้า แสน หก หมื่น เจ็ด พัน เก้า สิบ แปด</u>
/săam-rói yêe-sìp sèe láan hâa-săen hòk-mèun jèt-pan gâo-sìp bpàet/.

3.14	สาม จุด หนึ่ง สี่ (/săam/, three) (/jùt/, dot) (/nèung/, one) (/sèe/, four)
2.056	สอง จุด ศูนย์ ห้า หก (/sŏng/, two) (/jùt/, dot) (/sŏon/, zero) (/hâa/, five) (/hòk/, six)
22.559	ยี่สิบ สอง จุด ห้า ห้า เก้า (/yêe-sìp/, twenty) (/sŏng/, two) (/jùt/, dot) (/hâa/, five) (/hâa/, five) (/hòk/, six)
321.902	สามร้อย ยี่สิบเอ็ด จุด เก้า ศูนย์ สอง (/săam-rói/, three hundred) (/yêe-sìp-èt/, twenty-one) (/jùt/, dot) (/gâo/, nine) (/sŏon/, zero) (/sŏng/, two)

Figure 4.7 Reading the decimals in Thai.

- **Decimals**: To read a decimal, a number before the decimal point should be read normally as the same as the rules we explained above. After the decimal point they should be read a number, digit by digit. Some examples show in Figure 4.7. The word "จุด (/jùt/, dot)" refers to the decimal point.

Table 4.2 Thai pronunciations of fractions.

Expression	***Thai pronunciation***	***Pronunciation***	***Description***
$\frac{a}{b}$	เศษ *a* ส่วน *b*	sàyt ay sùan bee	*a* over *b*
$\frac{a}{b+c}$	เศษ *a* ส่วน *b* + *c*	sàyt ay sùan bee bùak see	*a* over *b* + *c*
$\frac{a+b}{c}$	เศษ *a* + *b* ทั้งหมด ส่วน *c*	sàyt ay bùak bee táng-mòt sùan see	*a* + *b* all over *c*
$\frac{a}{b^2}$	เศษ *a* ส่วน *b* ยกกำลัง *2*	sàyt ay sùan bee yók-gam-lang sǒng	*a* over *b* squared
$a + \frac{b}{c}$	*a* + เศษ *b* ส่วน *c*	ay bùak sàyt bee sùan see	*a* plus *b* over *c*
$\frac{a+b}{b+c}$	เศษ *a* + *b* ทั้งหมด ส่วน *b* + *c*	sàyt ay bùak bee táng-mòt sùan bee bùak see	*a* plus *b* all over *b* plus *c*
$\frac{\frac{a}{x}}{\frac{b}{y}}$	เศษ เศษ *a* ส่วน *x* ทั้งหมด ส่วน เศษ *b* ส่วน *y*	sàyt sàyt ay sùan èk táng-mòt sùan sàyt bee sùan waai	*a* over *x* all over *b* over *y*
$\frac{a^2}{b}$	เศษ *a* ยกกำลัง 2 ทั้งหมด ส่วน *b*	sàyt ay yók-gam-lang sǒng bee táng-mòt sùan bee	*a* squared all over *b*

2) Fractions: To read a fraction in Thai, a numerator is read first by beginning with the word "เศษ (/sàyt/, numerator)". Then, a denominator is followed by the word "ส่วน (/sùan/, denominator)". In Table 4.2, the expression,

$$\frac{a}{b}$$

is uttered "เศษ a ส่วน b" illustrated in the first row. To identify the end of the numerator, the word "ทั้งหมด (/táng-mòt/, all)" is read when the numerator is not one character. In the third row, the expression,

$$\frac{a + b}{c}$$

is read as “เศษ a บวก b ทั้งหมด ส่วน c”. The three underline words “เศษ”, “ทั้งหมด” and “ส่วน” are added into the utterance to identify the beginning of the numerator, the end of the numerator and the beginning of the denominator respectively. The word “ทั้งหมด” is added to read this expression because the numerator is comprised of three characters, ‘a’, ‘+’ and ‘b’. In the last row, the word “ทั้งหมด” is also added since the numerator is the expression “a^2”. Some examples of the Thai pronunciations for fractions show in Table 4.2.

3) Powers: A power is the math expression written in the superscript form,

$$a^b$$

involving two components, the base ‘a’ and the exponent ‘b’. The expression “a^b” can be read in Thai as “a ยกกำลัง b”. The underline word “ยกกำลัง (/yók-gam-lang/)” refers to “to the power of”. Once, when the base is not simple (Table 4.3), the word “ทั้งหมด (/táng-mòt/, all)” is spoken to identify the end of the base. In the second row, $(a+b)^c$ is read as “a บวก b ทั้งหมด ยกกำลัง c”. If the base is a kind of math expressions, e.g., a fraction in the last row of Table 4.3, the word “ทั้งหมด” must be added as well.

Table 4.3 Thai pronunciations of powers.

Expression	***Thai pronunciation***	***Pronunciation***	***Description***
a^b	*a* ยกกำลัง *b*	ay yók-gam-lang bee	*a* to the power of *b*
$(a+b)^c$	*a* บวก *b* ทั้งหมด ยกกำลัง *c*	ay bùak bee táng-mòt yók-gam-lang see	*a* + *b* to the power of *c*
$\left(\frac{a}{b}\right)^c$	เศษ *a* ส่วน *b* ทั้งหมด ยกกำลัง *c*	sàyt ay sùan bee táng-mòt yók-gam-lang see	*a* over *b* all to the power of *c*

4) Radicals: A radical is an expression written beneath a radical symbol, $\sqrt{\ }$. The expression,

$$\sqrt[n]{a}$$

denotes the n^{th} root of ‘a’ where ‘n’ is the degree of the root. In reading, the Thai word “รากที่ (/râak-têe/, root)” is uttered to identify the beginning of the radical before reading the degree of the radicals. Then, the word “ของ (/kŏng/, of)” is spoken before presenting the expression under the radical symbol. For example, the expression “$\sqrt[n]{a}$”

is spoken as “รากที่ n ของ a”. Otherwise, the root have no degree, for example the expression “$\sqrt{a}$” is always read “รากที่ 2 ของ a” denoting “the squared root of a”.

5) Vectors: A vector is represented in many forms such as it displays in boldface, **v**, and it has a carat ($\widehat{\ }$) above it appearing in some textbooks. However, in most Thai textbooks for the high school students a half-rightward arrow ($\overrightarrow{\ }$) written above an alphabet is used to represent the vector,

$$\vec{v}.$$

This vector can be read in Thai as “เวกเตอร์ v” where the word “เวกเตอร์ (/wâyk-dtêr/)” which is the Thai transliteration of “vector” is read to identify the beginning of the vector. Moreover, a rightward arrow ($\overrightarrow{\ }$) represents the ray while a carat ($\widehat{\ }$) refers to the angle and a left right arrow ($\overleftrightarrow{\ }$) is used for the straight line. Consequently, the expression, $\overrightarrow{AB}$, is read as “รังสี AB” which the word “รังสี (/rang-sěe/)” refers to the ray. The expression, $\hat{A}$, is uttered as “มุม A”, the word “มุม (/mum/)” means an angle in Thai. And, the expression, $\overleftrightarrow{PQ}$, is “เส้นตรง PQ”, as the word “เส้นตรง (/sên-dtrong/)” is a straight line.

6) Trigonometric functions: The trigonometric functions are normally denoted by English characters as the notations illustrated in Table 4.4. This set of characters does not read out character by character. The English characters are transliterated into Thai pronunciations. For example, “sin” is translated into Thai as “ซายน์ (/saai/)”.

Table 4.4 Thai pronunciations of trigonometric functions.

Expression	*Thai pronunciation*	*Pronunciation*	*Function*
$\sin A$	ซายน์ A	saai ay	Sine
$\cos A$	คอส A	kôt ay	Cosine
$\tan A$	แทน A	taen ay	Tangent
$\cot A$	คอท A	kòt ay	Cotangent
$\sec A$	เส็ก A	sék ay	Secant
$\csc A$, $\operatorname{cosec} A$	โค เส็ก A	koh- sék ay	Cosecant

7) Logarithm functions: A logarithm is written in a subscript form,

$$\log_a x$$

composing the base '*a*' and the expression '*x*'. It can be read as "ล็อก *x* ฐาน *a*". The word "ล็อก (/lók/)" is the transliteration of "log" while the word "ฐาน (/tǎan/)" refer to "to base". Another form of logarithm,

$$\ln x$$

is read as "แนชัวรอล ล็อก *x*". Again, the phrase "แนชัวรอล ล็อก" is the transliteration of "natural log".

8) Summations: A summation is a multi-level expression which consists of three components around the "$\sum$ " symbol. For example, the expression

$$\sum_{i=1}^{\infty} i$$

is comprised of the lower bound "i = 1", the upper bound '∞', and the expression '*i*'. This expression can be read in Thai as "ซัมเมชั่น ของ *i* จาก *i* เท่ากับ 1 ถึง ∞". The word "ซัมเมชั่น" is the transliteration of "summation". Similarly, the word "ของ (/kǒng/, of)" is uttered before the expression '*i*'. The two words "จาก (/jàak/, from)" and "ถึง (/tĕung/, to)" identify the beginning of the lower bound and the beginning of the upper bound, respectively. The word "เท่ากับ (/tâo-gàp/, equal)" refers to the operator '='.

9) Limits: In formula, a limit is usually abbreviated as "lim" and uses a right arrow (→) under the abbreviation to represent that a variable approaches a value as in the expression,

$$\lim_{x \to a} x$$

denotes limit of *x* as *x* approaches *a*. This expression can be stated in Thai as "ลิมิต ของ *x* ที่ *x* เข้าใกล้ *a*". The word "ลิมิต (/lí-mìt/)" is the transliteration of "limit". Again, the word "ของ (/kǒng/, of)" is uttered before the expression *x*. The word "ที่ (/têe/)" which mean "as" is uttered before the expression '*x*' under the abbreviation "lim". The word "เข้าใกล้ (/kâo-glâi/)" refers to the right arrow which means "approaches".

10) Integrals: An indefinite integral

$$\int x \ dx$$

is read as “อินทีเกรต $x\ d\ x$ ” as the “อินทีเกรต” is the transliteration of “integrate” which refers to the math symbol ‘$\int$ ’. For a definite integral

$$\int_a^b x\, dx$$

is stated as “อินทีเกรต $x\ d\ x$ จาก a ถึง b” The two words “จาก (/jàak/, from)” and “ถึง (/tĕung/, to)” identify the beginning of the lower bound and the beginning of the upper bound, respectively.

We compared math expressions and Thai in a term of appearances. The math expressions need extra words which do not appear in the expressions to convey accurate meaning of such expressions. Each math expression is analyzed to develop the reading rules. The simple expressions are easy to handle, however, the complicated ones, which are in multi-level (e.g., summations, limits, and integrals), are carefully considered in designing the system.

We focused on the secondary mathematics and extended to cover several topics of the high-school level including sequences and series, exponential and logarithm functions, vectors, limits, and integrals. To read the more complex math expressions, the same patterns of the reading rules are used in this research. For example, the expression, $\log \sqrt{\frac{4}{5}}$, is three levels of complexity that comprised of a logarithm, a radical, and a fraction. This expression can be uttered as “ล็อก รากที่ 2 ของ เศษ 4 ส่วน 5” In addition, the listeners can understand the utterance of the expression produced by our system (more details in chapter 8).For the more levels of the complexity, the utterances are very long. When listening to math operators, numbers, and symbols for a very long continuous period, not only the blind and VI students but also all listeners will loss the information on the way and cannot catch the exactly expression. This problem cannot be solved by simply pausing and repeating during utterances. However, this problem needs the research in depth on how to read the complex expressions that enable the listeners to view the exact expression.

CHAPTER V

AN EXTENSIBLE MARKUP LANGUAGE

In the previous chapter, we explained:

- how math expressions appear on the paper/screen,
- how the expressions are read in Thai,
- which extra words are added and where the words are placed to complete and convey the meaning of the expressions,
- which components of the expressions are rearranged.

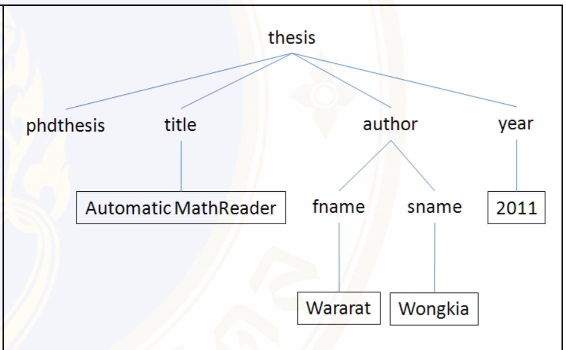
The math expressions appear in non-linear or multi-level forms. An eXtensible Markup Language (XML) is used to transform the multi-level expressions into a linear form for the easily procession. To add the extra words, we use an eXtensible Stylesheet Language Transformation (XSLT) to construct the reading rules of the math expressions. The right words are added into the right position of the expressions and the components of the expressions are rearranged.

XML is a simple text-based format for representations, manipulations, and exchanges of structure information (Bray, Paoli, Sperberg-McQueen & Maler, 2008). XML is widely used for sharing the information between programs and people which can be viewed in Web browsers (e.g., Internet Explorer, Mozilla Firefox). The XML documents enclose the information or the content inside tags (which are delimited by '<' and '>' such as <title> and </title>) shown in Figure 5.1a. The content information is bounded by a start tag (<title>) and an end tag (</title>). The tags provide the name of the content information. For example "<year> 2011 </year>", the tag <year> provides that "2011" is a year. XML allows the users to create their own tag names or vocabularies (a set of tag names). The tags are nested in a hierarchical and a consistent structure that represent as a tree structure (Figure 5.1b). Besides, another kind of a tag, called an empty tag (<phdthesis/>), has no content used to serve as markers in an XML document.

To support Microsoft Word (MS Word) as an input, industry-standard XML vocabularies are needed to consider. Office Open XML (OpenXML) defines the XML vocabularies for Microsoft Office documents including the word-processing, the spreadsheet, and the presentation documents (Paoli, Valet-Harper, Farquhar & Sebestyen, 2006). The details will be described in the next section. To generate the Thai pronunciations for the math expressions, XSLT is employed to transform an XML document into another XML document described in section 5.2. In section 5.3, XML Path Language (XPath) uses to select the specific elements in the XML document are summarized.

```
<thesis>
        <phdthesis/>
        <title> Automatic MathReader </title>
        <author>
                <fname> Wararat </fname>
                <sname> Wongkia </sname>
        </author>
        <year> 2011 </year>
</thesis>
```

(a)



(b)

Figure 5.1 Stream data in XML (a) and the data in a tree structure (b).

5.1 Office Open XML (OpenXML)

Initiating with Microsoft Office 2007, the Office Open XML (OpenXML) file format is proposed to define its XML vocabularies by ECMA-367 (Paoli et al., 2006). OpenXML is an open standard for representing the spreadsheets, charts, presentations, and word-processing documents. OpenXML also defines the XML vocabularies for math elements (i.e., equations, expressions formulas, matrices, and other math elements).

A word-processing document contains a part for the body of text, a part for an image referenced by the text, and parts for defining the document characteristics, styles, and fonts. In the word-processing document, stories of text (a main document, comments, headers, etc.) consist of one or more paragraphs as defined by the w:p tag. The stories contain the contents and the properties (styles, fonts, etc.) of the document. The content is stored inside the body element (w:body) within the main document (w:document). The main document part contains the following XML representation.

```
<w:document …>
        <w:body>
                <w:p/>
        </w:body>
</w:document>
```

This XML representation provides a single paragraph in the main document. Moreover, there is a set of markup languages used for the elements such as charts, diagrams, and math objects.

The math objects are used in the document to specify the structure and the appearance of math expressions. The root tags can be either m:oMathpara or m:oMath. m:oMathpara is a math paragraph containing one or more math expression(s). Each expression is specified in a single m:oMath. Inside each m:oMath, a combination of math elements such as text (m:t), fractions (m:f), and radical objects (m:rad) are presented. Examples of math elements and their syntax are described below (see more details in Appendix D):

1) Text and character:

- m:t (Text) specifies the arbitrary text including English alphabets, numerals, math operation signs (e.g., +, –, =, ±), Greek alphabets, and so on. The m:t is a leaf node for math expressions and has only the run (m:r) be the parent node.
- m:r (Run) specifies a run of math text.

2) Fraction Object:

- m:f (Fraction Object) specifies the fraction object, consisting of a numerator (m:num) and a denominator (m:den) separated by a fraction bar. The fraction bar can be horizontal or diagonal, depending on the fraction properties. The fraction object is also used to represent the stack function, which places one element above another, with no fraction bar. Examples of fractions are:

  $\frac{a}{b}$ (bar fraction),

  $^{a}/_{b}$ (skewed fraction),

  a/b (linear fraction), and

  $\genfrac{}{}{0pt}{}{a}{b}$ (no-bar fraction: stack).

  Within the properties of a fraction, the m:type value must be skw for the skewed fraction, lin for the linear fraction and without m:type for the bar fraction.

- m:num (Numerator Object) specifies a numerator of a fraction.
- m:den (Denominator Object) specifies a denominator of a fraction.

An example of the fraction $^{a}/_{b}$ is represented as the following XML representation.

```
<m:oMath>
    <m:f>
        <m:fPr>
            <m:type m:val= "skw"/>
        </m:Pr>
        <m:num>
            <m:r>
                <m:t> a </m:t>
            </m:r>
        </m:num>
        <m:den>
            <m:r>
                <m:t> b </m:t>
            </m:r>
        </m:den>
    </m:f>
</m:oMath>
```

3) Radical Object:

- m:rad (Radical Object) specifies the radical object, consisting of a radical, a base (m:e) and an optional degree (m:deg).
- m:e (Element (Argument)) serves several functions including the base argument of a math radical.
- m:deg (Degree) specifies the degree in the math radical. It is optional. In the square root function, as in $\sqrt{a}$, the degree is omitted.

Some examples of relationships between each element are shown below (more details in Paoli et al. (2006)).

<m:oMath>	::=	<m:f>|<m:oMath>|<m:r>|<m:rad>
<m:f>	::=	<m:num><m:den>
<m:num>	::=	<m:f>|<m:oMath>|<m:r>|<m:rad>
<m:den>	::=	<m:f>|<m:oMath>|<m:r>|<m:rad>
<m:rad>	::=	<m:deg><m:e>
<m:deg>	::=	<m:f>|<m:oMath>|<m:r>|<m:rad>
<m:e>	::=	<m:f>|<m:oMath>|<m:r>|<m:rad>
<m:t>	::=	{arbitrary text, e.g., English and Greek alphabets, numerals, and math operation signs}

The <m:oMath> element can have the <m:f>, <m:oMath>, <m:r>, or <m:rad> element as children elements while the <m:f> element must have two children that is the <m:num> and <m:den> elements. The <m:t> element must be a leaf node with the text content inside.

5.2 eXtensible Stylesheet Language Transformations (XSLT)

The important application of an XML is eXtensible Stylesheet Language Transformations (XSLT) which is a simple rule-based language (Clark, 1999). XSLT has the capabilities not only to transform an XML document into another XML document but also to select the specific content from an XML document, sort the content from an XML document, and combine the content from multiple XML documents (Ethier & Houser, 2001). The XSLT processor applies the style sheet rules to the XML source document and writes the results of the transformation to a result document shown in Figure 5.2.

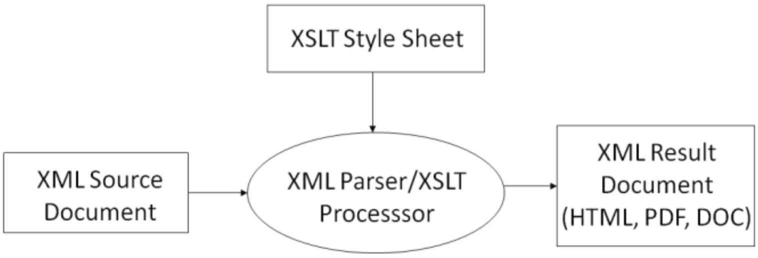


Figure 5.2 A flow diagram of an XML source document, XSLT, and XML result documents (Ethier & Houser, 2001).

Before creating the XSLT document, we must know the vocabularies which are used in an XML input document. The MS Word program version 2007 has used the standard OpenXML vocabularies to define the specific element names, as mentioned in the previous section. The element names (m:oMath, m:f, m:num, etc) will be processed by the style sheet. The following code shows a simple pattern of a style sheet which is applied to an XML source document.

```
<xsl:template match = “m:oMath”>
   …
   <xsl:apply-templates/>
   …
</xsl:template>
```

In this code, <xsl:template> is used to select a specified node. The match attribute is used to associate the template with an XML element. The body of this template (including text, child elements, and attributes) in the XML input is used to construct the corresponding part of the XML output (m:oMath). All remaining templates are applied to the children of the top-level element (<xsl:template>) with <xsl:apply-templates/> see more details at (Clark, 1999).

5.3 XML Path Language (XPath)

In addition, W3C introduces XML Path Language (Xpath) to access or refer to parts of an XML document for using with XSLT. The purpose of XPath is to address parts of an XML document. XSLT and XPath can select the specific elements of an XML input document and copy the element to an XML result document (Clark & DeRose, 1999). XPath can select the elements and the attributes by names, and their relationships with other elements. Xpath models an XML document as a tree. Figure 5.3 shows an example of the tree of a math expression. The tree represents both the content and the structure of the XML document. Each node is an element of an XML document while the leaves nodes are the content of an element.

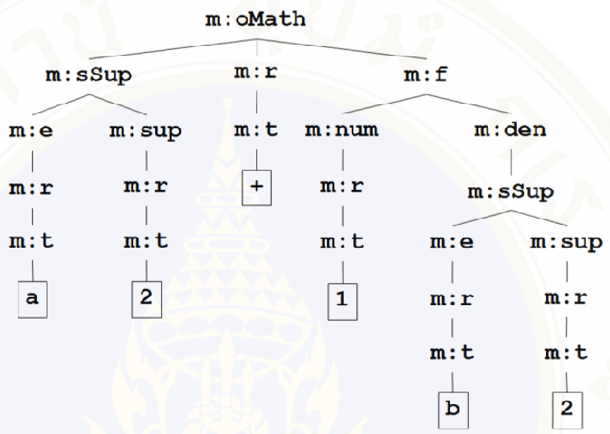


Figure 5.3 An XML representation, $a^2 + \frac{1}{b^2}$, as a tree of elements.

The path expression can combine to identify element within a context in an XML input document. Some examples show below:

/m:sSup/* select all child elements of the <m:sSup> element.

/m:f/m:num select the <m:num> child of the <m:f> element.

//m:oMath select all descendant <m:oMath> elements.

Table 5.1 shows the basic location path expressions. The match attribute on <xsl:template> and <xsl:apply-templates/> is used to the specific nodes in the source tree to be processed by the style sheet. For example <xsl:apply-templates match = "/">, means "apply any template in this style sheet that match the specified the Xpath expression". A forward-slash is used to select a child node of the current node (see more details in Clark & DeRose (1999)).

Table 5.1 Basic location path of XPath expressions.

Symbol	*Use in Location Path*
.	Current node
/	Child of the current node
../	Parent of the current node
//	Descendant of the current node
*	Matches all child elements of the current node
@league	Matches the attribute of the current node named league

Not all elements need to be processed for generating the Thai pronunciations for math expressions. For example, the elements of size and font text have no effect on reading the math expressions.

In this chapter, we introduce the basic knowledge of XML used for developing our *i-Math* including OpenXML, XSLT, and XPath. XML is chosen to transform multi-level math expressions appearing on the paper/screen into linear forms that are the easily process forms. OpenXML is derived to understand the element names of the expressions and their syntax while XSLT is applied to add the right words into the right locations of the expressions. XPath is utilized to correctly select the specific nodes of the expressions. In the next chapter, we will describe how the accurate Thai pronunciations of the math expressions are generated.

CHAPTER VI

AN INTELLIGENT ACCESSIBLE MATHEMATICS

An intelligent accessible mathematics (*i-Math*) is an alternative text-to-speech (TTS) approach with the capability to generate an accurate Thai speech output from Thai math expressions. To ensure the accuracy of the *i-Math* output, the relationships between notations (e.g., numerals, math operators, English alphabets, and Greek alphabets) appearing in the expressions, the locations and the order of appearances of characters must be taken into accounted. *i-Math* was designed to serve two purposes: first, to generate an unambiguous Thai speech output of math expressions as they display on the screen and second, to support an electronic Microsoft Word (MS Word) format. Thus, *i-Math* performs Thai speech generation in four modules: XML Extraction module, MathEx Structure Analysis module, Math–Thai Mapping module, and Speech Synthesis module (Figure 6.1).

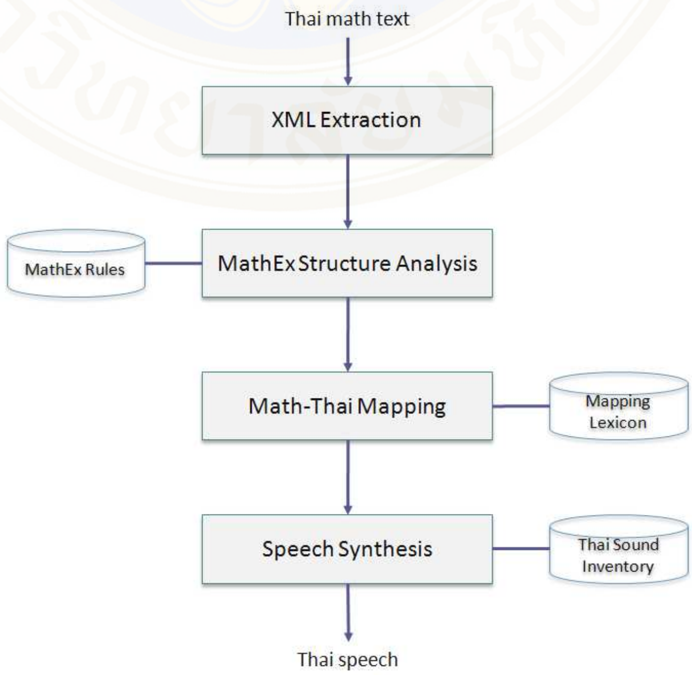
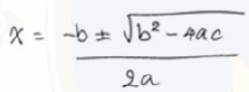


Figure 6.1 *i-Math* architecture.

The input of *i-Math* is the string containing both Thai text (Thai) and math expressions (MathEx) in a MS Word format. The XML Extraction module extracts an eXtensible Markup Language (XML) file from the MS Word document. To retain the complete meanings, the MathEx Structure Analysis module adds the necessary words required in reading the math expressions by analyzing several math expressions. To provide clear and correct pronunciations, the Math-Thai Mapping module replaces all foreign alphabets with their Thai pronunciation patterns and the Speech Synthesis module generates the corresponding Thai speech for all Thai pronunciation patterns. In the following section, the sequential steps of *i-Math* are described in detail.

6.1 XML Extraction



(a)

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

(b)

```
\[x=\frac{-b\pm \sqrt{b^{2} -4ac} }{2a} \]
```

(c)

```
<m:oMath>
    <m:r><m:t>x</m:t></m:r>
    <m:r><m:t>=</m:t></m:r>
    <m:f>
        <m:num>
            <m:r><m:t>-</m:t></m:r>
            <m:r><m:t>b</m:t></m:r>
            <m:r><m:t>±</m:t></m:r>
            <m:rad>
                <m:deg/>
                <m:e>
                    <m:sSup>
                        <m:e>
                            <m:r><m:t>b</m:t></m:r>
                        </m:e>
                        <m:sup>
                            <m:r><m:t>2</m:t></m:r>
                        </m:sup>
                    </m:sSup>
                    <m:r><m:t>-4</m:t></m:r>
                    <m:r><m:t>ac</m:t></m:r>
                </m:e>
            </m:rad>
        </m:num>
        <m:den>
            <m:r><m:t>2</m:t></m:r>
            <m:r><m:t>a</m:t></m:r>
        </m:den>
    </m:f>
</m:oMath>
```

(d)

Figure 6.2 A math expression in several representations: a hand written (a); an equation editor (b); LaTeX (c); and an XML representation (d).

Math expressions are used to communicate math concepts between people. Four different representations of the same math expression example illustrated in Figure 6.2. Two-dimensional math expressions are widely used by the hand writing with a pencil and paper (Figure 6.2a). Currently, most popular text editor, MS Word, allows the users to easily create the math expressions with an equation editor option

(Figure 6.2b). Other well-known editors are TeX and LaTeX system which can be written by the one-dimensional math expression. The example of LaTeX representation is shown in Figure 6.2c. W3C has recently introduced an XML technology (Bray et al., 2008). XML is used for representation, manipulation, and exchange of structure information including math expressions illustrated in Figure 6.2d. <m:oMath>, <m:f>, <m:num>, and more are tags of XML which are written between angle brackets. XML tags open with the ‘<’ symbol and end with the ‘>’ symbol. For example (in line 5), <m:num> is an starting tag. All starting tags must have ending tags, in this case the ending tag is </m:num> illustrated in line 24. The content is bounded by the starting and ending tags, for example the string “จงหาจำนวนจริง” is inside the tags <w:t> and </w:t> (line 1) while the characters ‘x’, ‘=’, and ‘-’ are inside <m:t> and </m:t> in line 2, 3, and 6, respectively. All tags and their syntax using in this research are described in Appendix D.

Input

จงหาจำนวนจริง x เมื่อ $\frac{x+1}{5} = \frac{7}{12}$

(Find a real number x that $\frac{x+1}{5} = \frac{7}{12}$)

(a)

XML Representation

```
1  <w:r><w:t>จงหาจำนวนจริง</w:t></w:r>
2  <w:r><w:t>x</w:t></w:r>
3  <w:t>เมื่อ</w:t></w:r>
4  <m:oMath>
5      <m:f>
6          <m:num>
7              <m:r><m:t>x</m:t></m:r>
8              <m:r><m:t>+</m:t></m:r>
9              <m:r><m:t>1</m:t></m:r>
10         </m:num>
11         <m:den>
12             <m:r><m:t>5</m:t></m:r>
13         </m:den>
14     </m:f>
15     <m:r><m:t> = </m:t></m:r>
16     <m:f>
17         <m:num>
18             <m:r><m:t>7</m:t></m:r>
19         </m:num>
20         <m:den>
21             <m:r><m:t>12</m:t></m:r>
22         </m:den>
23     </m:f>
24 </m:oMath>
```

(b)

Figure 6.3 An example of a Thai math problem and its XML representation.

The first module, XML Extraction, extracts a corresponding XML file from an input document. An input document containing math expressions and plain text is in a MS Word format file since the word processor program is widely used and most Thai teachers, blind and VI students are familiar with the program. In addition, MS Word 2007 is adapted to support XML, and allowed for accessing XML. Each document input is extracted its corresponding XML file. In an XML representation, the information is stored in the text-based format. Figure 6.3 presents the word problem example together with its XML representation. Any text and math expression are clearly separated by tags, e.g., <w:r> and <m:oMath>. Their English translations are provided in parentheses underneath.

6.2 MathEx Structure Analysis

In reading a math expression, unlike reading Thai plain text, some particular words that do not appear in the expression are uttered to clarify the meaning of the input expression. In doing so, some Thai words are required to convey the meaning of an original math expression. We therefore analyzed each math expression structure to develop the reading rules based on the syntax and semantics of the math expressions (see section 4.1 and 4.2).

MathEx Structure Analysis, the second module, analyzes the XML representation to determine which words should be added and where they should be placed to correctly retain the meaning of the input expression. The analysis is done using eXtensible Stylesheet Language Transformations (XSLT) by W3C (Clark, 1999). The result of this analysis is the MathEx Rules (see all in Appendix E) to add the particular words in the expressions based on the reading math expressions in Thai discussed in section 4.2. To understand the MathEx rules, Algorithm 1 presents an example of MathEx rules to clarify the adding words in a fraction.

<m:oMath> is declared as a math expression in XML, <m:f> is a fraction, <m:num> is a numerator, <m:den> is a denominator, and <m:r> is the run of the math text. As recall, <m:f> is the child node of <m:oMath>, and <m:f> is comprised of two main features: <m:num> and <m:den> (see more details in section 5.1 and Appendix D). The algorithm starts from the root node of the fraction tree. For all <m:f> in <m:oMath>, we select <m:num> and add <thsound> with the word "เศษ (/sàyt/, numerator)" as the first child node of <m:num>. Then if the number of <m:r> that is the child node of <m:num> are greater than or equal two, we add <thsound> with the

word “ทั้งหมด (/táng-mòt/, all)” as the last node of <m:num>. In the same way, we select <m:den> and add <thsound> with the word “ส่วน (/sùan/, denominator)” as the first child node of <m:den>.

Algorithm1 MathEx algorithm for a fraction.

```
    Input: an XML representation of a fraction
    Output: the fraction XML representation with thsound
1       start from a root node
2       find m:f node that be the child of m:oMath node
3       for each select m:num node that be the child of m:f node do
4           create thsound node as the first child node of m:num node with the “เศษ” text content
5           count m:r nodes that be the child of m:num node
6           if the number of m:r node >= 2 do
7               create thsound node as the last child node of m:num with the “ทั้งหมด” text content
8           end if
9       end for
10      for each select m:den node that be the child of m:f node do
11          create thsound node as the first child node of m:den with the “ส่วน” text content
12      end for
```

In the algorithm above, step 1 will only be run once. For the loops in step 3-9 and 10-12, the <m:num> and <m:den> nodes will be called N times for each <m:f> node in <m:oMath> to be added the word “เศษ (/sàyt/, numerator)” and “ส่วน (/sùan/, denominator)”. If there are N <m:f> nodes in <m:oMath>, the time complexity will be O(n^2). This quadratic complexity appears to be due to XSLT searches for a matching template for each selected node. Thus, the use of the XSLT algorithm is great for small and medium-sized files, less than 400 MB documents, (Sherman, 2008).

Figure 6.4 illustrates the using of this algorithm to create the XML result tree by adding necessary nodes and keeping any relation in the original XML. The XML structure of the fraction “$\frac{7}{12}$” and its XML result tree show in Figure 6.4a while the structure and the result tree of the fraction “$\frac{x+1}{5}$” is in Figure 6.4b. The structure of the MathEx analyzed output presents in Figure 6.5. In this example, the structure of a fraction is the same as the ordering of its Thai pronunciation pattern. Therefore, the structure of the MathEx analyzed output remains the same ordering with the original XML.

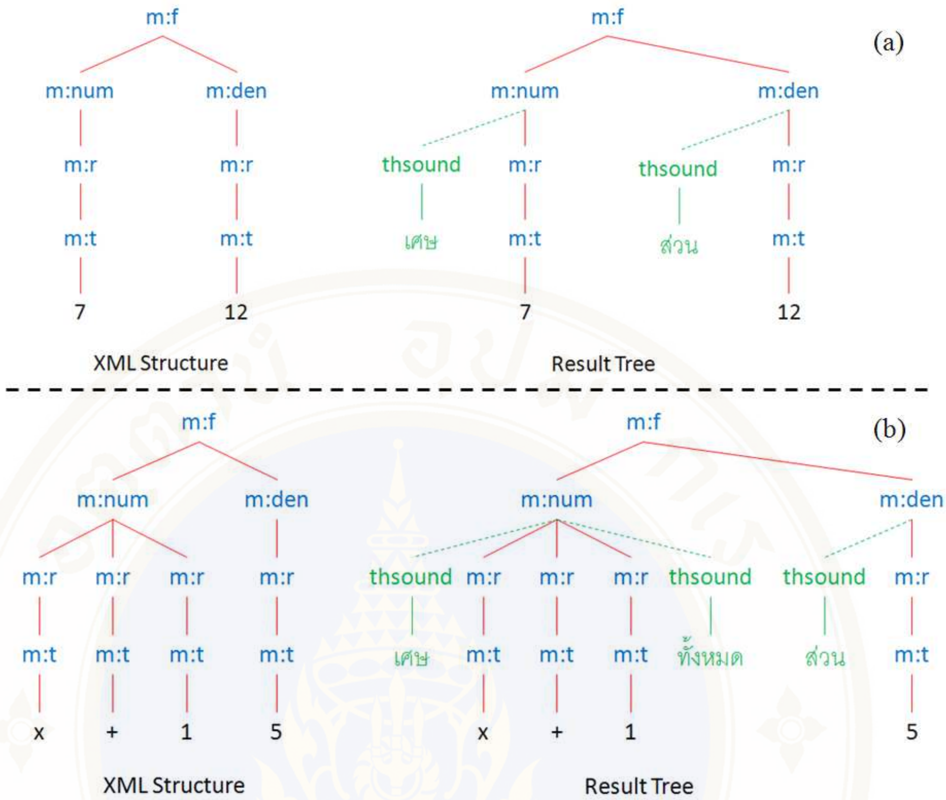
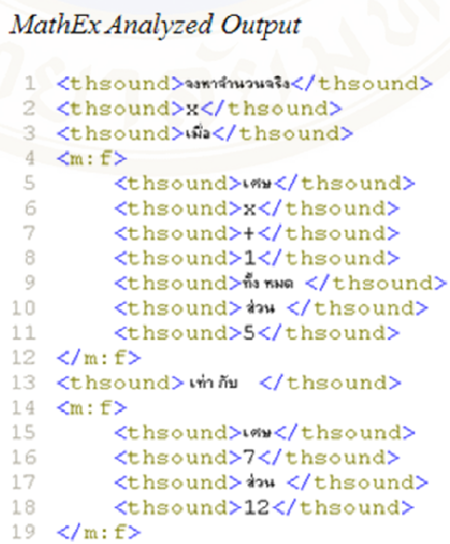


Figure 6.4 An example of XML trees and their result trees; the addition of two words "เศษ"and "ส่วน" (a) and the addition of three words "เศษ", "ทั้งหมด", and "ส่วน" (b).



MathEx Analyzed Output

```
<thsound>จงหาจำนวนจริง</thsound>
<thsound>x</thsound>
<thsound>เมื่อ</thsound>
<m:f>
     <thsound>เศษ</thsound>
     <thsound>x</thsound>
     <thsound>+</thsound>
     <thsound>1</thsound>
     <thsound>ทั้งหมด </thsound>
     <thsound>ส่วน </thsound>
     <thsound>5</thsound>
</m:f>
<thsound>เท่ากับ  </thsound>
<m:f>
     <thsound>เศษ</thsound>
     <thsound>7</thsound>
     <thsound>ส่วน </thsound>
     <thsound>12</thsound>
</m:f>
```

Figure 6.5 An example of the corresponding Thai Pronunciation patterns.

Moreover, the most commonly read math expressions are explored for constructing the MathEx rules as well. For example, the expression, $\log_x 8$, should be formally read in Thai as “ฟังก์ชัน ลอการิทึม ฐาน *x* ของ 8” where the word “ฟังก์ชัน (/fang-chan/)” is transliterated from the word “function”, the word “ลอการิทึม (/lor-gaa-rí-teum/)” is the transliteration of the word “logarithm”, the word “ฐาน (/tăan/) means “to the base”, and the word “ของ (/kŏng/)” refers to the preposition “of”. However, most people utter the expression, $\log_x 8$, as “ล็อก 8 ฐาน x” where the word “ล็อก (/lók/)” is the transliteration of the abbreviation “log”. As describing in chapter 4, *i-Math* generates the utterance “ล็อก 8 ฐาน x” for this expression to generate the concise pronunciation of the expression.

In this case, the order of appearances of characters in the expression structure is different from its pronunciation pattern. For example, in the expression, the base ‘*x*’ appears before the element ‘8’; however, the element ‘8’ is read before the base ‘*x*’ in the reading. Therefore, the order of the characters ‘*x*’ and ‘8’ must be rearranged as illustrated in Figure 6.6. Figure 6.6a shows an XML representation of the expressions, $\log_x 8$. The MathEx analyzed result (Figure 6.6b) of the logarithm shows the rearranging of the characters ‘*x*’ and ‘8’ by the MathEx rules.

XML Representation

```
<m:func>
    <m:fName>
        <m:sSub>
            <m:e>
                <m:r><m:t>log</m:t></m:r>
            </m:e>
            <m:sub>
                <m:r><m:t>x</m:t></m:r>
            </m:sub>
        </m:sSub>
    </m:fName>
    <m:e>
        <m:r><m:t>8</m:t></m:r>
    </m:e>
</m:func>
```

(a)

MathEx Analyzed Output

```
<m:func>
    <thsound>ล็อก </thsound>
    <thsound>8</thsound>
    <thsound>ฐาน</thsound>
    <thsound>x</thsound>
</m:func>
```

(b)

Figure 6.6 An example of the rearranged MathEx analyzed output.

6.3 Math-Thai Mapping

In the third module, Math-Thai Mapping, each math element is mapped into its corresponding Thai sound. All English and Greek alphabets, math symbols, numerals, and abbreviations are mapped into their Thai pronunciation patterns. As recalling, some mappings are embedded in parts of MathEx Structure Analysis module for particular string. For example, in the expression, $\sum_{i=1}^{n} i$, the Greek alphabet '$\sum$ ' is mapped into the word "ซัมเมชั่น (/sam-may-chan/)" that is transliterated word of "summation" which is processed in the previous module. Moreover, trigonometric functions, e.g., the string "sin", "cos", and "tan", and abbreviations of math terms, e.g., "lim" and "log", are mapped into their corresponding Thai pronunciation patterns in the previous module as well.

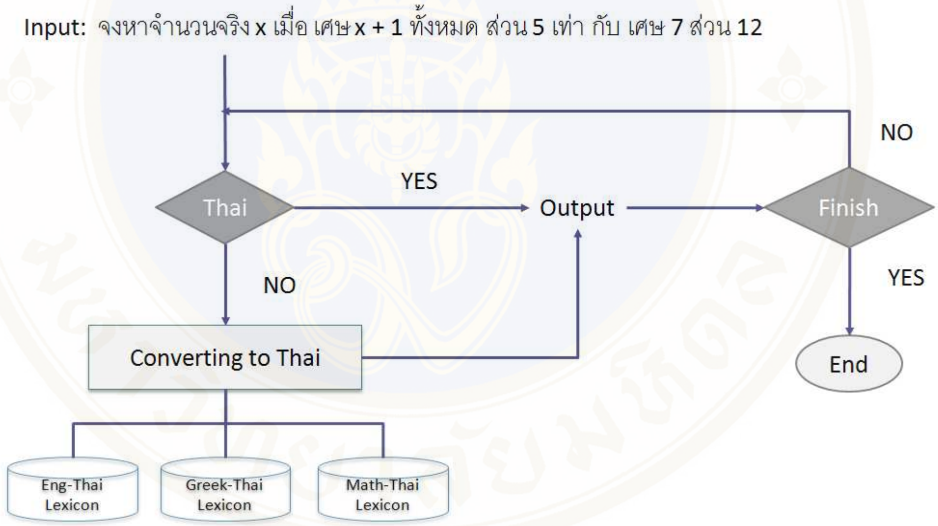


Figure 6.7 A Thai mapping diagram.

Except the particular string, all English and Greek alphabets, and math symbols are mapped into their corresponding Thai pronunciation patterns (see Appendix C), character by character. Search and replace functions of string processing in XSLT are applied. The XSLT mapping is not complete since XSLT is a programming language optimized for processing the XML markup, not for string (Mangano, 2002). The mapping replaces nothing in some alphabets or symbols. Thus, after XSLT mapping, the output string is scanned once from left to right while English-Thai, Greek-Thai, and Math-Thai lexicons are examined. Whenever, a match is found, the alphabet or symbol is transformed into its corresponding Thai pronunciation pattern. The searching and matching will process until the end of the input string or until no foreign alphabets or symbols in the string as illustrated in Figure 6.7.

Converting a number into their corresponding Thai pronunciation patterns needs a set of rules as described in section 4.2. We found that a stochastic knowledge-based the Thai TTS system (Narupiyakul et al., 2005) is comprised of an intelligent rules to perfectly convert whole numbers and decimals into the Thai pronunciation patterns. This module applies these rules to correctly read all numbers.

Moreover, an abbreviation appearing in a math document could refer to a measurement unit and a math term. Examples are shown in Table 6.1. In this module, all abbreviations are mapped into their full forms as well. However, some math terms are read by spelling the term, for example “ห.ร.ม. (GCD)” is be mapped as “หอ รอ มอ (/hŏr ror mor/, GCD)” (see Appendix F).

Table 6.1 Examples of abbreviations in a math document.

Abbreviation	*Full form*	*Description*
ซม.	เซน-ติ-เมตร	Centimeter
กก.	กิ-โล-กรัม	Kilogram
ตร.ม.	ตา-ราง-เมตร	Squared meter
มล.	มิล-ลิ-ลิตร	Milliliter
ห.ร.ม.	หอ รอ มอ (หาร ร่วม มาก)	GCD (Greatest Common Divisor)
ค.ร.น.	คอ รอ นอ (คูณ ร่วม น้อย)	LCM (Least Common Multiple)

Figure 6.8 illustrates the mapping output of the previous example. An English alphabet ‘x’ and an operator ‘+’ are mapped into “เอ๊กซ์ (/èk/)” and “บวก (/bùak/)”, one by one character by matching English-Thai rules and Math-Thai rules, respectively. The numbers, ‘1’, ‘5’, ‘7’, and ‘12’, are mapped into “หนึ่ง (/nèung/)”, “ห้า (/hâa/)”, “เจ็ด (/jèt/)”, and “สิบสอง (/sìp-sŏng/)” by the number rules. When the Mapping module has completed processing, the system will remove all tags of the XML format to retrieve only Thai writing string and Thai pronunciation patterns and forward into the next module.

Mapped Output

```
<thsound>จงหาจำนวนจริง</thsound>
<thsound>เอ็กซ์</thsound>
<thsound>เมื่อ</thsound>
<m:f>
     <thsound>เศษ </thsound>
     <thsound>เอ็กซ์</thsound>
     <thsound>บวก</thsound>
     <thsound>หนึ่ง</thsound>
     <thsound>ทั้งหมด</thsound>
     <thsound>ส่วน </thsound>
     <thsound>ห้า</thsound>
</m:f>
<thsound>เท่า กับ  </thsound>
<m:f>
     <thsound>เศษ </thsound>
     <thsound>เจ็ด</thsound>
     <thsound>ส่วน </thsound>
     <thsound>สิบสอง</thsound>
</m:f>
```

Figure 6.8 An example of the mapping result.

6.4 Speech Synthesis

Speech Synthesis module, the last module generates Thai speech output for the input string using a stochastic knowledge-based Thai TTS system (Narupiyakul et al., 2005). This system applies a rules-based strategy to analyze a Thai syllable, a basic pronunciation unit of Thai, and to generate sounds by a concatenation technique. The system contains Thai syllable analysis rules which are comprised of the tone analysis rules[10], consonant analysis rules, linking analysis rules, and syllable structure rules. The Thai syllable analysis rules deal with Thai writing strings to separate the syllables from the Thai writing strings, find the components of the syllables, and map them into Thai pronunciation characters. Therefore, Thai writing strings from Thai text of an original math text input are transformed into their corresponding Thai pronunciation patterns by employing the Thai syllable analysis rules.

Furthermore, the system initially processes Thai writing strings to query the special words in the exception dictionary, which contains the phonetic symbols of

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[10] Thai is a tonal language. Each syllable has a choice between five distinct tones: low, mid, rise, high, and falling. Its meaning changes with different tones.

some special words. These words are distinctively pronounced. They are not represented the correct pronunciation according to the syllable analysis rules. In math text, there are loads of these words since some words are loaned or transliterated from other languages. For example, the word “เวกเตอร์ (/wâyk-dtêr/)” is transliterated from “vector”. Its writing is hidden the Thai tone markers. To handle these words, the exception dictionary is extended by adding their special phonetic symbols for these math words. Moreover, this system contains a set of rules to convert whole numbers and decimals into their Thai pronunciation patterns as described in section 4.2 and 6.3.

To synthesize the natural Thai speech of the system, the Thai sound unit inventory was designed to select the suitable units. In addition, the TD-PSOLA model (Hamon, Moulines & Chapentier, 1989) was employed to prepare the recorded speech units, select the smooth concatenation, and provide the good control of pitch and duration. As adapting for *i-Math*, some Thai sound units are added to the Thai sound unit inventory, particularly transliterated sounds, e.g., /wâyk/, /dtêr/, and /máyt/. Figure 6.9 presents the generated Thai pronunciation pattern for the input in Figure 6.3. The bold typefaces indicate the MathEx analysed result while the highlights show the mapped output.

Input	*Thai pronunciation output*
จงหาจำนวนจริง x เมื่อ $\frac{x+1}{5} = \frac{7}{12}$	จง หา จำ นวน จริง เอ็กซ์ เมื่อ เศษ เอ็กซ์ บวก หนึ่ง ทั้ง หมด
(Find a real number x that $\frac{x+1}{5} = \frac{7}{12}$)	ส่วน ห้า เท่า กับ เศษ เจ็ด ส่วน สิบ สอง
(a)	(b)

Figure 6.9 An example of the Thai pronunciation result.

6.5 Reading Examples by *i-Math*

In this section, we present the results of the applying *i-Math* to some example math problems. Thai text and math expressions of Example 1 are separately shown in the first column of Table 6.2. The XML extracted output is show in the second column where the normal text display inside <w:r> tags and math expressions created by an equation editor is inside <m:oMath> tags and its children as described in section 5.1 and Appendix D. The third column illustrates the output after applying the MathEx rules e.g., the word “เศษ (/sàyt/, numerator)”, “ส่วน (/sùan/, denominator)”, and “ทั้งหมด (/táng mòt/, all)” are added in the specific locations of a fraction as discussed in section 4.2 and 6.2. Each foreign alphabet including abbreviations (if any) in the fourth column is mapped for its corresponding word in Thai (see section 6.3 and Appendix C). All pronunciation patterns of each word are shown in the last column.

Example 1

Thai: ถ้า $\frac{x+1}{6} = \frac{2}{3}$ ค่าของ $x + 5$ คือเท่าไร

English: If $\frac{x+1}{6} = \frac{2}{3}$, what is the value of $x + 5$?

In generating the Thai pronunciation patterns for Example 2, once all math expressions are analyzed and inserted the required words into the right places (the third column, Table 6.3). The word “ล็อก” is added to clarify the logarithm functions. The word “รากที่สอง”, “เศษ (/sàyt/, numerator)” and “ส่วน (/sùan/, denominator)” are also added as we discussed in section 4.2. The MathEx rules process the expressions and their sub-expressions even thought the expressions consist of several expressions or sub-expressions. For example, the expression “$\log\sqrt{\frac{4}{5}}$” is comprised of a sub-expression “$\sqrt{\frac{4}{5}}$”. Also, “$\sqrt{\frac{4}{5}}$” consists of a sub-expression “$\frac{4}{5}$”. The last row of Table 6.3 illustrates the results of each step in producing pronunciation patterns in Thai of the expression “$\log\sqrt{\frac{4}{5}}$”.

Example 2

Thai: ให้ $\log 2 = 0.3010$ และ $\log 5 = 0.6990$ จงหาค่าของ $\log\sqrt{\frac{4}{5}}$

English: Let $\log 2 = 0.3010$ and $\log 5 = 0.6990$. Find the value of $\log\sqrt{\frac{4}{5}}$.

Table 6.2 The *i-Math* steps applied to the math problem of Example 1.

Input	*XML extracted output*	*MathEX analyzed output*	*Mapped output*	*Pronunciation pattern*
ถ้า	<w:r><w:t>ถ้า</w:r></w:t>	<thsound>ถ้า</thsound>	<thsound>ถ้า</thsound>	/tâa/ (ถ้า)
$\frac{x+1}{6}=\frac{2}{3}$	<m:oMath>	<m:f>	<m:f>	/sàyt/ (เศษ)
	<m:f>	<thsound>เศษ</thsound>	<thsound>เศษ</thsound>	/èk/ (เอ็กซ์)
	<m:num>	<thsound>x</thsound>	<thsound>เอ็กซ์</thsound>	/bùak/ (บวก)
	<m:r><m:t>**x**</m:t></m:r>	<thsound>+</thsound>	<thsound>บวก</thsound>	/nèung/ (หนึ่ง)
	<m:r><m:t>**+**</m:t></m:r>	<thsound>1</thsound>	<thsound>หนึ่ง</thsound>	/táng mòt/ (ทั้ง หมด)
	<m:r><m:t>**1**</m:t></m:r>	<thsound>ทั้งหมด/thsound>	<thsound>ทั้งหมด</thsound>	/sùan/ (ส่วน)
	</m:num>	<thsound>ส่วน</thsound>	<thsound>ส่วน</thsound>	/hòk/ (หก)
	<m:den>	<thsound>6</thsound>	<thsound>หก</thsound>	/tâo gàp/ (เท่า กับ)
	<m:r><m:t>**6**</m:t></m:r>	</m:f>	</m:f>	/sàyt/ (เศษ)
	</m:den>	<thsound>=</thsound>	<thsound>เท่ากับ</thsound>	/sŏng/ (สอง)
	</m:f>	<m:f>	<m:f>	/sùan/ (ส่วน)
	<m:r><m:t>**=**</m:t></m:r>	<thsound>เศษ</thsound>	<thsound>เศษ</thsound>	/săam/ (สาม)
	<m:f>	<thsound>2</thsound>	<thsound>สอง</thsound>	
	<m:num>	<thsound>ส่วน</thsound>	<thsound>ส่วน</thsound>	
	<m:r><m:t>**2**</m:t></m:r>	<thsound>3</thsound>	<thsound>สาม</thsound>	
	</m:num>	</m:f>	</m:f>	
	<m:den>			
	<m:r><m:t>**3**</m:t></m:r>			
	</m:den>			
	</m:f>			
	</m:oMath>			
ค่าของ	<w:r><w:t>ค่าของ</w:r></w:t>	<thsound>ค่าของ</thsound>	<thsound>ค่าของ</thsound>	/kâa kŏng/ (ค่า ของ)
$x+5$	<w:r><w:t>x</w:t></w:r>	<thsound>x</thsound>	<thsound>เอ็กซ์</thsound>	/èk/ (เอ็กซ์)
	<w:r><w:t>+</w:r></w:t>	<thsound>+</thsound>	<thsound>บวก</thsound>	/bùak/ (บวก)
	<w:r><w:t>5</w:r></w:t>	<thsound>5</thsound>	<thsound>ห้า</thsound>	/hâa/ (ห้า)
คือเท่าไร	<w:r><w:t>คือเท่าไร</w:r></w:t>	<thsound>คือเท่าไร/thsound>	<thsound>คือเท่าไร</thsound>	/keu tâo rai/ (คือ เท่า ไร)

Table 6.3 The *i-Math* steps applied to the math problem of Example 2.

Input	***XML extracted output***	***MathEX analyzed output***	***Mapped output***	***Pronunciation pattern***
ให้	<w:r><w:t>ให้</w:r></w:t>	<thsound>ให้</thsound>	<thsound>ให้</thsound>	/hâi/ (ให้)
log 2 = 0.3010	<m:oMath> <m:func> <m:fName> <m:r><m:t>log</m:t></m:r> </m:fName> <m:e> <m:r><m:t>2</m:t></m:r> </m:e> </m:func> <m:r><m:t>=</m:t></m:r> <m:r><m:t>0.3010</m:t></m:r> </m:oMath>	<m: func > <thsound>ล็อก</thsound> <thsound>2</thsound> </m: func > <thsound>=</thsound> <thsound>0.3010</thsound>	<m: func > <thsound>ล็อก</thsound> <thsound>สอง</thsound> </m: func > <thsound>เท่ากับ</thsound> <thsound>ศูนย์ จุด สาม ศูนย์ หนึ่ง ศูนย์</thsound>	/lók/ (ล็อก) /sŏng/ (สอง) /tâo gàp/ (เท่า กับ) /sŏon jùt săam sŏon nèung sŏon/ (ศูนย์ จุด สาม ศูนย์ หนึ่ง ศูนย์)
และ	<w:r><w:t>และ</w:r></w:t>	<thsound>และ</thsound>	<thsound>และ</thsound>	/ láe/ (และ)
log 5 = 0.6990	<m:oMath> <m:func> <m:fName> <m:r><m:t>log</m:t></m:r> </m:fName> <m:e> <m:r><m:t>5</m:t></m:r> </m:e> </m:func> <m:r><m:t>=</m:t></m:r> <m:r><m:t>0.6990</m:t></m:r> </m:oMath>	<m: func > <thsound>ล็อก</thsound> <thsound>5</thsound> </m: func > <thsound>=</thsound> <thsound>0.6990</thsound>	<m: func > <thsound>ล็อก</thsound> <thsound>ห้า</thsound> </m: func > <thsound>เท่ากับ</thsound> <thsound>ศูนย์ จุด หก เก้า เก้า ศูนย์</thsound>	/lók/ (ล็อก) /hâa/ (ห้า) /tâo gàp/ (เท่า กับ) /sŏon jùt hòk gâo gâo sŏon/ (ศูนย์ จุด หก เก้า เก้า ศูนย์)
จงหาค่าของ	<w:r><w:t>จงหาค่าของ</w:r></w:t>	<thsound>จงหาค่าของ</thsound>	<thsound>จงหาค่าของ</thsound>	/jong hăa kâa kŏng/ (จง หา ค่า ของ)

(continued on next page)

Table 6.3 *(continued)*

Input	*XML extracted output*	*MathEX analyzed output*	*Mapped output*	*Pronunciation pattern*
$\log\sqrt{\frac{4}{5}}$	<m:oMath>	<m: func >	<m: func >	/lók/ (ล็อก)
	<m:func>	<thsound>ล็อก</thsound>	<thsound>ล็อก</thsound>	/râak têe (ราก ที่ สอง
	<m:fName>	<m:rad>	<m:rad>	sŏng ของ)
	<m:r><m:t>log</m:t></m:r>	<thsound>รากที่สองของ</thsound>	<thsound>รากที่สองของ</thsound>	kŏng/
	</m:fName>	<m:f>	<m:f>	/sàyt/ (เศษ)
	<m:e>	<thsound>เศษ</thsound>	<thsound>เศษ</thsound>	/sèe/ (สี่)
	<m:rad>	<thsound>4</thsound>	<thsound>สี่</thsound>	/sùan/ (ส่วน)
	<m:deg/>	<thsound>ส่วน</thsound>	<thsound>ส่วน</thsound>	/hâa/ (ห้า)
	<m:e>	<thsound>5</thsound>	<thsound>ห้า</thsound>	
	<m:f>	</m:f>	</m:f>	
	<m:num>	</m:rad>	</m:rad>	
	<m:r><m:t>4</m:t></m:r>	</m: func >	</m: func >	
	</m:num>			
	<m:den>			
	<m:r><m:t>4</m:t></m:r>			
	</m:den>			
	</m:f>			
	</m:e>			
	</m:rad>			
	</m:e>			
	</m:func>			
	</m:oMath>			

CHAPTER VII

I-MATH: AN EDUCATIONAL TOOL

Educational technologies or assistive technologies in education allow the blind and visually impaired (VI) students to have the opportunities to use the devices that help them focus on their study. There are special tools (e.g., physical equipments, electronic devices, and computer software) that are available for the students who are blind and VI. The blind and VI students can benefit from the assistive devices including talking calculators, textbooks on tapes, Braille books, talking dictionary, and tape recorders for talking note. For computer technologies, screen magnifier systems allow users to manipulate the appearance of text and image on the computer screen. Braille translation systems can be easily translated the plain text into Braille while Braille embossers can be connected to a computer to produce the hard-copy Braille. Optical character recognition systems allow the users access text in the combination with a screen reader to scan the text documents. Speech synthesizer systems operated with the screen reader systems produce the voice output on the computer. The synthesizer can read plaint text aloud. The current technologies allow the blind and VI students to access the printed text via the various means. The blind and VI students can maintain their independences during studying and practicing. The text-to-speech (TTS) system with the capability to read the math expressions is one of the powerful technologies that enable the blind and VI students in practicing and studying mathematics on their own.

We aim to provide an educational technology for the Thai blind and VI students to access mathematics via the voice synthesis. *i-Math* can read the math expressions and Thai text aloud. In this chapter, the roles of *i-Math* in education are discussed in section 7.1 and the usages of *i-Math* are described in section 7.2.

7.1 Roles of *i-Math* in Education

There are a number of possibilities of using *i-Math* to provide the opportunities for studying both inside and outside the classroom for the blind and VI students. Some possibilities are discussed below.

7.1.1 Math Teachers and Classroom

In a classroom, the conventional print-based materials such as textbooks, handouts, activity sheets, and tests present a barrier to the blind and VI students. To overcome such a barrier, *i-Math* must be incorporated into the materials that are already in digital forms. The digital materials augmented with *i-Math* allow the students with the different needs and the learning styles to access the same materials equally. The following are examples of how teachers can utilize *i-Math* in their classrooms.

- Create the classroom handouts, assignments, and exercises using MS Word so that the students can listen through *i-Math*.
- Look for the supplemental classroom materials on the Internet, download the files, and convert them into “*.docx” files to be used in the classroom with *i-Math*.
- Request digital files of the purchased textbooks, and then create an instant audio version of these textbooks simply and conveniently using *i-Math*.
- Have the students take tests via a computer. Create the tests in a digital form using MS Word, students can then use *i-Math* to read the test at any speed according to their own needs.

The key benefit of using *i-Math* during classes is that it provides the students a sense of independence and confidence that they do not have without the use of this tool. The other benefit is that teachers and teaching assistants can focus on other weaknesses of a student or other students who might have a higher level of need, instead of having to read text to the blind and VI students.

7.1.2 Blind and VI Students at Home

i-Math plays a vital role in making computers accessibility as a tool to a student at home. It has opened up the possibilities for the blind and VI students to study from the available materials and practice at their own pace at whatever time they choose. The students have no longer to wait for somebody to read to them. They can use *i-Math* in the following ways.

- Use *i-Math* to listen to the course materials, e.g., class notes, textbooks, and able to repeat the reading anytime they want.
- Create audio version from the course material or chosen materials for later use.
- Read the math problem exercises and practice on their own pace.
- Look for the materials and resources that are available on the Internet (e.g., CAI, e-books, and intelligent tutoring systems) and study using *i-Math*.
- Use *i-Math* to proofread the solutions or answers of the problems before turning them in, and correct any mistake if necessary.

With *i-Math*, students can enjoy their newfound ability to read anytime, anywhere. *i-Math* not only helps the blind and VI to build the independence text access on their own schedule, but also build confidence and self-esteem.

7.2 *i-Math* Usage

A primary application of *i-Math* is the system that allows the users to access math materials at their own pace. Since *i-Math* was aimed at being an educational tool to enable not only blind and VI people but also sighted people to individually and conveniently access mathematics. The speech conversion process and user interface of *i-Math* must be designed for their convenience, be able to display the clear information, and be easy to use.

Recently, the Internet is wildly used not only by sighted people but also by blind and VI people. The blind and VI people can access Webpage to get information with screen reader software. Many math materials are also available on the Internet. Math notations or expressions on Webpage are in various formats, e.g. images, linear text, and special HTML. Images present the displayed equations but the screen reader software cannot recognize the structure and their character appearances so that *i-Math* reads nothing aloud. For displaying math expressions with linear text, for example, the expression,$10^{\log x}$, is displayed as "10^(log x)" where '^' denotes "to the power of". With this display, it can present only uncomplicated math notation, *i-Math* can read character by character.

Putting both simple and complicated math expressions on Web, MathML (Mathematical Maekup Language), which is an XML application, is introduced by W3C for describing math notations. MathML has been attempted and developed to create math notations to display on the Internet. However, a few Webpage are available in the MathML format since web browsers for supporting MathML are limited. A major web browsers support MathML is Firefox while Internet Explorer does not support MathML natively. Therefore, we first pay attention to develop *i-Math* to automatic read math notations system support XML for a MS Word format as an input since a MS Word processing allows users to easily create math expressions and quite familiar to the use of MS Words. In addition, several and various math documents created by MS Word processing are available on Internet and allow users to efficiently retrieve the information if they want. Fortunately, the extension of *i-Math* to read the math expressions in the MathML format is not difficult since the structure of XML for a MS Word format and MathML are quite similar.

The implementation of *i-Math* used Microsoft Visual Basic supporting a Window platform. The interface of *i-Math* is comprised of three main windows: input, speech output, and file transformation windows shown in Figure 7.1 - 7.3.

The input window was designed to facilitate users to select the documents they want (Figure 7.1) in the ".docx" format. In this input window, the users can choose either the "ฟังทีละประโยค (listen to each sentence)" option or the "แปลงเป็นไฟล์

เสียง (convert into wave form)" option by checking the lists in the "รูปแบบการแสดงผล (output format)" part of this window.

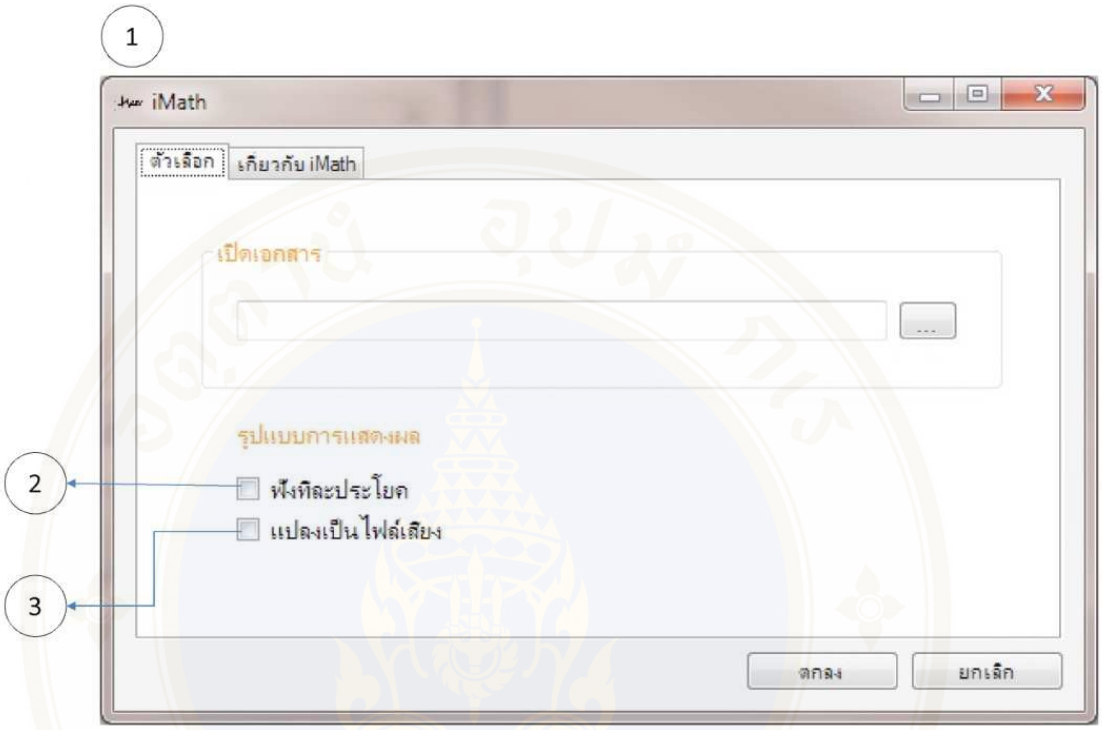

Figure 7.1 The user interface for the user input.

When choosing the "ฟังทีละประโยค (listen to each sentence)" option, a new speech output window (Figure 7.2) will open where the users can listen to each sentence within the document. The users can listen to which sentences they want by choose the number '1', '2', and so on. When the users select the sentence, the Thai pronunciation output will be displayed in the "ประโยค (sentence)" box of this window. Clicking the "อ่าน (read)" button, its speech of this sentence will be rendered during listening the user can pause the audio for better understanding the utterances if they want by the "หยุดชั่วคราว (pause)" button. The "บันทึกเสียง (save wave file)" button allows the users to keep this speech into the wave format for later use. Clicking the "บันทึกเสียง (save wave file)" button, the file transformation window (Figure 7.3) will open. This window allows the users to create the speech output in the wave format.

When choosing the "แปลงเป็นไฟล์เสียง (convert into wave form)" option, the users can save the converted documents into the wave forms without listening.

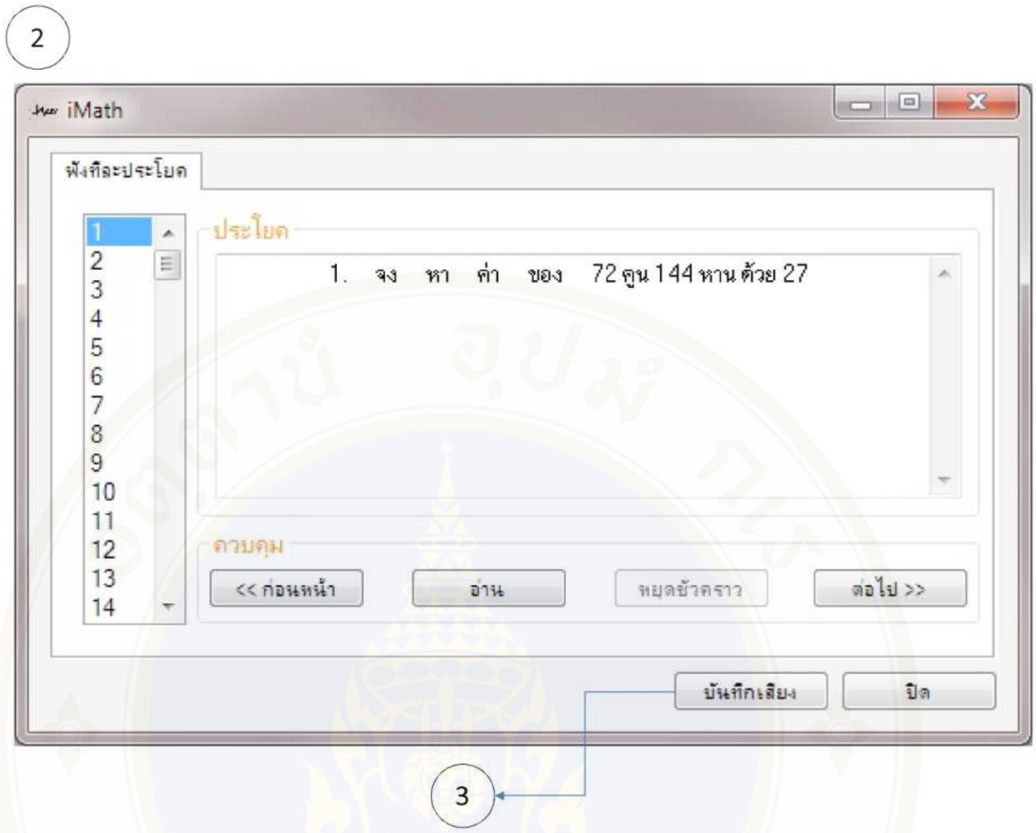

Figure 7.2 The user interface for the speech output.

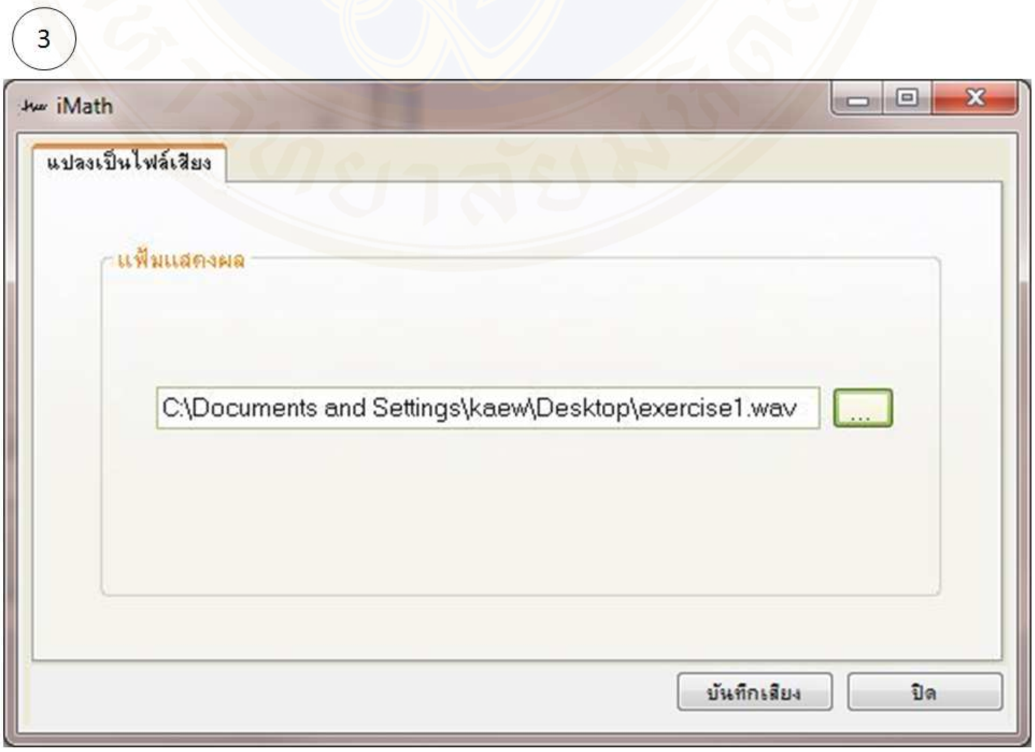

Figure 7.3 The user interface for the file transformation output.

CHAPTER VIII

I-MATH EVALUATIONS AND RESULTS

i-Math was evaluated in three aspects: (i) intelligibility, (ii) overall speech quality, and (iii) user satisfaction. The details of each evaluation are described in this chapter. *i-Math* was tested to generate the accurate speech (intelligibility and overall speech quality) for a math problem sample set and its usage (user satisfaction) was determined by voluntary participants, both students and teachers. The details and the evaluation results are explained in the following section.

8.1 *i-Math* Evaluations

To illustrate the performance of *i-Math*, the system was tested and evaluated in three aspects: intelligibility, overall speech quality, and user satisfaction to answer the following questions:

- Whether *i-Math* can generate the correct pronunciations in each word.
- Whether listeners can understand the text read by *i-Math*.
- Whether *i-Math* can produce the acceptant speech.
- Whether *i-Math* can facilitate blind and VI people's access to math materials.

The first two questions will be described more details in section 8.1.1. Details of the third and fourth questions are explained in section 8.1.2 and 8.1.3, respectively.

8.1.1 Intelligibility

We first evaluate whether *i-Math* can generate the correct pronunciations in each word. The pronunciations generated by *i-Math* are compared against the original math text in the text form. The number of correct words which are correctly pronounced is scored to evaluate the pronunciation correctness measurement: *precision (P), recall (R)* and *F-score* as shown below:

$$Precision\ (P) = \frac{Number\ of\ correct\ words\ in\ the\ pronunciation\ of\ i{-}Math}{Number\ of\ words\ in\ the\ pronunciation\ of\ i{-}Math},$$

$$Recall\ (R) = \frac{Number\ of\ correct\ words\ in\ the\ pronunciation\ of\ i{-}Math}{Number\ of\ words\ in\ the\ reference},$$

$$F\text{-}score = \frac{2PR}{P+R}.$$

The precision (a measure of exactness) is the fraction of correct words among all words pronounced by *i-Math*. The precision is 1. It means that all words pronounced by *i-Math* are correct. The recall (a measure of completeness) is the fraction of correct words among those all words in original input. Similarly, if the recall is 1 that refers to *i-Math* can correctly generate for all input words. As the *F-score* is the harmonic mean of *P* and *R*.

Then, both sighted and blind listeners with having math knowledge were asked to carefully listen to the utterances of *i-Math* and transcribe what they have heard. We aim to measure how well listeners can understand the text read by the system (Huang, et al., 2001). Some simply questions, such as

- "What are *the denominator of the fraction* you have heard?", or
- "What are *the index of the power* you have heard?", or
- "What are *the expressions beneath the radical sign* that you have heard?"

were usually used for clarifying the same understanding between a listener and a researcher. Once, the number of words heard correctly is used to calculate the standard measurements: P, R, and F-score. In this case, the precision is the fraction of correct words among all words transcribed by listeners and the recall is the fraction of correct words among those all words in the original input as displayed below:

$$Precision\ (P) = \frac{Number\ of\ correct\ words\ in\ the\ transcription}{Number\ of\ words\ in\ the\ transcription},$$

$$Recall\ (R) = \frac{Number\ of\ correct\ words\ in\ the\ transcription}{Number\ of\ words\ in\ the\ reference}.$$

In evaluation, we used Thai math problems which were collected from several mathematic practice books and some existing math questions extracted from

Internet. Examples of the test, math problems, are illustrated in Table 8.1 (see all items in Appendix G.1).

Table 8.1 Examples of math test used in this evaluation.

Category	***No***	***Mathematical questions***
Basics	01.	จงหาค่าของ $72 \times 144 \div 27$ (Find the value of $72 \times 144 \div 27$.)
Fractions	05.	แม่ค้ามีปลาแห้ง$10\frac{1}{2}$ กิโลกรัมแบ่งใส่ถุง ถุงละ $\frac{1}{4}$ กิโลกรัมจะแบ่งใส่ถุงได้ทั้งหมดกี่ถุง (A seller have dried fish $10\frac{1}{2}$ kilograms, divided into bags each bags weighs $\frac{1}{4}$ kilograms. How many bags of dried fish does the seller have?)
Powers	09.	จงหาค่าของ $3^2 \times 5^2 \times 7$ (Find the value of $3^2 \times 5^2 \times 7$.)
Trigonometry	14.	ถ้า $\sin A = \frac{4}{5}$ แล้ว $\tan A$ มีค่าเท่าใด (If $\sin A = \frac{4}{5}$, what is $\tan A$?)
Logarithms	17.	จงหาค่าของ $\log_5 \sqrt{125}$ (Find the value of $\log_5 \sqrt{125}$.)
	18.	ให้ $\log_{27} 5 = \mathrm{a}$ และ $\log_5 8 = \mathrm{b}$ จงหาค่าของ $\log_3 2$ (Let $\log_{27} 5 = \mathrm{a}$ and $\log_5 8 = \mathrm{b}$, what is $\log_3 2$?)
	19.	กำหนดให้ $\log 2 = 0.3010$ และ $\log 5 = 0.6990$ จงหาค่าของ $\log\sqrt{\frac{4}{5}}$ (Let $\log 2 = 0.3010$ and $\log 5 = 0.6990$, what is $\log\sqrt{\frac{4}{5}}$?)
Radicals	20.	จงหาค่าของ $\sqrt{112} + \sqrt[3]{343} - \sqrt{448}$ (Find the value of $\sqrt{112} + \sqrt[3]{343} - \sqrt{448}$.)
Summations	25.	จงหาค่าของ $\sum_{i=1}^{50} \mathrm{i}$ (Find the value of $\sum_{i=1}^{50} \mathrm{i}$.)
Vectors	28.	ให้ $\vec{u} = 2\vec{\imath} - 3\vec{\jmath}$ และ $\vec{a} = \vec{\imath} + \vec{\jmath}$ จงหา $\vec{u} - \vec{a}$ (Let $\vec{u} = 2\vec{\imath} - 3\vec{\jmath}$ and $\vec{v} = \vec{\imath} + \vec{\jmath}$, what is $\vec{u} - \vec{a}$?)
Limits	31.	จงหาค่าของ $\lim_{x \to 0} \sqrt{2\mathrm{x} + 3}$ (Find the value of $\lim_{x \to 0} \sqrt{2\mathrm{x} + 3}$.)
Integrals	34.	จงหาค่าของ $\int (x^2 - 2x)dx$ (Let f is a function that $x^2 + x - 1$, what is $\int_0^1 f(x)dx$?)

A sample set was developed based on the time and number of sentences that the students can concentrate, and the time frame that the schools can provide. The sample test contains 35 math texts, math problems, categorizing into ten groups:

- Basics
- Fractions
- Powers
- Radicals

- Vectors
- Trigonometry
- Logarithms
- Summations
- Limits
- Integrals

Each category consists of 2 – 5 items that present the variety of expressions that *i-Math* can handle. Each item contains both Thai text and math expressions. Their English translations are provided in parenthesis underneath. The different items in the same category represent the different math expressions. For example, 17^{th} – 19^{th} items are logarithms. The item 17^{th} contains the logarithm combined with the radicals. The item 18^{th} is the simple logarithm expressions with their bases while the simple logarithm expressions without the bases and the complicated logarithm combined with the radical of a fraction are in the item 19^{th}.

8.1.2 Overall Speech Quality

Besides intelligibility measurement, the *i-Math* speech quality must be evaluated whether *i-Math* can produce an acceptable speech. In this research, we employed *Mean Opinion Score* (MOS) and *Listening Effort Scale* (LES).

MOS is a human-subject judgment testing for TTS providing a numerical indication of the perceived quality of speech. The MOS determines whether the speech output is acceptable. The listeners, blind and VI participants, were asked to rate each math problem on a scale of 1 to 5, where 1 is bad and 5 is excellent. All scores are summed, and a mean score is derived, which is meant to represent the overall speech quality of the system. Typically, the mean score of 4.0 to 4.5 is referred to toll quality or complete satisfaction while the score below 3.5 are unacceptable by listener or inadequate level of naturalness (Huang, et al., 2001).

LES is to measure the listener's effort to understand the meaning of math text. The listeners assign the score of 1 to 5 point scale (Table 8.2) to assess the effort required to understand the meaning of each math problem. These scales are standard and are defined by The International Telecommunication Union (ITU) P.800 (Huang, et al., 2001). Similar to the MOS, the scores are averaged to represent listener's effort. Lower score means the more exertion to understand the meaning of the sentence.

Table 8.2 Score in Listening Effort Scale (Huang, et al., 2001).

Effort required to understand the meaning of sentence	***Score***
Complete relaxation possible; no effort required	5
Attention necessary; no appreciable effort required	4
Moderate effort required	3
Considerable effort required	2
No meaning understood with any feasible effort	1

8.1.3 User Satisfaction

Turning *i-Math* into an educational tool for blind and VI students is our one primary goal. In addition to *i-Math* performances evaluations, we also investigate whether *i-Math* can facilitate the blind and VI people's access to math materials. An interview was used to follow up the response of blind and VI participants after using our system.

Table 8.3 Questionnaire Items.

Teachers	***Students***
I would find that *i-Math* helped my students in reading math handouts, exercises, and tests.	I would find that *i-Math* helped me to read math expressions.
I would find that *i-Math* helped my students to pay more attentions in studying mathematics.	I would find that *i-Math* helped me to pay more attentions in studying mathematics.
I would find that *i-Math* was helpful to use with the effective available math CAI.	I would find that *i-Math* reduced time consumed in practicing mathematics.
I would find that *i-Math* could enhance the ability of my students in studying on their own.	I would find that *i-Math* was useful in my studying mathematics.
	I would find that *i-Math* was easy to use.
I would find that *i-Math* was easy to use.	I am willing to use *i-Math* in studying mathematics.
I am willing to use *i-Math* in my class.	
I will recommend *i-Math* to others.	I will recommend *i-Math* to my friends

It was found that the Technology Acceptance Model (TAM) by Davis (1989) is one of the most information systems theories used to measure how users accept and use a technology when the users are presented with a new technology.

Davis introduced perceived usefulness and perceived ease of use to indicate the users' beliefs. The perceived usefulness was defined as the degree to which a person believes that the use of a particular system would enhance his or her job performance while the perceived ease of use referred to the degree to which a person believes that the use of a particular system would be free of effort.

We adapted the questionnaire items for the participants, teachers, and students, based on TAM for perceived usefulness and perceived ease of use toward *i-Math* (Table 8.3, see Thai version in Appendix H.1 and Appendix H.2). Our designed questionnaire was approved by four experts in mathematics, computer education, educational assessment, and special education for disabilities. The Cronbach's alpha measurement (0.83) indicates that the designed questionnaire is reliable. After intelligibility and speech quality evaluations, the participants were asked to rate on a 1 to 5 point rating scale (5-stringly agree, 4-agree, 3-neither, 2-disagree, and 1-strongly disagree). After the questionnaire was completed, the items were analyzed separately. All scores are presented by the frequency (which is the value in a scale which occurs most often), means and standard deviations. In addition, the participants were asked to give additional comments and suggestions.

8.2 Experimental Results and Discussions

We conducted the experiment by sighted, blind, and VI participants. All participants have mathematical knowledge in high school level. All participants who are high school students (sighted, blind, and VI students), graduated students in computer education program and school teachers were ranged in age from 17 to 38 (*mean* = 25.15, *sd* = 5.33)[11]. The participants consisted of ten sighted participants (five males and five females), six blind (one male and five females), and four VI (two males and two females). During data collecting process, audio recording was allowed to record all conversations engaged during the process. The participants were asked to

[11] According to our collecting data, we can conclude that learning levels of blind and VI students are generally lower than those of ordinary students at the same age. The reason is a barrier to access the information or knowledge, rather than their leaning abilities.

say aloud what they thought and allowed to take a note (either in Braille or normal text) if they preferred.

The evaluated results will be discussed in terms of *intelligibility results*, *overall speech quality results*, and *user satisfaction results*. In the intelligibility evaluation, section 8.2.1, we asked the participants to carefully listen to *i-Math* and transcribe exactly what they have heard. Then, the participants were asked to rate the scale for the overall speech quality and user satisfaction evaluation discussed in section 8.2.2 and 8.2.3.

8.2.1 Intelligibility Results

The *i-Math* intelligibility was tested to generate Thai speech for math problems in ten different groups (described in section 8.1.1). We first compared the pronunciations generated by *i-Math* against the original questions in the text form. Then, the listeners' transcriptions were compared with the original questions in the text form. This section will present some a fragment of the intelligibility evaluation. A complete evaluation is provided in Appendix G.2.

i-Math Pronunciations

Figure 8.1 illustrates the 20th original math text input (IN), an original math text in text form (OM) comparing with their pronunciation generated by i-Math (PM). All word pronunciations generated for the math problems, for example IN20, are correct.

IN20	จงหาค่าของ $\sqrt{112} + \sqrt[3]{343} - \sqrt{448}$
OM	จงหาค่าของ รากที่ สอง ของ หนึ่ง ร้อย สิบ สอง บวก รากที่ สาม ของ สาม ร้อย สี่ สิบ สาม ลบ รากที่ สอง ของ สี่ ร้อย สี่ สิบ แปด
PM	จงหาค่าของ ราก ที่ สอง ของ หนึ่ง ร้อย สิบ สอง บวก ราก ที่ สาม ของ สาม ร้อย สี่ สิบ สาม ลบ ราก ที่ สอง ของ สี่ ร้อย สี่ สิบ แปด

Figure 8.1 All correct pronunciations generated by *i-Math*.

In some math problems, *i-Math* generates some words that are different from the words in the original math text divided into two types: *a pronounced word* and *a transliterated word*. The pronounced words are generated instead of their writing forms but they are the same pronunciations (Figure 8.2), for example, the word “เสด (/sàyt/)” replaces the word “เศษ (/sàyt/, numerator)” in IN06, “ถาน (/tǎan/)” instead of “ฐาน (/tǎan/, base)” in IN17, and “สูน (/sǒon/) ” instead of “ศูนย์ (/sǒon/, zero)” in IN19.

IN06	จงหาค่าของ $\frac{3}{7} \div \frac{9}{14} \times \frac{3}{2}$
OM	จงหาค่าของ เศษ สาม ส่วน เจ็ด หาร ด้วย เศษ เก้า ส่วน สิบ สี่ คูณ เศษ สาม ส่วน สอง
PM	จงหาค่าของ เสด สาม ส่วน เจ็ด หาน ด้วย เสด เก้า ส่วน สิบ สี่ คูน เสด สาม ส่วน สอง
IN17	จงหาค่าของ $\log_5 \sqrt{125}$
OM	จงหาค่าของ ล๊อก รากที่ สอง ของ หนึ่ง ร้อย ยี่ สิบ ห้า ฐาน ห้า
PM	จงหาค่าของ ล๊อก ราก ที่ สอง ของ หนึ่ง ร้อย ยี่ สิบ ห้า ถาน ห้า
IN19	กำหนดให้ $\log 2 = 0.3010$ และ $\log 5 = 0.6990$ จงหาค่าของ $\log \sqrt{\frac{4}{5}}$
OM	กำหนดให้ ล๊อก สอง เท่ากับ ศูนย์ จุด สาม ศูนย์ หนึ่ง ศูนย์ และ ล๊อก ห้า เท่ากับ ศูนย์ จุด หก เก้า เก้า ศูนย์ จงหาค่าของ ล๊อก รากที่ สอง ของ เศษ สี่ ส่วน ห้า
PM	กำหนดให้ ล๊อก สอง เท่า กับ สูน จุด สาม สูน หนึ่ง สูน และ ล๊อก ห้า เท่า กับ สูน จุด หก เก้า เก้า สูน จงหาค่าของ ล๊อก ราก ที่ สอง ของ เสด สี่ ส่วน ห้า

Figure 8.2 Writing forms and their pronouncing words.

IN03	แพรซื้อผ้าตัดเสื้อ 1.75 เมตร ซื้อผ้าตัดกระโปรง 2.25 เมตร แพรซื้อผ้ากี่เมตร
OM	แพรซื้อผ้าตัดเสื้อ หนึ่ง จุด เจ็ด ห้า เมตร ซื้อผ้าตัดกระโปรง สอง จุด สอง ห้า เมตร แพรซื้อผ้ากี่เมตร
PM	แพรซื้อผ้าตัดเสื้อ หนึ่ง จุด เจ็ด ห้า เม้ด ซื้อผ้าตัดกระโปรง สอง จุด สอง ห้า เม้ด แพรซื้อผ้ากี่เม้ด
IN28	ถ้า $\bar{u}$ แทนระยะทาง 50 กม. ในทิศ 170° จะได้ว่า $-\bar{u}$ คืออะไร
OM	ให้ เวกเตอร์ ยู แทนระยะทาง ห้า สิบ กิโลเมตร ในทิศ หนึ่ง ร้อย เจ็ด สิบ องศา จะได้ว่า ลบ เวกเตอร์ คืออะไร
PM	ให้ เว็ก เต้อ ยู แทนระยะทาง ห้า สิบ กิโลเม้ด ในทิศ หนึ่ง ร้อย เจ็ด สิบ องศา จะได้ว่า ลบ เว็ก เต้อ คือ อะไร
IN31	จงหาค่าของ $\lim_{x \to 0} \sqrt{2x + 3}$
OM	จงหาค่าของ ลิมิต ของ รากที่ สอง ของ สอง เอ๊กซ์ บวก สาม ที่ เอ๊กซ์ เข้าใกล้ ศูนย์
PM	จงหาค่าของ ลิ หมิด ของ ราก ที่ สอง ของ สอง เอ๊กซ์ บวก สาม ที่ เอ๊กซ์ เข้า ใกล้ สูน
IN34	จงหาค่าของ $\int (x^2 - 2x)dx$
OM	จงหาค่าของ อินทีเกรต เอ๊กซ์ ยกกำลัง สอง ลบ สอง เอ๊กซ์ ดี เอ๊กซ์
PM	จงหาค่าของ อิน ทิ เกรด เอ๊กซ์ ยก กำ ลัง สอง ลบ สอง เอ๊กซ์ ดี เอ๊กซ์

Figure 8.3 Writing forms and their transliterated words.

The transliterated words in the original math problem input are replaced by their pronunciation patterns, for example IN03 (Figure 8.3), the word "เมตร (/máyt/, meter) are replaced by the word "เม้ด (/máyt/)" in IN03, the words "เวกเตอร์ (/wâyk-dtêr/, vector)" by the word เว็ก-เต้อ (/wâyk-dtêr/) in IN28, the word "ลิมิต (/lí-mìt/, limit)" by the word "ลิ-หมิด (/lí-mìt/)" in IN31 and the word "อินทีเกรต (/in-tí-gràyt/, integral)" by the word "อิน-ทิ-เกรด (/in-tí-gràyt/) in IN34".

IN02	จงหาค่าของ x และ y ที่ทำให้สมการ $7x + 12y = 220$
OM	จงหาค่าของ เอ๊กซ์ และ วาย ที่ทำให้สมการ เจ็ด เอ๊กซ์ บวก สิบ สอง วาย เท่ากับ สอง ร้อย ยี่ สิบ
PM	จงหาค่าของ เอ๊กซ์ และ วาย ที่ทำให้สม มะ กาน เจ็ด เอ๊กซ์ บวก สิบ สอง วาย เท่า กับ สอง ร้อย ยี่ สิบ
IN05	แม่ค้ามีปลาแห้ง$10\frac{1}{2}$กิโลกรัมแบ่งใส่ถุง ถุงละ $\frac{1}{4}$ กิโลกรัม จะแบ่งใส่ถุงได้ทั้งหมดกี่ถุง
OM	แม่ค้ามีปลาแห้ง สิบ เศษ หนึ่ง ส่วน สอง กิโลกรัมแบ่งใส่ถุง ถุงละ เศษ หนึ่ง ส่วน สี่ กิโลกรัม จะแบ่งใส่ถุงได้ทั้งหมดกี่ถุง
PM	แม่ค้ามีปลาแห้ง สิบ เสด หนึ่ง ส่วน สอง กิโล่กรัม แบ่งใส่ถุง ถุงละ เสด หนึ่ง ส่วน สี่ กิโลกรัม จะแบ่งใส่ถุงได้ทั้งหมดกี่ถุง
IN35	กำหนดให้ f เป็นฟังก์ชันพหุนามที่ $f(x) = x^2 + x - 1$ แล้วค่าของ $\int_0^1 f(x)dx$ เท่ากับเท่าใด
OM	กำหนดให้ เอ๊ฟ เป็นฟังก์ชั่น พหุนาม ที่ เอ๊ฟ เอ๊กซ์ เท่ากับ เอ๊กซ์ ยกกำลัง สอง บวก เอ๊กซ์ ลบ หนึ่ง แล้วค่าของ อินทีเกรต เอ๊ฟ เอ๊กซ์ ดี เอ๊กซ์ จาก ศูนย์ ถึง หนึ่ง เท่ากับเท่าใด
PM	กำหนดให้ เอ๊ฟ เป็นฟังชัน พะ หน นามที่ เอ๊ฟ เอ๊กซ์ เท่า กับ เอ๊กซ์ ยก กำ ลัง สอง บวก เอ๊กซ์ ลบ หะ นึ่ง แล้วค่าของ อิน ทิ เกรด เอ๊ฟ เอ๊กซ์ ดี เอ๊กซ์ จาก สูน ถึง หนึ่ง เท่ากับเท่าใด

Figure 8.4 Incorrectly pronouncing words.

However, some generations of *i-Math* are incorrectly pronounced (IN02, IN05, and IN35, Figure 8.4), for example, the word "สมการ (/sà-má-gaan/, equation)" is pronounced as "สม-มะ-กาน (/sŏm-má-gaan/) in IN03 and this word also appears in seven math problems input shown in Appendix G.2. The syllable "โล (/loh/)" in the word "กิโลกรัม (/gì-loh gram/, kilogram)" appears two times in IN05. In the first time, *i-Math* incorrectly pronounces as "โล่ (/lôh/)" but in the second time, it correctly pronounces as "โล (/loh/)". Another example, IN35, three words are incorrectly pronounced: the word "ฟังก์ชัน (/fang-chân/, function)" as "ฟัง-ชัน (/fang-chan/), the word "พหุนาม (/pá-hù-naam/, polimomial)" as "พะ-หน-นาม (/pá-hŏn-naam/) and the word "หนึ่ง (/nèung/, one)" as "หะ-นึ่ง (/hà-nêung/). The word "หนึ่ง (/nèung/, one)" is the same as the syllable “โล (/loh/)” that is *i-Math* incorrectly produces in the first time but correctly produced in the second time.

In example IN04 and IN33 (Figure 8.5), *i-Math* generated the incomplete speech, some words are missing as shown in [ ].

IN04	ร้านค้าขายปากกาด้ามละ 30 บาท ขาดทุน 25% ร้านค้าลงทุนซื้อปากกาด้ามละกี่บาท
OM	ร้านค้าขายปากกาด้ามละ สาม สิบ บาท ขาดทุน ยี่ สิบ ห้า เปอร์เซนต์ ร้านค้าลงทุนซื้อปากกาด้ามละกี่บาท
PM	ร้านค้าขายปากกาด้ามละ สาม สิบ บาท ขาดทุน [ ] เปอ เซ็น ร้านค้าลงทุนซื้อปากกาด้ามละกี่บาท
IN33	จงหาค่าของ $\lim_{n\to\infty}(5 + \frac{2}{n})$
OM	จงหาค่าของ ลิมิต ของ ห้า บวก เศษ สอง ส่วน เอ็น ที่ เอ็น เข้าใกล้ อินฟินิตี้
PM	จงหาค่าของ ลิ หมิด ของ ห้า บวก เสด สอง ส่วน เอ็น ที่ เอ็น [ ] อิน ฟิ นิ ตี้

Figure 8.5 Missing words.

i-Math generates the pronounced words and transliterated words instead of their writing forms because it is aimed to increase the correct speech output. The pronunciation patterns would be easy to be processed in the speech synthesis step (see chapter 6). Both pronounced words and transliterated words are counted as the correct words because those words are correctly pronounced and do not affect the meaning of the math problem. According to the evaluation result shown in Table 8.4: 23 math texts are correct which contain five pronounced words and 26 transliterated words. The number of incorrectly pronouncing words is six words and the number of missing words is three words.

Table 8.4 The evaluation results on 35 math problems.

Measurement	Number of sentences / words	
All correctly pronunciations	23	Sentences
Pronounced words	5	Words
Transliterated words	26	Words
Some incorrectly pronunciations	12	Sentences
Incorrectly pronouncing words	6	Words
Missing words	3	Words

The correctness of pronunciations was measured by using the standard measures including precision (P), recall (R) and F-score. The intelligibilities of *i-Math* in each expression type are shown in Table 8.5: the results of each measurement with the 90 – 100 %. The logarithm, summation, and vector categories present the best correct pronunciation in row 6, row 8, and row 9, respectively. Total percentages of *i-Math* performance are shown in row 12 with the 97.84% precision, 97.51% recall, and 97.67% F-score.

Table 8.5 Precision (P), recall (R) and F-score of *i-Math* pronunciations.

Expression types	*Precision (%)*	*Recall (%)*	*F-score (%)*
Basics	96.43	94.19	95.29
Fractions	97.09	97.09	97.09
Powers	98.00	98.00	98.00
Trigonometry	95.51	95.51	95.51
Logarithms	100.00	100.00	100.00
Radicals	98.04	98.04	98.04
Summations	100.00	100.00	100.00
Vectors	100.00	100.00	100.00
Limits	98.25	96.55	97.39
Integrals	90.32	90.32	90.32
Total	97.84	97.51	97.67

Listeners' Transcription

The utterance of each problem was played to the participants so that they can transcribe what they have heard. To score results, the listener's transcriptions were compared with the original math problems in text forms. Descriptive statistics (mean and standard deviation) of the missing, incorrect and correct word of each transcription were calculated. Part of the calculations reported in Table 8.6. The number of missing words of IN30 is very high since the speech of math problems is very long; therefore the students were uncertain what should be written. The total in row 11 presents the descriptive statistics of all 35 transcriptions. It indicates that *i-Math* is able to produce an acceptable speech output since the number of missing and incorrect words is low (5.14%, *sd* = 2.00) while the number of correct word is high (93.92%, *sd* = 2.15).

Table 8.6 Descriptive statistics of missing words, incorrect words and correct words of some transcriptions.

Variable	*Mean (n* = 14)*				*Standard deviation (n = 14)*			
	IN17	IN20	IN30	Total	IN17	IN20	IN30	Total
Missing words (%)	0	2.08	31.11	5.14	0	5.10	17.80	2.00
Incorrect words (%)	0	0	6.67	1.67	0	0	8.17	1.58
Correct words (%)	100	97.92	68.89	93.92	0	5.10	18.43	2.15

* *n* = number of participants

The number of correct words and correct position in the sentence was directly counted and calculated in terms of precision (P), recall (R) and F-score (Table 8.7) as well. The highest intelligibility is found in the logarithm categories with 99.36% precision, 97.33% recall, and 98.33% F-score (row 5). *i-Math* can readily recognize the logarithms, with “$\log_a b$” denoting “log b to base a”. All participants correctly transcribed the simple logarithm (e.g. $\log_5 8 = \mathrm{b}$ in IN18). The more complicated forms of the logarithms are recognized the element and the base. Even though IN17 and IN19 contain the complicated logarithms, most participants can correctly identify the element and the base.

Table 8.7 Precision (P), recall (R) and F-score of listeners’ transcriptions.

Expression types	*Precision (%)*	*Recall (%)*	*F-score (%)*
Basics	96.69	90.50	93.49
Fractions	99.66	95.31	97.44
Powers	98.95	94.67	96.76
Trigonometry	98.42	93.45	95.87
Logarithms	99.36	97.33	98.33
Roots	98.81	91.46	94.99
Summations	98.47	92.80	95.55
Vectors	95.69	89.65	92.57
Limits	99.39	94.25	96.76
Integrals	100.00	92.59	96.15
Total	98.49	93.25	95.80

The vector category presents the lowest intelligibility with 95.69% precision, 89.65% recall, and 92.57% F-score. All “vectors” were repeatedly read as

“เวกเตอร์ (/wâyk-dtêr/, vector)”, for example ten times in IN30. These “เวกเตอร์” sounds distracted listeners from their attention. Moreover, IN30 is very long utterance containing totally 45 words. In basic category, simple expressions (e.g. $7x + 12y = 220$ and the decimals) can be correctly recognized by listeners, however, it could not reach the topmost score intelligibility (96.69% precision, 90.50% recall, and 93.49% F-score) since the utterances are too fast in Thai text parts. Thus, the listener can hardly transcribe these utterances. Moreover, a few incorrect pronunciations in the Thai text parts are caused the reduction of the intelligibility score. In overall intelligibility results of the transcriptions, the listeners clearly understood the utterances produced by *i-Math* with 98.49% precision, 93.25% recall, and 95.80% F-score as shown in the last row of Table 8.7.

IN23	**(a)**
Generated speech:	ราก-ที่-สอง ของ เอ ลบ เศษ หนึ่ง ส่วน ราก-ที่-สอง ของ เอ (Squared root *a* minus one over the squared root *a*.)
Possible expressions:	$\sqrt{a} - \frac{1}{\sqrt{a}}$ or $\sqrt{a - \frac{1}{\sqrt{a}}}$
IN26	**(b)**
Generated speech:	ซัม-เม-ชั่น ของ เศษ หนึ่ง ส่วน เอ็น ยก-กำ-ลัง สี่ ลบ เอ็น ยก-กำ-ลัง สอง จาก เอ็น เท่า-กับ หนึ่ง ถึง อิน-ฟิ-นิ-ตี้ (Summation of one over *n* to the power four minus *n* squared form *n* equal one to infinity.)
Possible expressions:	$\sum_{n=1}^{\infty} \frac{1}{n^4 - n^2}$ or $\sum_{n=1}^{\infty} \frac{1}{n^4} - n^2$
IN27	**(c)**
Generated speech:	ซัม-เม-ชั่น ของ เศษ สาม ส่วน สอง เอ็กซ์ ลบ ห้า ทั้ง-หมด ยก-กำ-ลัง ไอ จาก เอ็น เท่า-กับ หนึ่ง ถึง อิน-ฟิ-นิ-ตี้ (Summation of three over two *x* minus five to the power *i* from *i* equal one to infinity.)
Possible expressions:	$\sum_{i=1}^{\infty} \left(\frac{3}{2x-5}\right)^{i}$ or $\sum_{i=1}^{\infty} \left(\frac{3}{2}x - 5\right)^{i}$ or $\sum_{i=1}^{\infty} \left(\frac{3}{2x} - 5\right)^{i}$

Figure 8.6 Ambiguity of utterances.

However, *i-Math* can recognize the signs of radicals, with “$\sqrt{\ }$” denoting the square root, “$\sqrt[3]{\ }$” denoting the cube root, “$\sqrt[4]{\ }$” denoting the fourth root, and so on. All participants correctly transcribed the simple radicals (e.g. $\sqrt{112} + \sqrt[3]{343} -$

$\sqrt{448}$ in IN20). The more complicated forms of radicals are recognized the boundary of roots. Even though IN23 and IN24 contain the complicated roots, most participants can correctly indentify where the radical ends. However, in IN523 the transcriptions show two different expressions carrying two meanings from the same utterance illustrated in Figure 8.6a. It caused an ambiguous utterance itself. Similar ambiguities appear in IN26 and IN27 questions as well (Figure 8.6b and 8.6c).

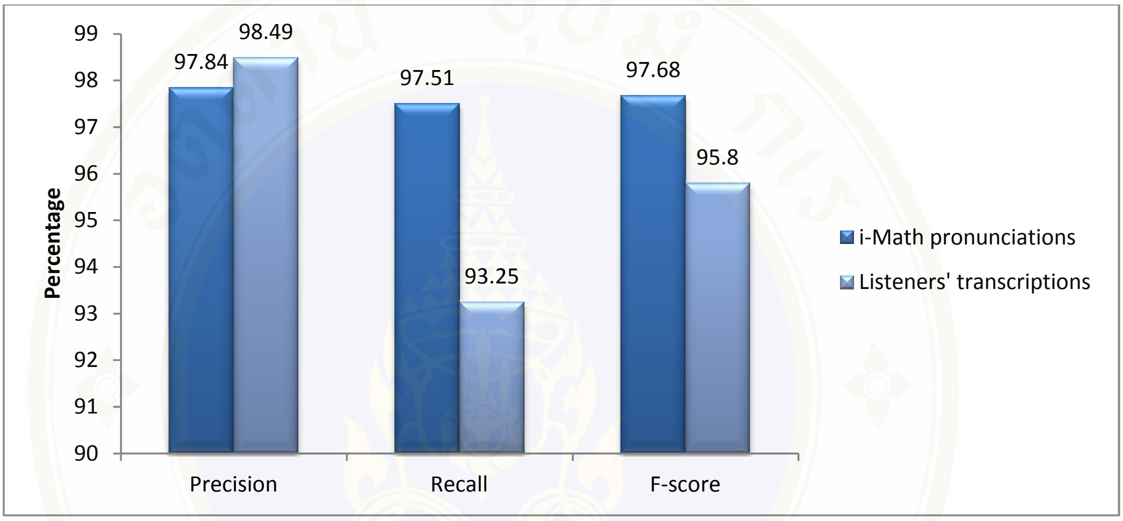

Figure 8.7 Comparison of i-*Math* pronunciations and listeners' transcriptions

Comparing the intelligibility scores of the *i-Math* pronunciation results (Table 8.5) and listeners' transcriptions (Table 8.6) reveal in Figure 8.7. The precision of listeners' transcription (98.49%) is slightly higher than the *i-Math* speech output (97.84%). It indicated that the listeners more exactly understand math problems read by *i-Math* than *i-Math* performs because listeners have their math knowledge. They therefore can guess unfamiliar pronunciations or incorrect pronunciations by the surrounding context. On the contrary, listeners' transcription (93.25%) is lower than speech output (97.51%) in recall which means listeners less completely or perfectly transcribe than *i-Math* performs. The reason is that the listeners particularly concentrated on conveying the meaning of the utterances especially math expressions, so they usually neglected linking words, e.g. "ที่ (/têe/, that, which, who)", "ของ (/kǒng/, of)", and "จาก (/jàak/, from)". Based on the intelligibility results, we can conclude that the listeners can understand math problems read by *i-Math* with their math knowledge and the context surrounding the math problems, although *i-Math* produces some incorrect pronunciations.

8.2.2 Overall Speech Quality Results

The subject tests of MOS and LES were carried out to measure the perceived quality and the effort required to understand the meaning of speech generated by *i-Math*, respectively. The average scores of all rating in MOS and LES are shown in Table 8.8. While each row presents the MOS and LES scores of math problems in each concept (i.e. basics, fractions, and powers) separately, the last row represents the total MOS and LES scores of all problems. The second column presents the MOS scores while the LES is in the third column.

Table 8.8 MOS of *i-Math* (1 = bad, and 5 = excellent) and LES of *i-Math* (1 = no meaning understood with any effort, and 5 = no effort required)

Expression types	***MOS Score***	***LES***
Basics	3.40	3.29
Fractions	4.55	4.44
Powers	4.76	4.57
Trigonometry	4.53	3.94
Logarithms	3.87	3.75
Radicals	4.54	4.23
Summations	4.07	3.97
Vectors	2.87	2.94
Limits	3.93	4.28
Integrals	3.70	3.67
Total	4.02	3.91

The total MOS score (4.02 out of 5) indicates that the utterances of *i-Math* are good quality (Huang, et al., 2001). However, the MOS score of vector questions are 2.87 because of the similar manner discussed in the previous section. Most LES scores are in level 3 or 4 which mean that the listeners are able to understand the utterances read by *i-Math* with slightly effort. Certainly, LES score of the vector items is lowest value (2.94) which shows that the listeners required effort in listening to the vector questions because of their very long utterances.

8.2.3 User Satisfaction Results

We determined the blind and VI people' perception on usefulness and ease of use of *i-Math* in a facility for their access to math materials as explained in section 8.1.3. Table 8.9 shows frequencies calculated on some questionnaire items responded by teachers. It shows that the teachers had positive perception toward the use of *i-Math*. All teachers agreed that *i-Math* helped their students in reading math documents since *i-Math* allows a user to input the math documents in widely available forms. Four teachers affirmed that *i-Math* helped their students to pay more attentions in studying mathematics. Most teachers will use *i-Math* in their classes and certainly recommend it to others. The following are some of their remarks.

Table 8.9 Frequencies of questionnaire items responded by teachers.

Questions	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
I would find that *i-Math* helped my students in reading math handouts, exercises and tests.	3	3	0	0	0
I would find that *i-Math* helped my students to pay more attentions in studying mathematics.	1	3	1	1	0
I would find that *i-Math* was helpful to use with the effective available math CAI.	0	4	2	0	0
I would find that *i-Math* could enhance the ability of my students in studying on their own.	1	3	2	0	0
I would find that *i-Math* was easy to use.	3	2	1	0	0
I am willing to use *i-Math* in my class.	5	0	1	0	0
I will recommend *i-Math* to others.	6	0	0	0	0

"I do not know Braille for mathematics well so *i-Math* is good for me because I can prepare the math lessons easily."

"I can type all math expressions on a regular editor and my students can use *i-Math* to read them. My students can practice exercises on their own. However, it is new to me. If I have more time to work on this tool I should be able to make it do whatever I want to do easier."

Table 8.10 summarized the frequencies calculated on some questionnaire items responded by students as percentages of the totals. It indicates that 79 % of the students agreed that *i-Math* helped them in reading math expressions. 66 % reported that *i-Math* reduced time consuming in doing their homework and exercises. The majority of the students found that *i-Math* is a usable tool and will recommend it to others. Some suggestions from the students for further improvement are following.

Table 8.10 Frequencies of questionnaire items responded by fourteen students.

Questions	Strongly agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly disagree (%)
I would find that i-Math helped me to read math expressions.	21	58	16	5	0
I would find that *i-Math* helped me to pay more attention in studying.	29	27	30	14	0
I would find that *i-Math* reduced time consumed in practicing mathematics.	22	44	13	15	6
I would find that *i-Math* was useful.	35	50	15	0	0
I would find that *i-Math* was easy to use.	27	44	10	18	1
I am willing to use *i-Math* in studying mathematics.	36	24	28	12	0
I will recommend i-Math to my friends.	54	19	21	5	1

"I do not like mathematics, but *i-Math* is good for me. I felt comfortable when using i-Math to read math problems, it made distorted voice sometimes though. If i-Math can produce a better Thai pronunciation, it will be good for any blind people in learning mathematics."

"It is difficult for me to try to remember what *i-Math* says and I felt a little bit uncomfortable using it. However, I think *i-Math* is a very good system in helping me to learn mathematics."

"I am low vision. *i-Math* is an interesting system that can help my friends who are blind to learn mathematics. However, *i-Math* should produce the better pronunciations. For complicated math expressions, the system should allow us go backward and go forward I need re-listening to understand and take a note."

CHAPTER IX

CONCULSIONS

We propose an intelligent mathematics (*i-Math*) approach to read the math expressions in Thai. We implemented the automatic mathematics accessibility system based on our approach, intended for being a mathematics educational tool for the blind and visually impaired (VI) students. The summary of the *i-Math* approach is given in section 9.1. The possible further works are discussed in section 9.2

9.1 Conclusions

Blind and VI students have difficulties in learning mathematics not excluding the Thai blind and VI students. One alternative way to assist them is the text-to-speech (TTS) technologies with the capability to read the math expressions out loud. However, none of available TTS can read the math expressions in Thai. We also surveyed the requirements in using TTS with the capability to read the math expressions in Thai as discussed in chapter 3. This survey can be concluded that the Thai blind and VI students needed a tool to help them in learning mathematics, especially in reading the math handouts, exercises, and assignments. Therefore, we proposed *i-Math*, a tool to enable the Thai blind and VI students independently and comfortably study and practice mathematics.

To implement *i-Math*, we have investigated the structure of math expressions in terms of syntax and semantics to produce the correct, concise, and clear Thai speech. Our investigation leaded to the set of rules to complete reading and to convey the same meaning of the original math expressions in Thai. The reading rules are composed of the addition of the necessary words in the correct position and the rearrangement of the element orders of the expression. The math expressions and their reading rules are introduced in chapter 4. We have introduced an eXtentensible

Markup Language (XML) and its applications in chapter 5. These markup languages were used to transform the non-linear expressions into the linear forms for easily processing.

The implementation of the *i-Math* systems is demonstrated in chapter 6, *i-Math* is comprised of four major components: XML Extraction, MathEx Structure Analysis, Math-Thai Mapping and Speech Synthesis. The XML Extraction separates out an XML file from an input document. The MathEx Structure Analysis adds the necessary words required in reading the math expressions. The Math-Thai Mapping replaces all non-Thai alphabets with their Thai pronunciation patterns. The Speech synthesis generates the corresponding Thai speech for all Thai pronunciation patterns.

The evaluation results are concluded in chapter 8. The evaluations of *i-Math* were conducted with sighted, blind, and VI students and their teachers. The *i-Math* system was tested and evaluated in three aspects: intelligibility, overall speech quality, and user satisfaction. The intelligibility results indicated that *i-Math* can generate the understandable pronunciations for Thai math text. In overall speech quality results, the utterances read by *i-Math* are good quality and understandable with slight effort rating by the students. The user satisfaction questionnaire indicated that the teachers and the students had positive perceptions toward the use of *i-Math* because math materials could be easily accessible for the blind and VI students through *i-Math*. Then, the students can independently and comfortably study and practice their mathematics.

With the capability to access math materials, *i-Math* can help the blind and VI students in learning mathematics better since the students can conveniently and individually practice and study mathematics on their own. Meanwhile, *i-Math* can be applied to promote educational technology in a mathematics classroom.

9.2 Discussion and Further Works

Several issues presented in this thesis require further works. The MathEx Structure Analysis module can be extended to resolve the reading ambiguity of some expressions, e.g., 2^{x+5} and $2^x + 5$. In doing so, the extra word additions must be revised, and the prosody information must be considered. To produce the concise and clear Thai speech we carefully select the extra words to add in the complete reading. To solve a kind of this problem, 2^{x+5} and $2^x + 5$, if we add the more extra words to identify the end of the expression. Either the word "ปิด (/bpìt/, close)" or the word "จบ (/jòp/, end)" is the choices. However, we need research that which the word is appreciate and where the word should be placed because these words do not normally use in reading a math expression. Otherwise, if we use the prosody, the pitch change alone does not help in clarifying the meaning of the math expressions in Thai because Thai language is a tonal language. Different tones result in different words with different meanings. Once, more researches are needed on what and which prosodic parameters are required to read these expressions.

Moreover, the ability of *i-Math* should be enhanced to indentify brackets (e.g., ( ), { }, and [ ]). For example, the notation "*(a, b)*" in the mathematics meaning can represent "an interval of numbers between *a* and *b*" and is often used to denote "an ordered pair" depended on its surrounding context.

To enhance the capability of Math-Thai Mapping rules, the mapping algorithm should be revised especially for the multiple characters since the mapping rules currently map one by one character. Further research is needed to determine when and which the multiple characters are required for the word mapping. For example, $x = \frac{degree℃ + 32}{40}$, the multiple character "*degree*" should map to its pronunciation "ดี-กรี (/dee-gree/, degree)".

The sound unit database coverage is currently limited, especially for transliterated words or loan words. When those sound units are fulfilled the database, the more correct pronunciations are increase.

Additional research is also required to explore the math expressions format on Webpage e.g., MathML. It is possible to extend *i-Math* to read the math expressions in MathML format since the structure of XML for an MS Word format and MathML are similar.

REFERENCES

AAWE-AEVH-NBA Advisory Council to the Braille Authority (1979). *The Nemath Braille code for mathematics and science notation 1972 version*. American Printing House for the Blind, Louisville, Kentucky.

Aroonmanakun, W. (2002). Collocation and Thai word segmentation. *Proceedings of the 5th Symposium on Natural Language Processing & the 5th Oriental COCOSDA Workshop, Thailand*, 68-75.

Aroonmanakun, W., Thapthong, N., Wattuya, P., Kasisopa, B. & Luksaneeyanawin, S. (2004). Automatic Thai transcription of English. *Proceedings of the 14th Annual Meeting of the Southeast Asian Linguistics Society, Thailand, 1*, 13-22.

Aroonmanakun, W. & Rivepiboon, W. (2004). A unified model of Thai romanization and word segmentation. *Proceedings of the 18th Pacific Asia Conference on Language, Information and Computation, Japan*, 205-214.

Awde, A., Bellik, Y. & Tadj, C. (2008). Complexity of mathematical expressions in adaptive multimodal multimedia system ensuring access to mathematics for visually impaired users. *International Journal of Computer and Information Science and Engineering*, *2*(2), 103 – 115.

Bray, T., Paoli, J., Sperberg-McQueen, C.M., & Maler, E. (2008). Extensible markup language (XML) 1.0 (fifth edition). *W3C Recommendation*. Retrieved July 10, 2009, from http://www.w3.org/TR/REC-xml/.

Carlisle, D., Ion, P., Miner, R. & Poppelier, N. (2003), Mathematical Markup Language (MathML) Version 2.0 (2nd Edition). *W3C Recommendation*. Retrieved December 14, 2008, from http://www.w3.org/TR/MathML2/

Center for Research in Speech and Language Processing (CRSLP), Chulalong-korn University (2002). *Area II: Computer Processing of Language and Speech*. Retrieved September 20, 2008, from http://www.crslp.chula.ac.th/research_projects.htm

Charoenpornsawat, P. & Schultz, T. (2006). Example-based grapheme-to-phoneme Conversion for Thai. *Proceedings of the 9th International Conference on Spoken Language Processing, USA*, 1-4

Charoenpornsawat, P. & Sornlertlamvanich, V. (2001). Automatic sentence break disambiguation for Thai. *Proceedings of the International Conference on Computer Processing of Oriental Languages, Korea*, 231-235.

Chomphan, S. & Kobayashi, T. (2008). Tone correctness improvement in speaker dependent HMM-based Thai speech synthesis. *Speech communication, 50*, 392–404.

Chotimongkol, A. & Black, A.W. (2000). Statistically trained orthographic to sound models for Thai. *Proceedings of the 6th International Conference on Spoken Language Processing (ICSLP), China, 2*, 551-554.

Clark, J. (1999). XSL Transformation (XSLT) Version 1.0. *W3C Reccomendation*. Retrieved October 17, 2009, from http://www.w3.org/TR/xslt.

Clark, J. & DeRose, S. (1999). XML Path Language (XPath) Version 1.0. *W3C Reccomendation*. Retrieved Octorber 30, 2009, from http://www.w3.org/TR/XPath.

DAISY Consortium (2008). *Technology Overview: What is a DTB?* Retrieved December, 2008, from http://www.daisy.org

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

Ethier, K. & Houser, A. (2001). XML Weekend Crash Course. NY: Hungry Minds, Inc.

Ferreira, H. & Freitas, D. (2004). Enhancing the accessibility of mathematics for blind people: the AudioMath project. *Proceedings of the 9th International Conference on Computers Helping People with Special Needs, France, LNCS 3118*, 678-685.

Ferreira, H. & Freitas, D. (2005). AudioMath towards automatic readings of mathematical expressions. *Proceedings of The 11th International Conference on Human-Computer Interaction (HCII2005), Nevada, USA.*

Freitas, D. & Kouroupetroglou, G. (2008). Speech technologies for blind and low vision persons. *Technology and Disability, 20*, 135-156.

Gardner, J. A., Lundquist, R., & Sahyun, S. (1998). TRIANGLE: A tri-modal access program for reading, writing, and doing math. *Proceedings of the 1998 CSUN International Conference on Technology and Persons with Disabilities*, USA.

Gaura, P. (2002). REMathEx: Reader and editor of the mathematical expressions for blind students. *Proceedings of the 8th International Conference on Computers Helping People with Special Needs, LNCS 2398*, Austria, 486-493.

Gillan, D.J., Barraza, P., Karshmer, A.I. & Pazuchanics, S. (2004). Cognitive analysis of equation reading: application to the development of the Math Genie. *Proceedings of the 9th International Conference on Computers Helping People with Special Needs, France, LNCS 3118,* 630-637.

Hamon, C. Moulines, E. & Charpentier, F. (1989). A diphone system based on time-domain prosodic modifications of speech. *Proceedings of the International Conference on Acoustic, Speech, and Signal Processing, 89* (5.7), 238-241.

Hansakunbuntheung, C. & Sagisaka, Y. (2004). Analysis of segmental duration for Thai speech synthesis. *Proceedings of the International Conference: Speech prosody,* Japan.

Huang, X., Acero, A., & Hon, H. (2001). *Spoken language processing: a guide to theory, algorithm, and system development*. Upper Saddle River, NJ: Prentice Hall.

Inthavisas, K., Khaorapapong, T. & Karnjanadecha, M. (2004b). Synthesis of Thai monophthongs by articulatory modules. *Proceedings of the 4th information Engineering Postgraduate workshop.*

Inthavisas, K., Karnjanadecha, M. & Khaorapapong, T. (2004a). Synthesis of vowels and tones in Thai language by articulatory modules. *Proceedings of the 8th International Conference on Spoken Language Processing, Korea.*

Karshmer, A. I., Bledsoe, C., & Stanley, P. B. (2004). The architecture of a comprehensive equation browser for print impaired. *Proceedings of the 9th International Conference on Computers Helping People with Special Needs, LNCS 3118*, France, 614-619.

Karshmer, A. I., & Bledsoe, C. (2002). Access to mathematics by blind students: Introduction to the special thematic session. *Proceedings of the 8th International Conference on Computers Helping People with Special Needs, LNCS 2398*, Austria, 471-476.

Kerscher, G. (1999). Braille production the DAISY way. *The 65th inter-national Federation of Library Associations and Institutions*, Thailand. Retrieved December 14, 2008, from http://archive.ifla.org/IV/ ifla65/65gk-e.htm.

Khamya, A., Narupiyakul, L., & Sirinaovakul, B. (2000b). SATTA: Syllable analysis for text-to-speech system. *Proceedings of the 4th Symposium on Natural Language processing, Thailand.*

Khamya, A., Narupiyakul, L., & Sirinaovakul, B. (2000a). Thai polysyllable analysis for text-to-speech system. *KMUTT Research and Development Journal, 23*(1), 57-70.

Khruahong, S., Nitsuwat, S. & Limmaneepraserth, P. (2003). Thai syllable segmentation for text-to-speech synthesis by using suited-syllable-structure mapping. *Proceedings of the International Conference on Communications and Information Technology.*

Kiat-arpakul, R. Fakcharoenphol, J. & Keretho, S. (1995). A compined phoneme-based and demisyllable-based approach for Thai speech synthesis. *Proceedings of International Symposium on Natural Language Processing, Thailand*, 361-369.

Lalitrojwong, P. (July, 2005). Component-based development of a Thai-to-Braille translation program [Abstract]. *Proceedings of the 11th International Conference on Human-Computer Interaction*, USA.

Luksaneeyanawin, S. (1993). Speech computing and speech technology in Thailand. *Proceedings of the Symposium on Natural Language processing in Thailand, Thailand*, 276-321.

Luksaneeyanawin, S. (1995). Tone transformation. *Proceedings of International Symposium on Natural Language Processing, Thailand*, 345-353.

Luksaneeyanawin, S. & Niyomphol, W. (1997). The application of the Thai text-to-speech system for the education of the blind [Abstract]. *Proceedings of the*

3rd UNESCO-ACEID International Conference: Education Innovation for Sustainable Development, *Thailand,* 253–254.

Mangano, S. (2002). XSLT Cookbook. Sebastopol, CA: O'Reilly & Associates, Inc.

Meknavin, S. & Kijsirikul, B. (2000). Thai grapheme-to-phoneme conversion. In D. Burnham, et al. (Eds.), *Interdisciplinary Approaches to Language Processing: The International Conference on Human and Machine Processing of Language and Speech*, *Thailand*, 214-223.

Mittrapiyanuruk, P. & Sornlertlamvanich, V. (2000). The automatic Thai sentence extraction. *Proceedings of the 4th Symposium on Natural Language Processing.Thailand.*

Mixdroff, H., Luksaneeyanawin, S., Charnvivit, P. & Thubthong, N. (2003). Modeling rhythmic variation in Thai and its application to speech synthesis. *International congress of phonetic science, Barcelona, Spain.*

Moço, V., & Archambault, D. (2004). Automatic conversions of mathematical Braille: A survey of main difficulties in different languages. *Proceedings of the 9th International Conference on Computers Helping People with Special Needs, LNCS 3118*, France, 638-643.

Naruedomkul, K. (2000). *Generate & Repair Machine Translation*. Doctoral dissertation, University of Regina, Canada.

Narupiyakul, L., Khamya, A., Sirinaovakul, B., & Cercone, N. (2005). A stochastic knowledge-based Thai text-to-speech system, *Mathematical and Computer Modeling*, *42*, 1-16.

Narupiyakul, L., Khamya, A., & Sirinaovakul, B. (1999). The Phonetic trans-cription of Thai words. *Proceedings of International Symposium on Intelligence Signal Processing and Communication*, *Thailand*, 789-792.

National Electronic and Computer Technology Center (NECTEC), Ministry of Science Technology and Environment (2007). *VAJA: Thai text-to-speech*. Retrieved September 8, 2008, from http://vaja.nectec.or.th

Niyomphol, W., Tandayya, P., Nantachaipitak, W. & Intasoi, C. (2008). A simple text-based method of producing math/science symbols or musical notes for use in a Thai/English Braille translation software. *Proceedings of the 2nd*

International Convention on Rehabilitation Engineering & Assistive Technology, Thailand, 2B-4, 0915 - 0930.

Nuntoyakul, A. (1990). *Thai text-to-speech synthesis*. Master's thesis, Chulalongkorn University, Bangkok, Thailand (in Thai).

Pansombat, N., Leelarasmee, E. & Luksaneeyanawin, S. (2002). Synthesis of stressed and unstressed syllables in Thai. *Proceedings of the 30th Electrical Engineering Conference, Thailand*, EL54-El58 (In Thai).

Paoli, J., Valet-Harper, J., Farquhar, A., & Sebestyen, I. (2006). ECMA-376 office open XML file formats, *Ecma International*. Retrieved December 18, 2009, from http//:www.ecme-international.org/publications/standards/ Ecma-376.htm.

Petkleang, S. & Tandayya, P. (2005). Thai Braille translation on Nfbtrans [Abstract]. *Proceedings of NSTDA Annual Conference,* Thailand.

Pittman, K. (2002). *The Digital Talking Book*. Retrieved December 14, 2008, from http://www.xml.com/pub/a/2002/10/16/dtb.html.

PPA Innovation (2005). *Biography and Master Work: Mr.Puttipan Ponyanun, Managing Director*. Retrieved September 25, 2008, from http://www. ppainnovation.com.

Raman, T. V., & Gries, D. (1995). Audio formatting–making spoken text and math comprehensible. *International Journal of Speech Technology, 1*, 21–31.

Reyes, K. (1987). *A speech synthesizer prototype using linear predictive coding.* Master's thesis, Chulalongkorn University, Thailand (in Thai).

Rugchatjaroen, A., Thangthai, A., Saychum, S. Thatphithakkul, N. & Wutiwiwatchai, C. (2007). Prosody-based naturalness improvement in Thai unit-selection speech synthesis. *Proceedings of Electrical Engineering /Electronics, Computer, Telecommunications and Information Technology Conference, Thailand.*

Saiyod, S., Thipchaksurat, S. & Mitatha, S. (2005). Thai speech synthesis for text-to-speech using formant synthesis. *KMITL Science and Technology Journal, 13*(3), 18-24.

Saravari, C. & Imai, S. (1983), A demisyllable approach to speech synthesis of Thai – a tone language. *Journal of the Acoustical Society of Japan (E), 4*(2), 97–106.

Schweikhardt, W., Bernareggi, C., Jessel, N., Encelle, B., & Gut, M. (2006). LAMBDA: A european system to access mathematics with Braille and audio synthesis. *Proceedings of the 10th International Conference Computers Helping People with Special Needs, LNCS 4061*, Austria, 1223–1230.

Seresangkul, P. & Takara, T. (2002). Analysis of pitch contour of Thai tone using Fujisaki's model. *Proceedings of the International Conference on Acoustics, Speech, and Signal Processing, USA, 1*, I-505 – I-508.

Seresangtakul, P. & Takara, T. (2003). A Generative Model of Fundamental Frequency Contours for Polysyllabic Words of Thai Tones. *Proceedings of the international Conference on Acoustics, Speech and Signal Processing,Japan,1, I452-I455*.

Sherman, G. (2008). A critical analysis of XSLT technology for XML transformation. *Senior Technical Report*. Retrieved January 29, 2012, from http://ruleml.org/papers/.

Soiffer, N. (2005). MathPlayer: Web-based math accessibility. *Proceedings of the 7th International ACM SIGACCESS Conference on Computer and Accessibility*, USA.

Soiffer, N. (2009). A flexible design for accessible spoken math. *C. Stephanidis (Eds.), Lecture Notes in Computer Science: Universal Access in Human-Computer Interaction. Applications and Services, 5616,* 130-139, Heidelberg, Germany: Springer.

Stevens, R.D., Edwards, A.D.N. & Harling, P.A. (1997). Access to mathematics for visually disabled srudents through multimodal interaction. *Human-Computer Interaction, 12*, 47-92.

Stevens, R.D. & Edwards, A.D.N. (1994). MathTalk: usable access to mathematics. *Information Technology and Disabilities*, 1. Retrieved June 20, 2008, from http://people.rit.edu/easi/itd/itdv01n4/ article5.htm

Tarsaku, P., Sornlertlamvanich, V. & Thongprasirt, R. (2001). Thai Grapheme–to–Phoneme Using Probabilistic GLR Parser. *Proceedings of European Conference on Speech Communication and Technology, 2*, Denmark, 1051–1060.

Tesprasit, V., Charoenpornsawat, P. & Sornlertlamvanich, V. (2003a). A Context sensitive homograph disambiguation in Thai text–to–speech synthesis. *Proceedings of the Conference of the North American Chapter of the Association for Computational Linguistics on Human Language Technology, 2, Canada*, 103-105.

Tesprasit, V., Charoenpornsawat, P. & Sornlertlamvanich, V. (2003b). Learning phrase break detection in Thai text–to–speech synthesis. *Proceedings of the 8th European Conference on Speech Communication and Technology.Switzerland.*

Thai Disabled Development Foundation (2010). *Library: Source about people who disability* [Thai]. Retrieved March 1, 2011, from http://www.tddf.or.th/tddf/library/files/doc/library-2007-11-08-339.doc.

Thailand Association of the Blind (2008). *PPA Tatip*. Retrieved October 25, 2008, from http://www.tabod.com/node/38.

Thailand National Committee on DAISY Production and Services (2008). *Daisy Thailand*. Retrieved December 15, 2008, from http://www.daisythailand.org/

Thai2English (n.d.). In *Online Thai to English dictionary, translation & transliteration - Thai2English*. Retrieved from http://www.thai2english.com/.

Thangthai, A., Hansakunbuntheung, C., Siricharoenchai, R. & Wutiwiwatchai, C. (2006). Autimatic Syllable-pattern induction in statistical Thai text-to-phone transcription. *Proceedings of the European Conference on Speech Communication and Technology*, 17-21.

Thangthai, A., Saychum, S., Rugchatjaroen, A., Thatphithakkul, N. & Wutiwiwatchai, C. (2007). Recent progress of “Vaja” Thai text-to-speech synthesis. *Proceedings of the NSTDA Annual Conference (NAC 2007), Thailand.*

Tsonos, D., Kaccori, H., & Kouroupetroglou, G. (2009). A design-for-all approach towards multimodal accessibility of mathematics. *P.L. Emiliani et al.*

(Eds.) Assistive Technology from Adapted Equipment to Inclusive Environments, Assistive Technology Research Series, 25, 393-397, IOS Press, Amsterdam.

Tumtavitikul, A. & Thitikannara, K. (2006). The Intonation of Thai emotional speech. *Proceedings of the 11th Australoan International Conference on Speech Science & Technology, New Zealand*, 287-291.

Varakulsiripunth, R. & Kongsupanich, S. (1991). Thai speech synthesis system by computer. *Proceedings of the 14th Electrical Engineering Conference, Thailand, 3,* 3-20 – 3-23 (in Thai).

Wongkia, W., Naruedomkul, K., & Cercone, N. (2009). Better access to mathematics for visually impaired. *Proceedings of the 2009 IEEE Toronto International Conference-Science and Technology for Humanity*, Canada, 43-48.

Wongkia, W., Naruedomkul, K., & Cercone, N. (2010). Thai visually impaired's requirements to access mathematics via an automatic math reader. *Proceedings of the 2nd International Conference on Computer Supported Education (CSEDU2010),* Spain, 239-244.

Wutiwiwatchai, C. & Furui, S. (2007). Thai speech processing technology: A review. *Speech Communication*, *49*, 8-27.

(Educational Media for People with Disabilities section, Centre for Educational Technology [CET], the Office of Non-Formal and Informal Education [ONIE], Ministry of Education, 2005) ส่วนส่งเสริมการผลิตสื่อการศึกษาเพื่อคนพิการ, ศูนย์เทคโนโลยีทางการศึกษา (2548). *รายงานการศึกษาสภาพและความต้องการใช้สื่อการศึกษาของนักเรียนตาบอดระดับมัธยมศึกษาตอนต้นในโรงเรียนเรียนร่วมในเขตกรุงเทพมหานครและปริมณฑล*. สำนักบริหารการศึกษานอกโรงเรียน, กระทรวงศึกษาธิการ

APPENDICES

APPENDIX A
RESEARCHERS, TASKS, APPROACHES, AND TECHNIQUES OF TEXT-TO-SPEECH SYSTEMS

This appendix illustrates the researchers, tasks, approaches, and techniques applying for the TTS system, discussed in section 2.2. Groups of researchers and publication years are shown in the first column. Types of tasks are shown in the second column, and approaches or techniques are shown in the third column.

Researchers	***Text-to-speech Tasks***	***Approaches/techniques***
Saravari & Imai (1983)	Prosody analysis Pitch contour, Duration, Stress level Speech synthesis	 Polynomial of 3rd order Rules Power of the spectral envelop component Concatenate rules {demisyllable} & LMA digital filter
Reyes (1987)	Speech synthesis	Concatenate rules {word} & LPC
Nuntoyakul (1990)	Speech synthesis	Concatenate rules {word} & LPC
Kiat-arpakul, et al. (1995)	Speech synthesis	Concatenate rules {demisyllable, phoneme}
Luksaneeyanawin (1995)	Speech synthesis	POSLA
Narupiyakul, et al. (1999)	Phonetic analysis	Rules
Chotimongkol & Black (2000)	Phonetic analysis	CART, N-gram model & Rules
Khumya, et al. (2000a, 2000b)	Phonetic analysis	Rules
Meknavin & Kijsirikul (2000)	Text analysis & Phonetic analysis	Confusion set, WINNOW & Collocation strength
Mittrapiyanuruk et al. (2000a)	Prosody analysis Tone Duration	 F0 Downdrift and Coarticulation Rules

Researchers	***Text-to-speech Tasks***	***Approaches/techniques***
Mittrapiyanuruk & Sornlertlamvanich (2000)	Text analysis Sentence segmentation	POS trigram
Charoenpornsawat & Sornlertlamvanich (2001)	Text analysis Sentence segmentation	WINNOW & POS trigram
Tarsaku, et al. (2001)	Phonetic analysis	PGLR parser
Aroonmanakun (2002)	Text analysis Word segmentation	Dictionary, Trigram model & Collocation strength
Pansombat, et al. (2002)	Speech synthesis	Concatenate rules {demisyllable} & TD–POSLA
Seresangkul & Takara (2002)	Prosody analysis Pitch contour Duration	Fujisaki's model Linear interpolation
Khruahong, et al. (2003)	Text analysis Syllable segmentation	Rules
Seresangkul & Takara (2003)	Prosody analysis Pitch contour Duration	Fujisaki's model Non linear least square error fitting curve
Mixdroff, et al. (2003)	Prosody analysis	Fujisaki's model & Corpus – based F0
Tesprasit, et al. (2003a)	Text analysis & Phonetic analysis	POS tagging & WINNOW
Tesprasit, et al. (2003b)	Text analysis Phrase, Word segmentation	POS tagging, Trigram model & C4.5/ RIPPER
Aroonmanakun, et al., (2004)	Phonetic analysis	Dictionary & Rules
Aroonmanakun & Rivepiboon (2004)	Text analysis Phonetic analysis	Trigram model & Viterbi algorithm Dictionary + Rules
Inthavisas, et al. (2004a, 2004b)	Speech synthesis	Articulatory model
Hansakunbuntheung & Sagisaka (2004)	Prosody analysis Duration	Linear regression

Researchers	***Text-to-speech Tasks***	***Approaches/techniques***
Seresangkul & Takara (2004)	Prosody analysis	
	Pitch contour	Fujisaki's model
	Speech synthesis	Rules
Narupiyakul, et al. (2005)	Phonetic analysis	Rules
	Speech synthesis	Concatenate rules {demisyllable, phoneme, diphones} & TD–PSOLA
Saiyod, et al. (2005)	Speech synthesis	Formant model
Charoenpornsawat & Schultz (2006)	Phonetic analysis	Example – based approach
Tumtavitikul & Thitikannara (2006)	Prosody analysis	Rules & ToBI
Thangthai, et al. (2006)	Phonetic analysis	Statistical approach, N – gram model & Rules
Rugchatjaroen et al. (2007)	Prosody analysis	CART & Linear regression
Thangthai, et al. (2007)	Text analysis	
	Word segmentation	POS tagging & CART
	Prosody analysis	Linear regression
Chomphan & Kobayashi (2008)	Prosody analysis	Decision tree based context clustering technique
	Speech synthesis	HMM model

APPENDIX B
AN INTERVIEW FOR SURVEYING BLIND AND VISUALLY IMPAIRED STUDENTS' REQUIREMENT FOR THE TEXT-TO-SPEECH ACCESS TO MATHEMATICS

This appendix illustrates the verbal interview items to determine blind and visually impaired (VI) students' requirements for the text-to-speech (TTS) access to mathematics, discussed in section 3.1. This interview consists of two parts: (1) students' background characteristics and (2) students' experiences of using existing TTS systems to access mathematics and students' requirements for using TTS with the capability to read math expressions in Thai in their mathematics study.

Interview

Part 1 *Students' background characteristics*

1. Personal information (sex, age, educational level and visual impairment)
2. Do you have a personal computer to use at home?
3. What platform do you use?
4. What computer software and supporting devices do you use with the computer?
5. What programs can you use? (Word, PowerPoint, Excel, Equation, PDF, Internet Explorer (IE), PPA TATIP, VAJA, Winam, Media Player, and Others)
6. Do you have experience using the Internet? If you have
   6.1 How long have you used the Internet?
   6.2 For what purposes do you use the Internet?

Part 2 *Students' opinions toward TTS to read the math expressions.*

7. Do you ever use a screen reader or text-to-speech (TTS) system? If yes, what software do you use?
8. Do you ever use an automatic mathematics reader system to read math expressions? If yes, what software do you use?
9. What languages of that system do you ever use to read math expressions?
10. What do you think of the contributions of the system that read math expressions in Thai?
11. What do you think of the contributions of such system for you?
12. In studying mathematics, what do you want from the instructional media?
13. How dose such system help you to study mathematics?
14. Do you need such system in your study of mathematics? If yes, why?
15. What do you think of using such system in your study of mathematics?
16. If *i-Math*, an automatic mathematics reader system to read math expressions in Thai, is developed, do you want to use such system?
17. What suggestions have you to produce and promote such a system?

APPENDIX C

THAI PRONUNCIATION PATTERNS OF ENGLISH AND GREEK ALPHABETS AND SOME MATHEMATICAL NOTATIONS

This appendix contains Thai pronunciation patterns of English and Greek alphabets, and some math notations discussed in section 4.2. The alphabets and notations are shown in the first and fourth column. Each transcription pattern is shown in the second and fifth column, and their descriptions are shown in the third and sixth column, respectively.

Notations	***Thai***	***Description***	***Notations***	***Thai***	***Description***
a	เอ	-	A	เอใหญ่	-
b	บี	-	B	บีใหญ่	-
c	ซี	-	C	ซีใหญ่	-
d	ดี	-	D	ดีใหญ่	-
e	อี	-	E	อีใหญ่	-
f	เอฟ	-	F	เอฟใหญ่	-
g	จี	-	G	จีใหญ่	-
h	เอช	-	H	เอชใหญ่	-
i	ไอ	-	I	ไอใหญ่	-
j	เจ	-	J	เจใหญ่	-
k	เค	-	K	เคใหญ่	-
l	แอล	-	L	แอลใหญ่	-
m	เอ็ม	-	N	เอ็มใหญ่	-
n	เอ็น	-	M	เอ็นใหญ่	-
o	โอ	-	O	โอใหญ่	-
p	พี	-	P	พีใหญ่	-
q	คิว	-	Q	คิวใหญ่	-
r	อาร์	-	R	อาร์ใหญ่	-
s	เอส	-	S	เอสใหญ่	-
t	ที	-	T	ทีใหญ่	-
u	ยู	-	U	ยูใหญ่	-
v	วี	-	V	วีใหญ่	-
w	ดับเบิลยู	-	W	ดับเบิลยูใหญ่	-
x	เอ็กซ์	-	X	เอ็กซ์ใหญ่	-
y	วาย	-	Y	วายใหญ่	-
z	แซด	-	Z	แซดใหญ่	-

Notations	***Thai***	***Description***	***Notations***	***Thai***	***Description***
Α, α	แอลฟ่า	Alpha	Β, β	เบต้า	Beta
Γ, γ	แกมม่า	Gamma	Δ, δ	เดลต้า	Delta
Ε, ε	เอปซิลอน	Epsilon	Ζ, ζ	ซีต้า	Zeta
Η, η	อีต้า	Eta	Θ, θ	ทีต้า	Theta
Ι, ι	ไอโอต้า	Iota	Κ, κ	เคปป้า	Kappa
Λ, λ	แลมด้า	Lambda	Μ, μ	มิว	Mu
Ν, ν	นิว	Nu	Ξ, ξ	ไซ	Xi
Ο, ο	โอมิครอน	Omicron	Π, π	พาย	Pi
Ρ, ρ	โร	Rho	Σ, ς, σ	ซิกม่า	Sigma
Τ, τ	ทาว	Tau	Υ, υ	อัปซิลอน	Upsilon
Φ, φ	ฟี	Phi	Χ, χ	ไค	Chi
Ψ, ψ	ไซ	Psi	Ω, ω	โอเมก้า	Omega
+	บวก	Plus	-	ลบ, ถึง	Minus, to
±	บวก ลบ	Plus or minus	∓	ลบ บวก	Minus or plus
×	คูณ	Time, multiplied by	*	ดอก-จัน	Star
·	คูณ	Time	÷	หาร-ด้วย	Divided by
/	ทับ	Over, slash	=	เท่า-กับ	Equals, equal to
≠	ไม่-เท่า-กับ	Not equal to	~	คล้าย-กับ	Be asymptotic to
∝	แปร-ผัน-ตรง	Be proportional to	≅	เท่า-กัน-ทุก-ประ-การ	Be congruent to
≡	สม-มูล	Equivalent to, identical with	≈	ประ-มาณ	Nearly equal to
>	มาก-กว่า	Greater than	<	น้อย-กว่า	Less than
≫	มาก-กว่า มาก-กว่า	Much greater than	≪	น้อย-กว่า น้อย-กว่า	Much smaller than
≥	มาก-กว่า หรือ เท่า-กับ	Greater than or equal to	≤	น้อย-กว่า หรือ เท่า-กับ	Less than or equal to
%	เปอร์-เซ็นต์	Percent	°	อง-ศา	Degree
°F	อง-ศา-ฟา-เรน-ไฮ	Degree Fahrenheit	℃	อง-ศา-เซล-เซียส	Degree Celsius
:	ต่อ	to	//, ‖	ขนาน	Parallel to
∴	เพราะ-ฉนั้น	Therefore	…	ไป-เรื่อย-เรื่อย	So on
⊥	ตั้ง-ฉาก	Be perpendicular to	∞	อิน-ฟี-นิ-ตี้	Infinity
∩	อิน-เตอร์-เซ็ก	Intersect	∪	ยู-เนียน	Union
⊄	ไม่-เป็น-ซับ-เซต	Not contained in	⊂	เป็น-ซับ-เซต	Be a subset of

Notations	*Thai*	*Description*	*Notations*	*Thai*	*Description*
$\subseteq$	เป็น-ซับ-เซต หรือ เท่า-กับ	Be not a subset of or equal to	$\in$	เป็น-สมาชิก	Be an element of
$\notin$	ไม่-เป็น-สมาชิก	Be not an element of	$\angle$	มุม	Angle
$\varnothing$	เซต ว่าง	Null set			

APPENDIX D
XML REPRESENTATIONS OF MATHEMATICAL ELEMENTS AND THEIR SYNTAX

This appendix contains math elements and their syntax in an XML format, discussed in section 5.1 and 6.2. The following elements used in this research are provided (see full details at Paoli et al., 2006). Their features are shown in the first column. Each description is shown in the second column, and their parent elements and child element are shown in the third and forth column, respectively.

Features	***Description***	[12]***Parent elements***	[12]***Child elements***
[13]m:acc	Specify the accent function, consisting of a base and a combining diacritical mark (e.g., $\dot{a}$, $\acute{a}$ and $\vec{a}$).	m:deg, m:den, m:e, m:fName, m:lim, m:num, m:oMath, m:sub, m:sup	m:accPr, m:e
m:accPr	Specify the properties of the Accent function (m:acc).	m:acc	m:chr
m:begChr	Specify the beginning or opening delimiter character (e.g., ‘(’, ‘[’, ‘{’ and ‘|’).	m:dPr	m:val
m:chr	Specify the character to be attached to the base of and accent object (m:acc), and an n-ary operator (m:nary). When the parent element is m:accPr, the m:chr value should be the specific codes of diacritical marks such as $\dot{}$, $\acute{}$ and $\vec{}$. When the parent element is m:naryPr, the m:chr value should be an n-ary operator such as $\int$, $\sum$ and $\prod$.	m:accPr, m:naryPr	m:val

[12] Parent and child elements used in this research are provided in this appendix (see details at Paoli et al., (2006)).

[13] Elements in XML which begin with ‘m:’ are math elements while arbitrary or literal text start with ‘w:’.

Features	***Description***	[12]***Parent elements***	[12]***Child elements***
m:d	Specify the delimiter object, consisting of opening and closing delimiters and an element contained inside. The delimiter may have more than one element, with a designated separator character between each element.	m:deg, m:den, m:e, m:fName, m:lim, m:num, m:oMath, m:sub, m:sup	m:dPr, m:e
m:deg	Specify the degree in the math radical. This element is optional. When m:deg is omitted, the square root function is assumed.	m:rad	m:acc, m:d, m:eqArr, m: f, m:func, m:limLow, m:nary, m:oMath, m:r, m:rad, m:sSub, m:sSup
m:den	Specify the denominator of a fraction.	m:f	m:acc, m:d, m:eqArr, m:f, m:func, m:limLow, m:nary, m:oMath, m:r, m:rad, m:sSub, m:sSup
m:dPr	Specify the properties of m:d, including the enclosing and separating characters, and the properties that affect the shape of the delimiters.	m:d	m:begChr
m:e	Specify the element of several functions including the base of math object, the elements in an array.	m:acc, m:d, m:eqArr, m:func, m:lomLow, m:nary, m:rad, m:sSub, m:sSup	m:acc, m:d, m:eqArr, m:f, m:func, m:limLow, m:nary, m:oMath, m:r, m:rad, m:sSub, m:sSup
m:eqArr	Specify the Array object, an object consisting of one or more equations, expressions, and other math text runs (m:r) that can be vertically justified as a unit with respect to surrounding text on the line.	m:deg, m:den, m:e, m:fName, m:lim, m:num, m:oMath, m:sub, m:sup	m:e

Features	***Description***	***[12]Parent elements***	***[12]Child elements***
m:f	Specify the fraction object, consisting of a numerator and denominator separated by a fraction bar. The fraction bar can be horizontal or diagonal.	m:deg, m:den, m:e, m:fName, m:lim, m:num, m:oMath, m:sub, m:sup	m:den, m:num
m:fName	Specify the name of the function in the Function-Apply object (m:func).	m:func	m:acc, m:d, m:eqArr, m:f, m:func, m:limLow, m:nary, m:oMath, m:r, m:rad, m:sSub, m:sSup
m:fPr	Specify the properties of the fraction object. Properties of the Fraction object include the type or style of the fraction.	m:f	-
m:func	Specify the Function-Apply object, which consisting of a function name and an argument element (m:e) acted upon.	m:deg, m:den, m:e, m:fName, m:lim, m:num, m:oMath, m:sub, m:sup	m:e, m:fMane
m:lim	Specify the lower limit of the m:limLow object and the upper limit of the m:limUpp function.	m:limLow	m:acc, m:d, m:eqArr, m:f, m:func, m:limLow, m:nary, m:oMath, m:r, m:rad, m:sSub, m:sSup
m:limLoc	Specify the location of limits in n-ary operators. Limits can be either center, above and below.	m:naryPr	m:val
m: limLow	Specify the Lower-Limit object, consisting of text on the baseline and reduced-size text immediately below it.	m:deg, m:den, m:e, m:fName, m:lim, m:num, m:oMath, m:sub, m:sup	m:e, m:lim

Features	*Description*	[12]*Parent elements*	[12]*Child elements*
m:nary	Specify an n-ary object, consisting of an n-ary object, a base or operand, and optional upper and lower limits.	m:deg, m:den, m:e, m:fName, m:lim, m:num, m:oMath, m:sub, m:sup	m:e, m:naryPr, m:sub, m:sup
m:naryPr	Specify the properties of the n-ary object, including the n-ary operator character (e.g., ∫, ∑ and ∏), and the location of limits.	m:nary	m:chr, m:limLoc
m:num	Specify the numerator of the Fraction object (m:f).	m:f	m:acc, m:d, m:eqArr, m:f, m:func, m:limLow, m:nary, m:oMath, m:r, m:rad, m:sSub, m:sSup
m:oMath	Specify an instance of math text. All math text include equations, expressions, arrays of equations and formulas represented by m:oMath blocks.	m:deg, m:den, m:e, m:fName, m:lim, m:num, m:oMath, m:sub, m:sup	m:acc, m:d, m:eqArr, m:f, m:func, m:limLow, m:nary, m:oMath, m:r, m:rad, m:sSub, m:sSup
m:r	Specify a run of math text.	m:deg, m:den, m:e, m:fName, m:lim, m:num, m:oMath, m:sub, m:sup	m:t
m:rad	Specify the radical object, consisting of a radical, a base (m:e), and an optional degree (m:deg).	m:deg, m:den, m:e, m:fName, m:lim, m:num, m:oMath, m:sub, m:sup	m:deg, m:e
m:sSub	Specify the subscript object which consists of a base (m:e) and a reduced-size (m:sub) placed below and to the right.	m:deg, m:den, m:e, m:fName, m:lim, m:num, m:oMath, m:sub, m:sup	m:e, m:sub

Features	***Description***	***[12]Parent elements***	***[12]Child elements***
m:sSup	Specify the superscript object, which consists of a base (m:e) and a reduced-size (m:sup) placed above and to the right.	m:deg, m:den, m:e, m:fName, m:lim, m:num, m:oMath, m:sub, m:sup	m:e, m:sup
m:sub	Specify the subscript of subscript object.	m:nary, m:sSub	m:acc, m:d, m:eqArr, m:f, m:func, m:limLow, m:nary, m:oMath, m:r, m:rad, m:sSub, m:sSup
m:sup	Specify the superscript of superscript object.	m:nary, m:sSub	m:acc, m:d, m:eqArr, m:f, m:func, m:limLow, m:nary, m:oMath, m:r, m:rad, m:sSub, m:sSup
m:t	Specify the arbitrary text including English alphabets, numbers, math operation sign (e.g., +, –, =, ±), Greek alphabets and so on.	m:r	-
m:val	Specify a value used by the parent element such as delimiter characters, fraction bar, and limit positions.	m:begChr, m:chr, m:limLoc	-
w:body	Specify the contents of the body of the document.	w:document	m:oMath
w:char	Specify the hexadecimal code for the Unicode character value of the symbol (w:sym).	w:sym	-
w:document	Specify the contents of a main document part in a WordprocessingML document.	-	w:body
w:p	Specify a paragraph of content in the document.	w:body	m:oMath, w:r
w:r	Specify a run of content in the paragraph.	w:p	w:rPr, w:t

Features	*Description*	*[12]Parent elements*	*[12]Child elements*
w:rPr	Specify a set of run properties which is applied to the contents of the parent run after all style formatting has been applied to the text.	w:r	m:oMath, w:vertAllign
w:sym	Specify the presence of a symbol character at the current location in the run's content. A symbol character is a special character within a run's content which does not use any of run fonts.	w:r	w:char
w:t	Specify literal text displaying in the document.	w:r	-
w:val	Specify the types of vertical alignment applied to the contents of the run text (w:r). The value of w:val can be subscript or superscript.	w:vertAlign	-
w:vertAlign	Specify the alignment which is applied to the contents of this run in relation to the appearance of the run's text. It allows the text to be repositioned as subscript and superscript without altering the font size of the run properties.	w:rPr	-

APPENDIX E
MATHEX RULES

This appendix illustrates a fragment of MathEx Rules, discussed in section 6.2 in the XSLT representation style. The different expressions have different rules to add necessary words and place in the right locations.

E.1 A fraction

Three words, “เศษ (/sàyt/, numerator)” or it pronunciation “เสด (/sàyt/, numerator)”, “ส่วน (/sùan/, denominator)”, and “ทั้งหมด (/táng-mòt/, all)”, are required to clarify a fraction meaning.

```
<!-- ======= Fraction: add thsound tags into the math fraction =============================== -->
    <xsl:template match="m:f">
        <xsl:copy>
            <xsl:choose>
                <xsl:when test="./m:fPr/m:type[@m:val='noBar']">
                    <xsl:for-each select="./m:num">
                        <xsl:apply-templates match="m:t"/>
                    </xsl:for-each>

                    <xsl:for-each select="./m:den">
                        <thsound> เลือก </thsound>
                        <xsl:apply-templates match="m:t"/>
                    </xsl:for-each>
                </xsl:when>

                <xsl:otherwise>
                    <xsl:for-each select="./m:num">
                    <!-- starting word for a m:num -->
                        <thsound> เสด </thsound>
                        <xsl:apply-templates match="m:t"/>

                        <!-- boundary word for a m:num-->
                        <xsl:choose>
                            <xsl:when test="child::m:r[position()=1]">
                                <xsl:variable   name="level_r"
                                                select="count(./m:r)"/>
                                <!-- count m:r -->
                                <xsl:if test= "$level_r &gt;=2">
                                    <thsound> ทั้ง หมด </thsound>
                                </xsl:if>
                                <xsl:if test="following-sibling::m:f
                                        or following-sibling::m:oMath
                                        or following-sibling::m:rad
                                        or following-sibling::m:sSup
                                        or following-sibling::m:sSub
                                        or following-sibling::m:func
```

```
                                        or following-sibling::m:nary
                                        or following-sibling::m:d">
                                    <thsound> ทั้งหมด </thsound>
                                </xsl:if>
                            </xsl:when>
                            <xsl:otherwise>
                                <thsound> ทั้งหมด </thsound>
                            </xsl:otherwise>
                        </xsl:choose>
                    </xsl:for-each>

                    <xsl:for-each select="./m:den">
                        <!-- starting word for a den ==-->
                        <thsound> ส่วน </thsound>
                        <xsl:apply-templates match="m:t"/>
                    </xsl:for-each>
                </xsl:otherwise>
            </xsl:choose>

            <thsound># </thsound>
        </xsl:copy>
    </xsl:template>
<!-- ========= End Fraction ================================================================== -->
```

E.2 A radical

Two words, “รากที่ (/râak-têe/, root)” and “ของ (/kǒng/, of)”, are required to clarify the n^{th} root meaning. Otherwise, the phrase “รากที่ (/râak-têe sǒng kǒng/, squared root)” is required to clarify the squared root.

```
<!-- ======= Radical: add thsound tags into the math Radical ================================ -->
    <xsl:template match="m:rad">
        <xsl:copy>
            <xsl:for-each select="./m:deg">
                <xsl:choose>
                    <xsl:when test="*"><!--'node'element has child elements-->
                        <!--beginning m:deg word for a root-->
                        <thsound> ราก ที่ </thsound>
                        <xsl:apply-templates match="m:t"/>
                        <thsound> ของ </thsound>
                    </xsl:when>

                    <xsl:otherwise>       <!-- doesn't have child elements-->
                        <!--beginning m:deg word for a square root-->
                        <thsound> ราก ที่ สอง ของ </thsound>
                        <xsl:apply-templates match="m:t"/>
                    </xsl:otherwise>
                </xsl:choose>
            </xsl:for-each>

            <xsl:for-each select="./m:e">
                <xsl:apply-templates match="m:t"/>
            </xsl:for-each>
            <thsound># </thsound>
        </xsl:copy>
    </xsl:template>
<!-- ========= End Radical ==================================================================== -->
```

E.3 A superscript or a power

Three words, “ยกกำลัง (/yók-gam-lang/, to the power)” and “ทั้งหมด (/táng-mòt/, all)”, are required to clarify an exponentiation meaning.

```
<xsl:template match="m:sSup">
    <xsl:copy>
        <xsl:for-each select="./m:e">
            <xsl:apply-templates match="m:t"/>

            <!-- boundary word for a base of sSup-->
            <xsl:choose>
                <xsl:when test="child::m:r[position()=1]">
                    <xsl:variable   name="level_e"
                                    select="count(./m:r)"/>
                            <!-- count m:r -->
                    <xsl:if test= "$level_e &gt;=2">
                        <thsound> ทั้ง หมด </thsound>
                    </xsl:if>
                    <xsl:if test="following-sibling::m:f
                            or following-sibling::m:oMath
                            or following-sibling::m:rad
                            or following-sibling::m:sSup">
                        <thsound> ทั้ง หมด </thsound>
                    </xsl:if>
                </xsl:when>
                <xsl:otherwise>
                    <thsound> ทั้ง หมด </thsound>
                </xsl:otherwise>
            </xsl:choose>
            </xsl:for-each>

        <xsl:for-each select="./m:sup">
            <!-- starting word for a index of superscript -->
            <thsound> ยก กำ ลัง </thsound>
            <xsl:apply-templates match="m:t"/>
        </xsl:for-each>
        <thsound># </thsound>
    </xsl:copy>
</xsl:template>
```

E.4 A subscript

One word “ฐาน (/<u>tăan</u> /, base)” or its pronunciation “ถาน (/<u>tăan</u> /, base)” which means a base are required to clarify the meaning of base number (e.g., 4302_5, 70065_8). However, no word is required to clarify a subscript meaning if the base is not a number.

```
<xsl:template match="m:sSub">
    <xsl:copy>
        <xsl:for-each select="./m:e">
            <xsl:apply-templates match="m:t"/>
        </xsl:for-each>

        <xsl:for-each select="./m:sub">
            <!-- starting word for subscript, then have to check whether the content inside
            m:e/m:t is number (if yes substitute 'ฐาน' for 'sub', if no delete 'sub' -->
            <xsl:variable name="base" select = "preceding-sibling::m:e/descendant::m:t"/>
            <xsl:choose>
                <xsl:when test= "string(number($base)) = 'NaN'">
                    <thsound> </thsound>
                </xsl:when>
                <xsl:otherwise>
                    <thsound> ฐาน </thsound>
                </xsl:otherwise>
            </xsl:choose>
            <xsl:apply-templates match="m:t"/>
        </xsl:for-each>
        <thsound># </thsound>
    </xsl:copy>
</xsl:template>
```

E.5 Other function names

Functions such as “lim”, “min”, “max”, “log”, “ln”, and trigonometric functions requires special words to complete reading as discussed in section 4.2.

```
<!-- ====== Function name ================================================================== -->
<xsl:template match="m:func">
    <xsl:copy>
        <xsl:for-each select="./m:fName">
            <xsl:choose>
                <xsl:when test="child::m:limLow">
                    <xsl:for-each select="./m:limLow">
                        <xsl:for-each select="./m:e">
                            <thsound>
                                <xsl:choose>
                                    <xsl:when test="./m:r/m:t[.='lim']"> ลิ หมิต    </xsl:when>
                                    <xsl:when test="./m:r/m:t[.='min']"> มิน นิ มั่ม </xsl:when>
                                    <xsl:when test="./m:r/m:t[.='max']"> แม็ก ลิ มั่ม </xsl:when>
                                </xsl:choose>
                            </thsound>

                            <xsl:for-each select="./ancestor::m:fName/following-sibling::m:e">
                                <thsound> ของ </thsound>
                                <xsl:apply-templates match="m:t"/>
                            </xsl:for-each>
                        </xsl:for-each>

                        <xsl:for-each select="./m:lim">
                            <thsound> ที่ </thsound>
                            <xsl:apply-templates match="m:t"/>
                        </xsl:for-each>

                    </xsl:for-each>
                </xsl:when>

                <xsl:when test="child::m:r">
                    <xsl:for-each select="./m:r">
                        <thsound>
                            <xsl:choose>
```

```
                                    <xsl:when test="./m:t[.='log']"> ล็อก </xsl:when>
                                    <xsl:when test="./m:t[.='ln']"> เน ชัว เร่า ล็อก </xsl:when>

                                    <xsl:when test="./m:t[.='sin']"> ชายน์ </xsl:when>
                                    <xsl:when test="./m:t[.='cos']"> คอส </xsl:when>
                                    <xsl:when test="./m:t[.='tan']"> แทน </xsl:when>
                                    <xsl:when test="./m:t[.='csc']"> โค เส็ก </xsl:when>
                                    <xsl:when test="./m:t[.='sec']"> เส็ก</xsl:when>
                                    <xsl:when test="./m:t[.='cot']"> ขอท </xsl:when>
                                </xsl:choose>
                            </thsound>

                            <xsl:for-each select="./ancestor::m:fName/following-sibling::m:e">
                                <xsl:apply-templates match="m:t"/>
                            </xsl:for-each>
                        </xsl:for-each>
                    </xsl:when>

                    <xsl:when test="child::m:sSub">
                        <xsl:for-each select="./m:sSub">
                            <xsl:for-each select="./m:e">
                                <thsound>
                                    <xsl:choose>
                                        <xsl:when test="./m:r/m:t[.='log']"> ล็อก </xsl:when>
                                    </xsl:choose>
                                </thsound>
                                <xsl:for-each select="./ancestor::m:fName/following-sibling::m:e">
                                    <xsl:apply-templates match="m:t"/>
                                </xsl:for-each>
                            </xsl:for-each>

                            <xsl:for-each select="./m:sub">
                                <thsound> ถาน </thsound>
                                <xsl:apply-templates match="./m:r/m:t"/>
                             </xsl:for-each>
                        </xsl:for-each>
                    </xsl:when>
                </xsl:choose>
            </xsl:for-each>
            <thsound># </thsound>
        </xsl:copy>
    </xsl:template>
<!-- ========= End Function ================================================================= -->
```

E.6 An accent

Particular alphabets appear above characters to indicate a vector, a ray, an angle, and a straight line, discussed in section 4.2.

```
<!-- ======= Accent ========================================================================= -->
    <xsl:template match="m:acc">
        <xsl:copy>
            <xsl:for-each select=".">
                <xsl:choose>
                    <xsl:when test="./m:accPr/m:chr[@m:val='']">
                        <xsl:apply-templates match="m:t"/>
                        <thsound> ซ้ำ </thsound>
                    </xsl:when>

                    <xsl:otherwise>
                        <xsl:for-each select="./m:accPr">
                            <xsl:choose>
                                <xsl:when test="child::m:chr[position()=1]">
```

```
<!--test this node has m:chr has the first element-->
<xsl:for-each select="./m:chr">
    <thsound>
        <xsl:choose>
            <xsl:when test="@m:val=‾">
                <xsl:variable name="bar"
                              select = "./parent::m:accPr/
                                        following-sibling::m:e/
                                         descendant::m:t"/>
                <xsl:choose>
                    <xsl:when test="string-length($bar)=1">
                        <xsl:for-each select="./
                                    parent::m:accPr/
                                    following-sibling::m:e">
                            <xsl:apply-templates match="m:t"/>
                        </xsl:for-each>
                        <thsound> บาร์ </thsound>
                    </xsl:when>
                    <xsl:when test="string-length($bar)=2">
                        <thsound> ส่วนของเส้นตรง </thsound>
                        <xsl:for-each select="./
                                    parent::m:accPr/
                                    following-sibling::m:e">
                            <xsl:apply-templates match="m:t"/>
                        </xsl:for-each>
                    </xsl:when>
                    <xsl:otherwise>
                        <thsound> bar </thsound>
                    </xsl:otherwise>
                </xsl:choose>
            </xsl:when>

            <xsl:when test="@m:val='□'">
                <thsound> รังสี </thsound>
                <xsl:for-each select="./parent::m:accPr/
                                following-sibling::m:e">
                    <xsl:apply-templates match="m:t"/>
                </xsl:for-each>
            </xsl:when>
            <xsl:when test="@m:val='□'">
            <thsound> เส้นตรง </thsound>
                <xsl:for-each select="./parent::m:accPr/
                                following-sibling::m:e">
                    <xsl:apply-templates match="m:t"/>
                </xsl:for-each>
            </xsl:when>
            <xsl:when test="@m:val='□'">
            <thsound> เว็กเต้อ </thsound>
                <xsl:for-each select="./parent::m:accPr/
                                following-sibling::m:e">
                    <xsl:apply-templates match="m:t"/>
                </xsl:for-each>
            </xsl:when>
        </xsl:choose>
    </thsound>
</xsl:for-each>
</xsl:when>
<xsl:when test="child::m:ctrlPr[position()=1]">
    <thsound> มุม </thsound>
</xsl:when>
</xsl:choose>
</xsl:for-each>
</xsl:otherwise>
</xsl:choose>
<thsound># </thsound>
</xsl:for-each>
</xsl:copy>
</xsl:template>
<!-- ========= End Accent ==================================================================== -->
```

E.7 N-array functions

N-array functions such as ‘summation’, ‘product’, ‘union’, and ‘integral’, comprised of two or more components around the main function notations, for example, $\sum_{i=0}^{n} i$. Once, these functions require special words to complete reading as discussed in section 4.2.

```
<!-- ======= nary ============================================================================ -->
    <xsl:template match="m:nary">
        <xsl:copy>
            <xsl:for-each select="./m:naryPr">
                <xsl:choose>
                    <xsl:when test="child::m:chr[position()=1]">
                        <xsl:for-each select="./m:chr">
                            <thsound>
                                <xsl:choose>
                                    <xsl:when test="@m:val='∑'"> ซัมเมชั่น </xsl:when>
                                    <xsl:when test="@m:val='Π'"> ผนคูน </xsl:when>
                                    <xsl:when test="@m:val='⋃'"> ยูเนี่ยน </xsl:when>
                                </xsl:choose>
                            </thsound>
                            <xsl:for-each select="./parent::m:naryPr/following-sibling::m:e">
                                <thsound> ของ </thsound>
                                <xsl:apply-templates match="m:t"/>
                            </xsl:for-each>
                        </xsl:for-each>
                    </xsl:when>

                    <xsl:when test="child::m:limLoc[position()=1]">
                        <thsound> อินทิเกรต </thsound>

                        <xsl:for-each select="./following-sibling::m:e">
                            <xsl:apply-templates match="m:t"/>
                        </xsl:for-each>
                    </xsl:when>

                </xsl:choose>
            </xsl:for-each>

            <xsl:for-each select="./m:sub">
                <xsl:choose>
                    <xsl:when test="*">
                        <thsound> จาก </thsound>
                        <xsl:apply-templates match="./m:t"/>
                    </xsl:when>

                    <xsl:otherwise><thsound> </thsound></xsl:otherwise>
                </xsl:choose>
            </xsl:for-each>

            <xsl:for-each select="./m:sup">
                <xsl:choose>
                    <xsl:when test="*">
                        <thsound> ถึง </thsound>
                        <xsl:apply-templates match="./m:t"/>
                    </xsl:when>
                    <xsl:otherwise><thsound> </thsound></xsl:otherwise>
                </xsl:choose>
            </xsl:for-each>

            <thsound># </thsound>
        </xsl:copy>
    </xsl:template>
<!-- ========= End nary ====================================================================== -->
```

APPENDIX F
FULL FORMS OF ABBREVIATIONS

This appendix contains full forms of abbreviations including math terms, measurement units, and some Thai abbreviations, described in section 6.3. The abbreviations are shown in the first column. Their full forms are in the second column while their descriptions show in the third column.

Abbreviation	***Full form***	***Description***	***Abbreviation***	***Full form***	***Description***
*ห.ร.ม.	หอ รอ มอ (หาร ร่วม มาก)	Greatest Common Divisor (GCD)	*ค.ร.น	คอ รอ นอ (คูณ ร่วม น้อย)	Least Common Multiply (LCM)
ด.ม.ด.	ด้าน มุม ด้าน	Side-angle-side (SAS)	ม.ด.ม.	มุม ด้าน มุม	Angle-side-angle (ASA)
ด.ด.ด.	ด้าน ด้าน ด้าน	Side-side-side (SSS)	ฉ.ด.ด.	ฉาก ด้าน ด้าน	Right angle-side-side (RASS)
ตร.กม.	ตารางกิโลเมตร	Square kilometer	ตร.ม	ตารางเมตร	Square meter
ตร.ซม.	ตาราง เซนติเมตร	Square centimeter	**ตร.ว.	ตารางวา	Square Wah
ตร.น.	ตารางหน่วย	Square unit	ลบ.ซม	ลูกบาศก์ เซนติเมตร	Cubic centimeter
ลบ.ม.	ลูกบาศก์เมตร	Cubic meter	ดคก.	เดคากรัม	Decagram
ดคม.	เดคาเมตร	Decameter	ดคล.	เดคาลิตร	Decaliter
กก.	กิโลกรัม	Kilogram	กม.	กิโลเมตร	Kilometer
กล.	กิโลลิตร	Kilolitre	ซก.	เซนติกรัม	Centigram
ซม.	เซนติเมตร	Centimeter	ซล.	เซนติลิตร	Centiliter
ดก.	เดซิกรัม	Decigram	ดม.	เดซิเมตร	Decimeter
ดล.	เดซิลิตร	Deciliter	มก.	มิลลิกรัม	Milligram
มม.	มิลลิเมตร	Millimeter	มล.	มิลลิลิตร	Milliliter
ฮก.	เฮกโตกรัม	Hectogram	ฮม.	เฮกโตเมตร	Hectometer
ฮล.	เฮกโตลิตร	Hectolitrer	ก.	กรัม	Gram
ซ.	เซนติเกรด	Centigrade	ม.	เมตร	Meter
ต.	เมตริกตัน	Metric ton	ล.	ลิตร	Liter
**ว.	วา	Wah	น.	นาฬิกา	a.m. or p.m.
ม.ค.	มกราคม	January	ก.พ.	กุมภาพันธ์	February

Abbreviation	***Full form***	***Description***	***Abbreviation***	***Full form***	***Description***
มี.ค.	มีนาคม	March	เม.ย.	เมษายน	April
พ.ค.	พฤษภาคม	May	มิ.ย.	มิถุนายน	June
ก.ค.	กรกฎาคม	July	ส.ค.	สิงหาคม	August
ก.ย.	กันยายน	September	ต.ค.	ตุลาคม	October
พ.ย.	พฤศจิกายน	November	ธ.ค.	ธันวาคม	December
*พ.ศ.	พอ ศอ (พุทธศักราช)	Buddhist era	*ค.ศ.	คอ ศอ (คริสตศักราช)	Anno Domini
ด.ช.	เด็กชาย	Boy	ด.ญ.	เด็กหญิง	Girl
น.ส.	นางสาว	Miss	น.ศ	นักศึกษา	University student

* Some abbreviations are read by spelling the term.

** The word “วา /wah/” means a Thai of measurement which equal to two meters.

APPENDIX G
INTELLIGIBILITY EVALUATION

This appendix contains the evaluation of *i-Math* with respect to the intelligibility as outlined in chapter 8. A sample test used in the evaluation presents in the next section. The comparison of original math text in the text form against the pronunciation generated by *i-Math* is shown in section G.2.

G.1 A Sample Test

Category	***No***	***Mathematical questions***
Basic	01.	จงหาค่าของ 72 × 144 ÷ 27 (Find the value of 72 × 144 ÷ 27.)
	02.	จงหาค่าของ x และ y ที่ทำให้สมการ $7x + 12y = 220$ (Find *x* and *y*, so that $7x + 12y = 220$.)
	03.	แพรซื้อผ้าตัดเสื้อ 1.75 เมตร ซื้อผ้าตัดกระโปรง 2.25 เมตร แพรซื้อผ้ากี่เมตร (Prea buys 1.75 meters of cloth for her shirt and 2.25 meters for her skirt, how many meters of cloth Prea does buy?)
	04.	ร้านค้าขายปากกาด้ามละ 30 บาท ขาดทุน 25% ร้านค้าลงทุนซื้อปากกาด้ามละกี่บาท (A shop sells each pen for 30 Bath that makes 25% loss. How much does the shop invest with each pen?)
Fraction	05.	แม่ค้ามีปลาแห้ง $10\frac{1}{2}$กิโลกรัมแบ่งใส่ถุง ถุงละ $\frac{1}{4}$ กิโลกรัม จะแบ่งใส่ถุงได้ทั้งหมดกี่ถุง (A seller have dried fish $10\frac{1}{2}$ kilograms, divided into bags each bags weighs $\frac{1}{4}$ kilograms. How many bags of dried fish does the seller have?)
	06.	จงหาค่าของ $\frac{3}{7} \div \frac{9}{14} \times \frac{3}{2}$ (Find the value of $\frac{3}{7} \div \frac{9}{14} \times \frac{3}{2}$.)
	07.	จงหาค่าของ x จากสมการ $\frac{x}{2} - \frac{3}{5} = \frac{x}{5} + \frac{3}{10}$ (Find *x* from an equation $\frac{x}{2} - \frac{3}{5} = \frac{x}{5} + \frac{3}{10}$.)
	08.	จงหาค่า x จากสมการ $\frac{3x+1}{x+2} = \frac{3x-2}{x-1}$ (Find *x* from an equation $\frac{3x+1}{x+2} = \frac{3x-2}{x-1}$.)
Exponent	09.	จงหาค่าของ $3^2 \times 5^2 \times 7$ (Find the value of $3^2 \times 5^2 \times 7$.)

Category	***No***	***Mathematical questions***
	10.	ถ้า $x = 2$ และ $y = -3$ แล้ว $(x + y)^3$ มีค่าเท่าใด (If $x = 2$ and $y = -3$, what is the value of $(x + y)^3$.)
	11.	ถ้า a และ b เป็นคำตอบของสมการ $6x^2 - 2x - 8 = 0$ แล้ว $a + b$ มีค่าเท่าใด (If a and b are solutions of an equation $6x^2 - 2x - 8 = 0$, what is the value of $a + b$?)
	12.	จงหาค่าของ $\frac{a^2+5a+6}{a+3}$ (Find the value of $\frac{a^2+5a+6}{a+3}$.)
	13.	จงหาเซตคำตอบของสมการ $8^{x-1} \cdot 2^{-2x} = 4^{x+2}$ (Find a solution set of an equation $8^{x-1} \cdot 2^{-2x} = 4^{x+2}$.)
Trigonometric	14.	ถ้า $\sin A = \frac{4}{5}$ แล้ว $\tan A$ มีค่าเท่าใด (If $\sin A = \frac{4}{5}$, what is $\tan A$?)
	15.	$\sin A + \cos A = \frac{23}{17}$ และ $\sin A - \cos A = \frac{7}{17}$ แล้ว $\tan A$ มีค่าเท่าใด ($\sin A + \cos A = \frac{23}{17}$ and $\sin A - \cos A = \frac{7}{17}$, what is $\tan A$?)
	16.	ถ้า $7 \tan A = 6$ แล้ว ค่าของ $\frac{21\cos A - 8\sin A}{\cos A + 2\sin A}$ คือเท่าใด (If $7\tan A = 6$, then what is $\frac{21\cos A - 8\sin A}{\cos A + 2\sin A}$?)
Logarithm	17.	จงหาค่าของ $\log_5 \sqrt{125}$ (Find the value of $\log_5 \sqrt{125}$.)
	18.	ให้ $\log_{27} 5 = \mathrm{a}$ และ $\log_5 8 = \mathrm{b}$ จงหาค่าของ $\log_3 2$ (Let $\log_{27} 5 = \mathrm{a}$ and $\log_5 8 = \mathrm{b}$, what is $\log_3 2$?)
	19.	กำหนดให้ $\log 2 = 0.3010$ และ $\log 5 = 0.6990$ จงหาค่าของ $\log\sqrt{\frac{4}{5}}$ (Let $\log 2 = 0.3010$ and $\log 5 = 0.6990$, what is $\log\sqrt{\frac{4}{5}}$?)
Root	20.	จงหาค่าของ $\sqrt{112} + \sqrt[3]{343} - \sqrt{448}$ (Find the value of $\sqrt{112} + \sqrt[3]{343} - \sqrt{448}$.)
	21.	ผลบวกของรากของสมการ $\sqrt{x-1} = \mathrm{x} - 1$ มีค่าเท่าไร (What is a summation of solutions of an equation, $\sqrt{x-1} = \mathrm{x} - 1$?)
	22.	จงหาเซตคำตอบของอสมการ $\sqrt{x^2 - 6\mathrm{x} + 9} \leq 4$ (What is a solutions set of an inequality $\sqrt{x^2 - 6\mathrm{x} + 9} \leq 4$?)
	23.	ถ้า $\sqrt{a} - \frac{1}{\sqrt{a}} = \sqrt{3}$ แล้ว $\sqrt{a} + \frac{1}{\sqrt{a}}$ มีค่าเท่าใด (If $\sqrt{a} - \frac{1}{\sqrt{a}} = \sqrt{3}$, what is $\sqrt{a} + \frac{1}{\sqrt{a}}$?)
	24.	ผลบวกของคำตอบของสมการ $\sqrt{\frac{x}{x-1}} + \sqrt{\frac{x-1}{x}} = 2\frac{1}{6}$ มีค่าเท่าใด (What is a summation of solutions of an equation $\sqrt{\frac{x}{x-1}} + \sqrt{\frac{x-1}{x}} = 2\frac{1}{6}$?)
Summation	25.	จงหาค่าของ $\sum_{i=1}^{50} \mathrm{i}$ (Find the value of $\sum_{i=1}^{50} \mathrm{i}$.)
	26.	ถ้า $\sum_{n=2}^{\infty} \frac{1}{n^4 - n^2} = \mathrm{A}$ แล้ว $\sum_{n=2}^{\infty} \frac{1}{n^2}$ มีค่าเท่าใด (If $\sum_{n=2}^{\infty} \frac{1}{n^4 - n^2} = \mathrm{A}$, what is $\sum_{n=2}^{\infty} \frac{1}{n^4 - n^2} = \mathrm{A}$?)

Category	*No*	*Mathematical questions*
	27.	ถ้า $\sum_{i=1}^{\infty}\left(\frac{3}{2y-5}\right)^{i}$ ลู่เข้าแล้ว y มีค่าเท่าใด (If $\sum_{i=1}^{\infty}\left(\frac{3}{2y-5}\right)^{i}$ converts, what is *y*?)
Vector	28.	ถ้า $\vec{u}$ แทนระยะทาง 50 กม. ในทิศ 170° จะได้ว่า $-\vec{u}$ คืออะไร (If $\vec{u}$ is 50 km. in length and 170° in direction, what is $-\vec{u}$?)
	29.	ให้ $\vec{u} = 2\vec{\imath} - 3\vec{\jmath}$ และ $\vec{a} = \vec{\imath} + \vec{\jmath}$ จงหา $\vec{u} - \vec{a}$ (Let $\vec{u} = 2\vec{\imath} - 3\vec{\jmath}$ and $\vec{a} = \vec{\imath} + \vec{\jmath}$, what is $\vec{u} - \vec{a}$?)
	30.	ให้ $\vec{a} = 3\vec{\imath} - 4\vec{\jmath} + 2\vec{k}$ และ $\vec{b} = \vec{\imath} - \vec{\jmath} + 2\vec{k}$ ถ้า y เป็นมุมระหว่าง $\vec{a}$ และ $\vec{b}$ แล้ว $\sin y$ เป็นเท่าใด (Let $\vec{a} = 3\vec{\imath} - 4\vec{\jmath} + 2\vec{k}$ and $\vec{b} = \vec{\imath} - \vec{\jmath} + 2\vec{k}$. If *y* is an angle between $\vec{a}$ and $\vec{b}$, what is $\sin y$?)
Limit	31.	จงหาค่าของ $\lim_{x \to 0} \sqrt{2x + 3}$ (Find the value of $\lim_{x \to 0} \sqrt{2x + 3}$.)
	32.	ค่าของ $\lim_{x \to 1} \frac{x^2 - 1}{2x + 1}$ มีค่าเท่าใด (What is $\lim_{x \to 1} \frac{x^2 - 1}{2x + 1}$?)
	33.	จงหาค่าของ $\lim_{n\to\infty}(5 + \frac{2}{n})$ (Find the value of $\lim_{n\to\infty}(5 + \frac{2}{n})$.)
Integral	34.	จงหาค่าของ $\int(x^2 - 2x)dx$ (Find the value of $\int(x^2 - 2x)dx$.)
	35.	กำหนดให้ f เป็นฟังก์ชันพหุนามที่ $f(x) = x^4 + 2x^3 - x^2 + x - 1$ แล้วค่าของ $\int_0^1 f(x)dx$ เท่ากับเท่าใด (Let *f* is a function that $f(x) = x^2 + x - 1$, what is $\int_0^1 f(x)dx$?)

G.2 *i-Math* Pronunciations

Each problem (IN01 – IN35) is compared between original math text in the text form (OM) and the pronunciations generated by *i-Math* (PM).

- A missing word refers to the word that *i-Math* do not generate, denoting by **[ ]**. It causes the problem to be meaningless or the problem conveys a different meaning from the original.
- An incorrect word refers to the word that i-*Math* differently from what the original math text refers indicating by **highlight**, it affects the meaning of the problem.
- **Underline typeface** denotes the word or phrase is missing, incorrect or wrongly placed but it does not affect the meaning of the problem.

No	***Compare***	***Mathematical questions***
01.	IN	จงหาค่าของ 72 × 144 ÷ 27
	OM	จงหาค่าของ เจ็ด สิบ สอง คูณ หนึ่ง ร้อย สี่ สิบ สี่ หาร ด้วย ยี่ สิบ เจ็ด
	PM	จงหาค่าของ เจ็ด สิบ สอง คูน หนึ่ง ร้อย สี่ สิบ สี่ หาน ด้วย ยี่ สิบ เจ็ด
02.	IN	จงหาค่าของ x และ y ที่ทำให้สมการ $7x + 12y = 220$
	OM	จงหาค่าของ เอ๊กซ์ และ วาย ที่ทำให้สมการ เจ็ด เอ๊กซ์ บวก สิบ สอง วาย เท่ากับ สอง ร้อย ยี่ สิบ
	PM	จงหาค่าของ เอ๊กซ์ และ วาย ที่ทำให้สม มะ กาน เจ็ด เอ๊กซ์ บวก สิบ สอง วาย เท่า กับ สอง ร้อย ยี่ สิบ
03.	IN	แพรซื้อผ้าตัดเสื้อ 1.75 เมตร ซื้อผ้าตัดกระโปรง 2.25 เมตร แพรซื้อผ้ากี่เมตร
	OM	แพรซื้อผ้าตัดเสื้อ หนึ่ง จุด เจ็ด ห้า เมตร ซื้อผ้าตัดกระโปรง สอง จุด สอง ห้า เมตร แพรซื้อผ้ากี่เมตร
	PM	แพรซื้อผ้าตัดเสื้อ หนึ่ง จุด เจ็ด ห้า เม้ด ซื้อผ้าตัดกระโปรง สอง จุด สอง ห้า เม้ด แพรซื้อผ้ากี่เม้ด
04.	IN	ร้านค้าขายปากกาด้ามละ 30 บาท ขาดทุน 25% ร้านค้าลงทุนซื้อปากกาด้ามละกี่บาท
	OM	ร้านค้าขายปากกาด้ามละ สาม สิบ บาท ขาดทุน ยี่ สิบ ห้า เปอร์เซนต์ ร้านค้าลงทุนซื้อปากกาด้ามละกี่บาท
	PM	ร้านค้าขายปากกาด้ามละ สาม สิบ บาท ขาดทุน [ ] เปอ เซ็น ร้านค้าลงทุนซื้อปากกาด้ามละกี่บาท
05.	IN	แม่ค้ามีปลาแห้ง10 $\frac{1}{2}$กิโลกรัมแบ่งใส่ถุง ถุงละ $\frac{1}{4}$ กิโลกรัม จะแบ่งใส่ถุงได้ทั้งหมดกี่ถุง
	OM	แม่ค้ามีปลาแห้ง สิบ เศษ หนึ่ง ส่วน สอง กิโลกรัมแบ่งใส่ถุง ถุงละ เศษ หนึ่ง ส่วน สี่ กิโลกรัม จะแบ่งใส่ถุงได้ทั้งหมดกี่ถุง
	PM	แม่ค้ามีปลาแห้ง สิบ เสด หนึ่ง ส่วน สอง กิโล่กรัม แบ่งใส่ถุง ถุงละ เสด หนึ่ง ส่วน สี่ กิโลกรัม จะแบ่งใส่ถุงได้ทั้งหมดกี่ถุง
06.	IN	จงหาค่าของ $\frac{3}{7} \div \frac{9}{14} \times \frac{3}{2}$
	OM	จงหาค่าของ เศษ สาม ส่วน เจ็ด หาร ด้วย เศษ เก้า ส่วน สิบ สี่ คูณ เศษ สาม ส่วน สอง
	PM	จงหาค่าของ เสด สาม ส่วน เจ็ด หาน ด้วย เสด เก้า ส่วน สิบ สี่ คูน เสด สาม ส่วน สอง
07.	IN	จงหาค่าของ x จากสมการ $\frac{x}{2} - \frac{3}{5} = \frac{x}{5} + \frac{3}{10}$
	OM	จงหาค่าของ เอ๊กซ์ จากสมการ เศษ เอ๊กซ์ ส่วน สอง ลบ เศษ สาม ส่วน ห้า เท่ากับ เศษ เอ๊กซ์ ส่วน ห้า บวก เศษ สาม ส่วน สิบ
	PM	จงหาค่าของ เอ๊กซ์ จากสม มะ กาน เสด เอ๊กซ์ ส่วน สอง ลบ เสด สาม ส่วน ห้า เท่า กับ เสด เอ๊กซ์ ส่วน ห้า บวก เสด สาม ส่วน สิบ

No	Compare	Mathematical questions
08.	IN	จงหาค่า x จากสมการ $\frac{3x+1}{x+2} = \frac{3x-2}{x-1}$
	OM	จงหาค่า เอ๊กซ์ จากสมการ เศษ สาม เอ๊กซ์ บวก หนึ่ง ทั้งหมด ส่วน เอ๊กซ์ บวก สอง เท่ากับ เศษ สาม เอ๊กซ์ ลบ สอง ทั้งหมด ส่วน เอ๊กซ์ ลบ หนึ่ง
	PM	จงหาค่า เอ๊กซ์ จากสม มะ กาน เสด สาม เอ๊กซ์ บวก หนึ่ง ทั้ง หมด ส่วน เอ๊กซ์ บวก สอง เท่า กับ เสด สาม เอ๊กซ์ ลบ สอง ทั้ง หมด ส่วน เอ๊กซ์ ลบ หนึ่ง
09.	IN	จงหาค่าของ $3^2 \times 5^2 \times 7$
	OM	จงหาค่าของ สาม ยกกำลัง สอง คูณ ห้า ยกกำลัง สอง คูณ เจ็ด
	PM	จงหาค่าของ สาม ยก กำ ลัง สอง คูน ห้า ยก กำ ลัง สอง คูน เจ็ด
10.	IN	ถ้า $x = 2$ และ $y = -3$ แล้ว $(x+y)^3$ มีค่าเท่าใด
	OM	ถ้า เอ๊กซ์ เท่ากับ สอง และ วาย เท่ากับ ลบ สาม แล้ว เอ๊กซ์ บวก วาย ทั้งหมด ยกกำลัง สาม มีค่าเท่าใด
	PM	ถ้า เอ๊กซ์ เท่า กับ สอง และ วาย เท่า กับ ลบ สาม แล้ว เอ๊กซ์ บวก วาย ทั้ง หมด ยก กำ ลัง สาม มีค่าเท่าใด
11.	IN	ถ้า a และ b เป็นคำตอบของสมการ $6x^2 - 2x - 8 = 0$ แล้ว $a + b$ มีค่าเท่าใด
	OM	ถ้า เอ และ บี เป็นคำตอบของสมการ หก เอ๊กซ์ ยกกำลัง สอง ลบ สอง เอ๊กซ์ ลบ แปด เท่ากับ ศูนย์ แล้ว เอ บวก บี มีค่าเท่าใด
	PM	ถ้า เอ และ บี เป็นคำตอบของสม มะ กาน หก เอ๊กซ์ ยก กำ ลัง สอง ลบ สอง เอ๊กซ์ ลบ แปด เท่า กับ สูน แล้ว เอ บวก บี มีค่าเท่าใด
12.	IN	จงหาค่าของ $\frac{a^2+5a+6}{a+3}$
	OM	จงหาค่าของ เศษ เอ ยกกำลัง สอง บวก ห้า เอ บวก หก ทั้งหมด ส่วน เอ บวก สาม
	PM	จงหาค่าของ เสด เอ ยก กำ ลัง สอง บวก ห้า เอ บวก หก ทั้ง หมด ส่วน เอ บวก สาม
13.	IN	จงหาเซตคำตอบของสมการ $8^{x-1} \cdot 2^{-2x} = 4^{x+2}$
	OM	จงหาเซตคำตอบของสมการ แปด ยกกำลัง เอ๊กซ์ ลบ หนึ่ง คูณ สอง ยกกำลัง ลบ สอง เอ๊กซ์ เท่ากับ สี่ ยกกำลัง เอ๊กซ์ บวก สอง
	PM	จงหาเซตคำตอบของสม มะ กาน แปด ยก กำ ลัง เอ๊กซ์ ลบ หนึ่ง คูน สอง ยก กำ ลัง ลบ สอง เอ๊กซ์ เท่า กับ สี่ ยก กำ ลัง เอ๊กซ์ บวก สอง
14.	IN	ถ้า $\sin A = \frac{4}{5}$ แล้ว $\tan A$ มีค่าเท่าใด
	OM	ถ้า ซายน์ เอใหญ่ เท่ากับ เศษ สี่ ส่วน ห้า แล้ว แทน เอใหญ่ มีค่าเท่าใด
	PM	ถ้า ซายน์ เอ ใหญ่ เท่า กับ เสด สี่ ส่วน ห้า แล้ว แทน เอ ใหญ่ มีค่าเท่าใด
15.	IN	$\sin A + \cos A = \frac{23}{17}$ และ $\sin A - \cos A = \frac{7}{17}$ แล้ว $\tan A$ มีค่าเท่าใด
	OM	ซายน์ เอใหญ่ บวก คอส เอใหญ่ เท่ากับ เศษ ยี่ สิบ สาม ส่วน สิบ เจ็ด และ ซายน์ เอใหญ่ ลบ คอส เอใหญ่ เท่ากับ เศษ เจ็ด ส่วน สิบ เจ็ด แล้ว แทน เอใหญ่ มีค่าเท่าใด
	PM	ซายน์ เอ ใหญ่ บวก คอด เอ ใหญ่ เท่า กับ เสด ยี่ สิบ สาม ส่วน สิบ เจ็ด และ ซายน์ เอ ใหญ่ ลบ คอด เอ ใหญ่ เท่า กับ เสด เจ็ด ส่วน สิบ เจ็ด แล้ว แทน เอ ใหญ่ มีค่าเท่าใด

No	*Compare*	*Mathematical questions*
16.	IN	ถ้า $7\tan A = 6$ แล้วค่าของ $\frac{21\cos A-8\sin A}{\cos A+2\sin A}$ คือเท่าใด
	OM	ถ้า เจ็ด แทน เอใหญ่ เท่ากับ หก ค่าของ เศษ ยี่ สิบ เอ็ด คอส เอใหญ่ ลบ แปด ซายน์ เอใหญ่ ทั้งหมด ส่วน คอส เอใหญ่ บวก สอง ซายน์ เอใหญ่ คือเท่าใด
	PM	ถ้า เจ็ด แทน เอ ใหญ่ เท่า กับ หก ค่าของ เสด ยี่ สิบ เอ็ด คอด เอ ใหญ่ ลบ แปด ซายน์ เอ ใหญ่ ทั้ง หมด ส่วน คอด เอ ใหญ่ บวก สอง ซายน์ เอ ใหญ่ คือเท่าใด
17.	IN	จงหาค่าของ $\log_5 \sqrt{125}$
	OM	จงหาค่าของ ล๊อก รากที่ สอง ของ หนึ่ง ร้อย ยี่ สิบ ห้า ฐาน ห้า
	PM	จงหาค่าของ ล๊อก ราก ที่ สอง ของ หนึ่ง ร้อย ยี่ สิบ ห้า ถาน ห้า
18.	IN	ให้ $\log_{27} 5 = a$ และ $\log_5 8 = b$ จงหาค่าของ $\log_3 2$
	OM	ให้ ล๊อก ห้า ฐาน ยี่ สิบ เจ็ด เท่ากับ เอ และ ล๊อก แปด ฐาน ห้า เท่ากับ บี จงหาค่าของ ล๊อก สอง ฐาน สาม
	PM	ให้ ล๊อก ห้า ถาน ยี่ สิบ เจ็ด เท่า กับ เอ และ ล๊อก แปด ถาน ห้า เท่า กับ บี จงหาค่าของ ล๊อก สอง ถาน สาม
19.	IN	กำหนดให้ $\log 2 = 0.3010$ และ $\log 5 = 0.6990$ จงหาค่าของ $\log\sqrt{\frac{4}{5}}$
	OM	กำหนดให้ ล๊อก สอง เท่ากับ ศูนย์ จุด สาม ศูนย์ หนึ่ง ศูนย์ และ ล๊อก ห้า เท่ากับ ศูนย์ จุด หก เก้า เก้า ศูนย์ จงหาค่าของ ล๊อก รากที่ สอง ของ เศษ สี่ ส่วน ห้า
	PM	กำหนดให้ ล๊อก สอง เท่า กับ สูน จุด สาม สูน หนึ่ง สูน และ ล๊อก ห้า เท่า กับ สูน จุด หก เก้า เก้า สูน จงหาค่าของ ล๊อก ราก ที่ สอง ของ เสด สี่ ส่วน ห้า
20.	IN	จงหาค่าของ $\sqrt{112} + \sqrt[3]{343} - \sqrt{448}$
	OM	จงหาค่าของ รากที่ สอง ของ หนึ่ง ร้อย สิบ สอง บวก รากที่ สาม ของ สาม ร้อย สี่ สิบ สาม ลบ รากที่ สอง ของ สี่ ร้อย สี่ สิบ แปด
	PM	จงหาค่าของ ราก ที่ สอง ของ หนึ่ง ร้อย สิบ สอง บวก ราก ที่ สาม ของ สาม ร้อย สี่ สิบ สาม ลบ ราก ที่ สอง ของ สี่ ร้อย สี่ สิบ แปด
21.	IN	ผลบวกของคำตอบของสมการ $\sqrt{x-1} = x-1$ มีค่าเท่าไร
	OM	ผลบวกของคำตอบของสมการ รากที่ สอง ของ เอ๊กซ์ ลบ หนึ่ง เท่ากับ เอ๊กซ์ ลบ หนึ่ง มีค่าเท่าไร
	PM	ผลบวกของคำตอบของสม มะ กาน ราก ที่ สอง ของ เอ๊กซ์ ลบ หนึ่ง เท่า กับ เอ๊กซ์ ลบ หนึ่ง มีค่าเท่าไร
22.	IN	จงหาเซตคำตอบของอสมการ $\sqrt{x^2-6x+9} \leq 4$
	OM	จงหาเซตคำตอบของอสมการ รากที่ สอง ของ เอ๊กซ์ ยกกำลัง สอง ลบ หก เอ๊กซ์ บวก เก้า น้อยกว่า หรือ เท่ากับ สี่
	PM	จงหาเซตคำตอบของอะสม มะ กาน ราก ที่ สอง ของ เอ๊กซ์ ยก กำ ลัง สอง ลบ หก เอ๊กซ์ บวก เก้า น้อย กว่า หรือ เท่า กับ สี่

No	Compare	Mathematical questions
23.	IN	ถ้า $\sqrt{a} - \frac{1}{\sqrt{a}} = \sqrt{3}$ แล้ว $\sqrt{a} + \frac{1}{\sqrt{a}}$ มีค่าเท่าใด
	OM	ถ้า รากที่สอง ของ เอ ลบ เศษ หนึ่ง ส่วน รากที่ สอง ของ เอ เท่ากับ รากที่ สอง ของ สาม แล้ว รากที่ สอง ของ เอ บวก เศษ หนึ่ง ส่วน รากที่ สอง ของ เอ มีค่าเท่าใด
	PM	ถ้า ราก ที่ สอง ของ เอ ลบ เสด หนึ่ง ส่วน ราก ที่ สอง ของ เอ เท่า กับ ราก ที่ สอง ของ สาม แล้ว ราก ที่ สอง ของ เอ บวก เสด หนึ่ง ส่วน ราก ที่ สอง ของ เอ มีค่าเท่าใด
24.	IN	ผล บวก ของ คำตอบ ของ สมการ $\sqrt{\frac{x}{x-1}} + \sqrt{\frac{x-1}{x}} = 2\frac{1}{6}$ มีค่าเท่าใด
	OM	ผลบวกของคำตอบของสมการ รากที่ สอง ของ เศษ เอ๊กซ์ ส่วน เอ๊กซ์ ลบ หนึ่ง บวก รากที่ สอง ของ เศษ เอ๊กซ์ ลบ หนึ่ง ทั้งหมด ส่วน เอ๊กซ์ เท่ากับ สอง เศษ หนึ่ง ส่วน หก มีค่าเท่าใด
	PM	ผลบวกของคำตอบของสม มะ กาน ราก ที่ สอง ของ เสด เอ๊กซ์ ส่วน เอ๊กซ์ ลบ หนึ่ง บวก ราก ที่ สอง ของ เสด เอ๊กซ์ ลบ หนึ่ง ทั้ง หมด ส่วน เอ๊กซ์ เท่า กับ สอง เสด หนึ่ง ส่วน หก มีค่าเท่าใด
25.	IN	จงหาค่าของ $\sum_{i=1}^{50} i$
	OM	จงหาค่าของ ซัมเมชัน ของ ไอ จาก ไอ เท่ากับ หนึ่ง ถึง ห้า สิบ
	PM	จงหาค่าของ ซัม เม ชั่น ของ ไอ จาก ไอ เท่า กับ หนึ่ง ถึง ห้า สิบ
26.	IN	ถ้า $\sum_{n=2}^{\infty} \frac{1}{n^4-n^2} = A$ แล้ว $\sum_{n=2}^{\infty} \frac{1}{n^2}$ มีค่าเท่าใด
	OM	ถ้า ซัมเมชัน ของ เศษ หนึ่ง ส่วน เอ็น ยกกำลัง สี่ ลบ เอ็น ยกกำลัง สอง จาก เอ็น เท่ากับ สอง ถึง อินฟินิตี้ เท่ากับ เอใหญ่ แล้ว ซัมเมชัน ของ เศษ หนึ่ง ส่วน เอ็น ยกกำลัง สอง จาก เอ็น เท่ากับ สอง ถึง อินฟินิตี้ มีค่าเท่าใด
	PM	ถ้า ซัม เม ชั่น ของ เสด หนึ่ง ส่วน เอ็น ยก กำ ลัง สี่ ลบ เอ็น ยก กำ ลัง สอง จาก เอ็น เท่า กับ สอง ถึง อินฟินิตี้ เท่ากับ เอใหญ่ แล้ว ซัม เม ชั่น ของ เสด หนึ่ง ส่วน เอ็น ยก กำ ลัง สอง จาก เอ็น เท่า กับ สอง ถึง อิน ฟี นิ ตี้ มีค่าเท่าใด
27.	IN	ถ้า $\sum_{i=1}^{\infty}\left(\frac{3}{2y-5}\right)^i$ ลู่เข้าแล้ว y มีค่าเท่าใด
	OM	ถ้า ซัมเมชัน ของ เศษ สาม ส่วน สอง วาย ลบ ห้า ทั้งหมด ยกกำลัง ไอ จาก ไอ เท่ากับ หนึ่ง ถึง อินฟินิตี้ ลู่เข้าแล้ว วาย มีค่าเท่าใด
	PM	ถ้า ซัม เม ชั่น ของ เสด สาม ส่วน สอง วาย ลบ ห้า ทั้ง หมด ยก กำ ลัง ไอ จาก ไอ เท่า กับ หนึ่ง ถึง อิน ฟี นิ ตี้ ลู่เข้าแล้ว วาย มีค่าเท่าใด
28.	IN	ถ้า $\vec{u}$ แทนระยะทาง 50 กม. ในทิศ 170° จะได้ว่า $-\vec{u}$ คืออะไร
	OM	ให้ เวกเตอร์ ยู แทนระยะทาง ห้า สิบ กิโลเมตร ในทิศ หนึ่ง ร้อย เจ็ด สิบ องศา จะได้ว่า ลบ เวกเตอร์ คืออะไร
	PM	ให้ เว็ก เต้อ ยู แทนระยะทาง ห้า สิบ กิโลเม้ด ในทิศ หนึ่ง ร้อย เจ็ด สิบ องศา จะได้ว่า ลบ เว็ก เต้อ คืออะไร

No	*Compare*	*Mathematical questions*
29.	IN	ให้ $\vec{u} = 2\vec{i} - 3\vec{j}$ และ $\vec{a} = \vec{i} + \vec{j}$ จงหา $\vec{u} - \vec{a}$
	OM	ให้ เวกเตอร์ ยู เท่า กับ สอง เวกเตอร์ ไอ ลบ สาม เวกเตอร์ เจ และ เวกเตอร์ เอ เท่า กับ เวกเตอร์ไอ บวก เวกเตอร์ เจ จงหา เวกเตอร์ ยู ลบ เวกเตอร์ เอ
	PM	ให้ เว็ก เต้อ ยู เท่า กับ สอง เว็ก เต้อ ไอ ลบ สาม เว็ก เต้อ เจ และ เว็ก เต้อ เอ เท่า กับ เว็ก เต้อ ไอ บวก เว็ก เต้อ เจ จงหา เว็ก เต้อ ยู ลบ เว็ก เต้อ เอ
30.	IN	ให้ $\vec{a} = 3\vec{i} - 4\vec{j} + 2\vec{k}$ และ $\vec{b} = \vec{i} - \vec{j} + 2\vec{k}$ ถ้า y เป็นมุมระหว่าง $\vec{a}$ และ $\vec{b}$ แล้ว $\sin y$ เป็นเท่าใด
	OM	ให้ เวกเตอร์ เอ เท่ากับ สาม เวกเตอร์ ไอ ลบ สี่ เวกเตอร์ เจ บวก สอง เวกเตอร์ เค และ เวกเตอร์ บี เท่ากับ เวกเตอร์ ไอ ลบ เวกเตอร์ เจ บวก สอง เวกเตอร์ เค ถ้า วาย เป็นมุม ระหว่าง เวกเตอร์ เอ และ เวกเตอร์ บี แล้ว ซายน์ วาย เป็นเท่าใด
	PM	ให้ เว็ก เต้อ เอ เท่า กับ สาม เว็ก เต้อ ไอ ลบ สี่ เว็ก เต้อ เจ บวก สอง เว็ก เต้อ เค และ เว็ก เต้อ บี เท่า กับ เว็ก เต้อ ไอ ลบ เว็ก เต้อ เจ บวก สอง เว็ก เต้อ เค ถ้า วาย เป็นมุม ระหว่าง เว็ก เต้อ เอ และ เว็ก เต้อ บี แล้ว ซายน์ วาย เป็นเท่าใด
31.	IN	จงหาค่าของ $\lim_{x\to 0}\sqrt{2x + 3}$
	OM	จงหาค่าของ ลิมิต ของ รากที่ สอง ของ สอง เอ๊กซ์ บวก สาม ที่ เอ๊กซ์ เข้าใกล้ ศูนย์
	PM	จงหาค่าของ ลิ หมิด ของ ราก ที่ สอง ของ สอง เอ๊กซ์ บวก สาม ที่ เอ๊กซ์ เข้า ใกล้ สูน
32.	IN	ค่าของ $\lim_{x\to 1}\frac{x^2-1}{2x+1}$ มีค่าเท่าใด
	OM	ค่าของลิมิต ของ เศษ เอ๊กซ์ ยกกำลัง สอง ลบ หนึ่ง ทั้งหมด ส่วน สอง เอ๊กซ์ บวก หนึ่ง ที่ เอ๊กซ์ เข้าใกล้ หนึ่ง มีค่าเท่าใด
	PM	ค่าของลิ หมิด ของ เสด เอ๊กซ์ ยก กำ ลัง สอง ลบ หนึ่ง ทั้ง หมด ส่วน สอง เอ๊กซ์ บวก หนึ่ง ที่ เอ๊กซ์ เข้า ใกล้ หนึ่ง มีค่าเท่าใด
33.	IN	จงหาค่าของ $\lim_{n\to\infty}(5 + \frac{2}{n})$
	OM	จงหาค่าของ ลิมิต ของ ห้า บวก เศษ สอง ส่วน เอ็น ที่ เอ็น เข้าใกล้ อินฟินิตี้
	PM	จงหาค่าของ ลิ หมิด ของ ห้า บวก เสด สอง ส่วน เอ็น ที่ เอ็น [ ] อิน ฟิ นิ ตี้
34.	IN	จงหาค่าของ $\int(x^2 - 2x)dx$
	OM	จงหาค่าของ อินทีเกรต เอ๊กซ์ ยกกำลัง สอง ลบ สอง เอ๊กซ์ ดี เอ๊กซ์
	PM	จงหาค่าของ อิน ทิ เกรด เอ๊กซ์ ยก กำ ลัง สอง ลบ สอง เอ๊กซ์ ดี เอ๊กซ์
35.	IN	กำหนดให้ f เป็นฟังก์ชันพหุนามที่ $f(x) = x^2 + x - 1$ แล้วค่าของ $\int_0^1 f(x)dx$ เท่ากับเท่าใด
	OM	กำหนดให้ เอ๊ฟ เป็นฟังก์ชั่น พหุนาม ที่ เอ๊ฟ เอ๊กซ์ เท่ากับ เอ๊กซ์ ยกกำลัง สอง บวก เอ๊กซ์ ลบ หนึ่ง แล้วค่าของ อินทีเกรต เอ๊ฟ เอ๊กซ์ ดี เอ๊กซ์ จาก ศูนย์ ถึง หนึ่ง เท่ากับเท่าใด
	PM	กำหนดให้ เอ๊ฟ เป็นฟังชัน พะ หน นามที่ เอ๊ฟ เอ๊กซ์ เท่า กับ เอ๊กซ์ ยก กำ ลัง สอง บวก เอ๊กซ์ ลบ หะ นึ่ง แล้วค่าของ อิน ทิ เกรด เอ๊ฟ เอ๊กซ์ ดี เอ๊กซ์ จาก สูน ถึง หนึ่ง เท่ากับเท่าใด

APPENDIX H
USER SATISFACTION

This appendix contains the evaluation of *i-Math* with respect to user satisfaction as described in chapter 8. A questionnaire items used in the evaluation presents in the next section and section H.2.

H.1 Questionnaire for Teachers (Thai)

แบบสัมภาษณ์

เรื่อง

ความคิดเห็นต่อการใช้โปรแกรมอ่านภาษาคณิตศาสตร์ออกเสียงเป็นภาษาไทย (*i-Math*)

คำชี้แจง

แบบสอบถามนี้ผู้วิจัยสร้างขึ้นเพื่อศึกษาความพึงพอใจของการใช้โปรแกรมอ่านภาษาคณิตศาสตร์ออกเสียงเป็นภาษาไทยของ**ครูผู้สอน**นักเรียนที่มีความบกพร่องทางการมองเห็น แบ่งออกเป็น 3 ตอน ประกอบด้วย

ตอนที่ 1 ข้อมูลส่วนตัวของผู้เข้าร่วมงานวิจัย

ตอนที่ 2 ความคิดเห็นต่อการใช้โปรแกรมอ่านภาษาคณิตศาสตร์ออกเสียงเป็นภาษาไทย

ตอนที่ 3 ข้อเสนอแนะในการพัฒนาและปรับปรุงโปรแกรมอ่านภาษาคณิตศาสตร์ออกเสียงเป็นภาษาไทย

ตอนที่ 1 ข้อมูลส่วนตัวของผู้เข้าร่วมงานวิจัย

1. เพศ ☐ ชาย ☐ หญิง
2. อายุ...........................ปี
3. ระดับการศึกษา

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4. ลักษณะความสามารถในการมองเห็น

□ สามารถอ่านตัวอักษรขนาดบนจอคอมพิวเตอร์ได้

ขนาด 12 14 16 20 24 อื่นๆ (โปรดระบุ)................................

ตัวอักษรชนิดไหน..

□ สามารถอ่านตัวอักษรบนจอคอมพิวเตอร์ได้แต่ต้องใช้ขนาดตัวอักษรขยายใหญ่หรือใช้โปรแกรมขยายจอภาพหรือใช้แว่นขยาย

□ ไม่สามารถอ่านตัวอักษรบนจอคอมพิวเตอร์ได้ ต้องใช้เครื่องสังเคราะห์เสียงหรือโปรแกรมอ่านจอภาพและเครื่องแสดงผลเบรลล์เท่านั้น

□ อื่นๆ (โปรดระบุ)..

ตอนที่ 2 ความคิดเห็นต่อการใช้โปรแกรมอ่านภาษาคณิตศาสตร์ออกเสียงเป็นภาษาไทยต่อการเข้าใจโจทย์ปัญหาทางคณิตศาสตร์

5. ท่านพบว่า *i-Math* ช่วยให้นักเรียนอ่านเอกสารประกอบการเรียน แบบฝึกหัด และแบบทดสอบวิชาคณิตศาสตร์

ดีอย่างยิ่ง	5	4	3	2	1	ไม่ดีอย่างยิ่ง

6. ท่านพบว่า *i-Math* ช่วยให้นักเรียนสนใจเรียนคณิตศาสตร์มากยิ่งขึ้น

ดีอย่างยิ่ง	5	4	3	2	1	ไม่ดีอย่างยิ่ง

7. ท่านพบว่า *i-Math* มีประโยชน์ในการใช้งานร่วมกับโปรแกรมช่วยสอนที่มีประสิทธิภาพที่มีอยู่

ดีอย่างยิ่ง	5	4	3	2	1	ไม่ดีอย่างยิ่ง

8. ท่านพบว่า *i-Math* ช่วยส่งเสริมความสามารถของนักเรียนของท่านในการศึกษาคณิตศาสตร์ด้วยตนเอง

ดีอย่างยิ่ง	5	4	3	2	1	ไม่ดีอย่างยิ่ง

9. ท่านพบว่า *i-Math* ง่ายต่อการใช้งาน

ดีอย่างยิ่ง	5	4	3	2	1	ไม่ดีอย่างยิ่ง

10. ท่านจะใช้ *i-Math* ในชั้นเรียนคณิตศาสตร์

ดีอย่างยิ่ง	5	4	3	2	1	ไม่ดีอย่างยิ่ง

11. ท่านจะแนะนำ *i-Math* ให้กับเพื่อนครูท่านอื่นๆ

ดีอย่างยิ่ง	5	4	3	2	1	ไม่ดีอย่างยิ่ง

ตอนที่ 3 ข้อเสนอแนะในการพัฒนาและปรับปรุงโปรแกรมอ่านภาษาคณิตศาสตร์ออกเสียงเป็นภาษาไทย

12. ท่านต้องการให้ *i-Math* ปรับปรุงในเรื่องใดบ้าง โปรดระบุ

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13. ท่านมีคำถามเพิ่มเติมหรือข้อเสนอแนะอื่นๆ สำหรับ *i-Math* หรือไม่ อย่างไร

คำถามเพิ่มเติม

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ข้อเสนอแนะ

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H.2 Questionnaire for Students (Thai)

แบบสัมภาษณ์

เรื่อง

ความคิดเห็นต่อการใช้โปรแกรมอ่านภาษาคณิตศาสตร์ออกเสียงเป็นภาษาไทย (*i-Math*)

คำชี้แจง

แบบสอบถามนี้ผู้วิจัยสร้างขึ้นเพื่อศึกษาความพึงพอใจของการใช้โปรแกรมอ่านภาษาคณิตศาสตร์ออกเสียงเป็นภาษาไทยของ**นักเรียน**ที่มีความบกพร่องทางการมองเห็น แบ่งออกเป็น 3 ตอน ประกอบด้วย

ตอนที่ 1 ข้อมูลส่วนตัวของผู้เข้าร่วมงานวิจัย

ตอนที่ 2 ความคิดเห็นต่อการใช้โปรแกรมอ่านภาษาคณิตศาสตร์ออกเสียงเป็นภาษาไทย

ตอนที่ 3 ข้อเสนอแนะในการพัฒนาและปรับปรุงโปรแกรมอ่านภาษาคณิตศาสตร์ออกเสียงเป็นภาษาไทย

ตอนที่ 1 ข้อมูลส่วนตัวของผู้เข้าร่วมงานวิจัย

1. เพศ ☐ ชาย ☐ หญิง
2. อายุ...........................ปี
3. ระดับการศึกษา

   ....

4. ลักษณะความสามารถในการมองเห็น

□ สามารถอ่านตัวอักษรขนาดบนจอคอมพิวเตอร์ได้

ขนาด 12 14 16 20 24 อื่นๆ (โปรดระบุ)................................

ตัวอักษรชนิดไหน..

□ สามารถอ่านตัวอักษรบนจอคอมพิวเตอร์ได้แต่ต้องใช้ขนาดตัวอักษรขยายใหญ่หรือใช้โปรแกรมขยายจอภาพหรือใช้แว่นขยาย

□ ไม่สามารถอ่านตัวอักษรบนจอคอมพิวเตอร์ได้ ต้องใช้เครื่องสังเคราะห์เสียงหรือโปรแกรมอ่านจอภาพและเครื่องแสดงผลเบรลล์เท่านั้น

□ อื่นๆ (โปรดระบุ)...

ตอนที่ 2 ความคิดเห็นต่อการใช้โปรแกรมอ่านภาษาคณิตศาสตร์ออกเสียงเป็นภาษาไทยต่อการเข้าใจโจทย์ปัญหาทางคณิตศาสตร์

5. นักเรียนพบว่า *i-Math* ช่วยให้อ่านสัญลักษณ์และภาษาคณิตศาสตร์

ดีอย่างยิ่ง						ไม่ดีอย่างยิ่ง
	5	4	3	2	1	

6. นักเรียนพบว่า *i-Math* ช่วยให้นักเรียนสนใจเรียนคณิตศาสตร์มากยิ่งขึ้น

ดีอย่างยิ่ง						ไม่ดีอย่างยิ่ง
	5	4	3	2	1	

7. นักเรียนพบว่า *i-Math* ช่วยลดระยะเวลาในการทำแบบฝึกหัด

ดีอย่างยิ่ง						ไม่ดีอย่างยิ่ง
	5	4	3	2	1	

8. นักเรียนพบว่า *i-Math* มีประโยชน์ในการศึกษาคณิตศาสตร์

ดีอย่างยิ่ง						ไม่ดีอย่างยิ่ง
	5	4	3	2	1	

9. นักเรียนพบว่า *i-Math* ง่ายต่อการใช้งาน

ดีอย่างยิ่ง						ไม่ดีอย่างยิ่ง
	5	4	3	2	1	

10. นักเรียนจะใช้ *i-Math* ในการเรียนคณิตศาสตร์

ดีอย่างยิ่ง	5	4	3	2	1	ไม่ดีอย่างยิ่ง

11. นักเรียนจะแนะนำ *i-Math* ให้กับเพื่อนๆ

ดีอย่างยิ่ง	5	4	3	2	1	ไม่ดีอย่างยิ่ง

ตอนที่ 3 ข้อเสนอแนะในการพัฒนาและปรับปรุงโปรแกรมอ่านภาษาคณิตศาสตร์ออกเสียงเป็นภาษาไทย

12. นักเรียนต้องการให้ *i-Math* ปรับปรุงในเรื่องใดบ้าง โปรดระบุ

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13. นักเรียนมีคำถามเพิ่มเติมหรือข้อเสนอแนะอื่นๆ สำหรับ *i-Math* หรือไม่ อย่างไร

คำถามเพิ่มเติม

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