NTUs: An Intelligent Tutorial System Fosters Number Concepts Through Computational Scaffolding

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Abstract
The present article describes how scaffolding is implemented in an intelligent tutorial system call NTUs (Number Transcoding tUtorial System), and what are the results of the system tested empirically on a group of grade students in fostering their number concepts. To use NTUs, the system first analyzes a user’s errors on a number transcoding task, and the results of analysis are used to infer the user’s zone of proximal development (ZPD). A scaffolding process which was designed with inspiration from how people learn Chinese calligraphy will be provided next in the user’s ZPD. Empirical test indicates that NTUs can not only foster students’ number concepts but also attract them to use it.
A scaffold is a temporary framework that supports workers to construct a building. Wood, Bruner and Ross (1976) used this kind of “scaffolding” process as metaphor to illustrate how mothers assisted their young children in performing novel and complex tasks. According to Wood et al., in the scaffolding process, mothers would provide helps to the children on those elements of tasks that are beyond the children’s capacity, and would allow the children to concentrate upon those elements that are within their range of competence.

The purpose of the present research is to test the effectiveness of an intelligent tutorial system called NTUs (Number Transcoding tUtorial System) in fostering grade students’ number concepts. The system adopts computational scaffolding strategy to teach number concepts by asking the users to perform a number transcoding task. In the following sections, the design of the system and the results that the system is tested in an experiment are discussed.

The design of NTUs

To show clearly how NTUs is designed, the task and the domain knowledge the task tested will be discussed first. Following, the process of scaffolding used in the system will be discussed.

The Number Transcoding Task

Some researchers argued that the Chinese number system correspond “regularly” with the Arabic numeral system and that such correspondence facilitates Chinese children to learn number concepts and arithmetic (Fuson & Kwon, 1991). For example, “21” is expressed as “er(2)-shi(10)-yi(1)” in Chinese. That is, Chinese number system is regular because usually each digit of a multiple-digit number is associated with two syllables, one represents the digit and the other represents the place value of the digit in the number. However, Hue (1997) pointed out that there are two types of irregular number words in Chinese. One involves numbers containing consecutive “0”s. For example, “2002” is expressed as “er(2)-chien(1000)-lin(o)-er(2)”. The two consecutive “0”s are expressed only once in
the number word. Secondly, the place value of the rightmost non-zero digit of a multiple-digit number can be omitted in number word. Thus, “2200” can be expressed as “er(2)-chien(1000)-er(2)-bai(100)” or “er(2)-chien(1000)-er(2)”. In an experiment, Hue (1997) asked a group of grade students (from 2\textsuperscript{nd} to 6\textsuperscript{th} grade) to transcode Chinese number words into Arabic numbers. He found that (1) the students made more errors when they were transcoding irregular number words than regular ones, (2) the errors that the students made could be categorized into a few categories, each indicating that certain number concepts were not been used in transcoding.

Computational Scaffolding

To implement scaffolding in teaching, researchers usually adopt a social constructivist perspective and argue that successive scaffolding requires teachers to determining a student’s “zone of proximal development” (ZPD), and scaffolding should be in the ZPD (Roehler & Cantlon, 1997). Although the concept of ZPD is easily understood conceptually, its definition is vague and usually post hoc in nature. For example, it was typically defined following Vygotsky’s original idea as “the distance between the child’s actual developmental level as determined by independent problem solving and the higher level of potential development as determined through problem solving under adult guidance and in collaboration with more capable peers (Wertsch, 1985, pp. 67-68)”. According to the definitions, it is difficult, if not impossible, to determine a child’s ZPD before the child has been taught and tested. This creates a paradox for a teacher because in order to set up scaffolding process the teacher needs to know the students’ ZPDs, however ZPD could only be determined after teaching.

The paradox of locating ZPD creates much difficulty when researchers try to design intelligent tutoring system (ITS) to perform scaffolding, because a concept has to be “computational” to be programmed in computer and ZPD is certainly not “computational” if it is defined strictly according to Vygotsky’s original idea. There are a few computerized learning environments providing “computational” scaffolding, however the way ZPD was defined in these systems was just “spiritually” following Vygotsky’s original idea. For example, in MEMOLAB (Mendelsohn, 1996), a learner goes through a sequence of microworlds, or levels, to gain knowledge of experimental psychology. Each level consists of a different set of psychological experiments, and a learner requires to use different sets of commands to create or to modify the components of the experiments in different levels. Thus, ZPD is operationally defined as the difference between level L and L+1. However, the commands used in different levels are the same for all the learners and were assigned by the researchers.
The way NTUs handled the ZPD paradox was similar as MEMOLAB, only that NTUs was inspired by how human tutors interact with their tutees (Lepper, Drake & O'Donnell-Johnson, 1997). Lepper et al. found that good tutors constantly alert to tutees’ systematic errors, and that the tutors are continuously diagnosing, monitoring and fixing the misconceptions underlying tutees’ errors. Thus, NTUs will infer a user’s knowledge based on a pre-designed structure of number concepts and the errors the user made on a test. That is, the ZPD of a user is defined in NTUs as the deficient number concepts indicated in the errors the user made on the test.

To be more specific, NTUs consists of four subsystems.

Knowledge representation system. The number concepts require to transcode correctly Chinese number words into Arabic numbers are represented in the system using the INFOMAP algorithm design by Hsu (Hsu, Wu, & Chen, 2001). In addition, the system represents the typology of Chinese number words. The words are organized according to the regularity and the quantity the words represented.

Problem posing system. The system writes outs problems for users to solve based on the knowledge represented in the knowledge representation system. In NTUS, two problems are posed for each word type. The users interact with NTUs through two cartoon characters, a prince and his mentor, who are taking an adventurous journey to save a princess. In the journey, the prince has to compete with evil force in a number of computer games in order to arrive at the princess’ castle. The problems that the problem posing system posed are embedded in the computer games.

Error diagnosis system. According to our previous studies, grade students are likely to make four types of systematic errors in a number transcoding task. The errors and the deficient number concepts indicated by the errors were represented in the system using INFOMAP. The test results will be feed into the present system, and the errors along with their types and deficient number concepts with be computed. The results computed by the present system will feed to the teaching system so that scaffolding will proceed.

Teaching system. The design of the scaffolding process used in NTUs was inspired by how people learn to write Chinese calligraphy. A calligraphy master will guide a new pupil to develop his/her writing style through four stages. In the “leading” stage, the master will ask the pupil to hold a brush pen, and he will hold the pupil’s hand while writing some “basic” strokes. The pupil will learn how to write the strokes by feeling how the master uses the brush. In “pattern tracing” stage, the master will write a few characters as patterns, and the pupil will trace the characters to learn how strokes are put together to form characters. In the “coping” stage, the pupil will imitate the writings of famous calligraphy maters, and learn further how strokes of a character should be arranged in considering the figures of the characters surrounded it.
Finally, in the “stylization” stage, the pupil will learn different writing styles and develop his/her own style.

In NTUs, when a user is diagnosed needed to learn certain number concept, the system will follow a procedure similar to how people learn to write Chinese calligraphy to build (and to fade away) scaffolds to allow the user to learn the concept. In the first stage, the computer “leads” the problem solving process and the user watches how each step the computer takes to solve a problem. In the second stage, in each step of the process to solve a problem, the computer will finish only part of it. The user needs to finish the rest. In the third stage, the computer will not solve the problem for the user, but only list the steps needed to solve it. The user needs to solve the problem all by himself/herself. Finally, the computer will generate problems and embedded them in different context for the user to solve.

In each scaffolding stage, the computer will check for the user’s answer. The teaching will not move to an advanced stage unless the user can solve all the problems of the stage his working on correctly. For people who make different errors, the computer will assume that their knowledge of the number concepts is different, and they will receive different scaffolding materials although the scaffolding processes they experienced are the same.

The effectiveness of NTUs

The NTUs was test on a group of 3rd graders. The 130 students were divided into two groups. Both the control and the experimental group received diagnosis test, however only the experimental group received scaffolding teaching. All the subjects received a paper and pencil test using another set of problems generated by the problem posing system and a questionnaire to indicate their attitude toward the system. The results of the test and questionnaire were listed in Table 1 and 2, which indicated that NTUs is not only an effective way to foster students’ number concepts but also an attractive educationware.

References


Table 1: Pre- and post-scaffolding test results (percent of errors) of two groups of students on number transcoding tasks.

<table>
<thead>
<tr>
<th></th>
<th>Experimental group</th>
<th>Control group</th>
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<tbody>
<tr>
<td>Pre-test</td>
<td>19.01%</td>
<td>15.76%</td>
</tr>
<tr>
<td>Post-test</td>
<td>13.02%</td>
<td>15.23%</td>
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</table>

Table 2: The students’ attitude toward NTUs, indicated in a 9-item questionnaire. The items were grouped into the three dimensions of attitude.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Negative</th>
<th>Neutral</th>
<th>Positive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognition</td>
<td>27.03%</td>
<td>12.21%</td>
<td>60.65%</td>
</tr>
<tr>
<td>Affect</td>
<td>8.43%</td>
<td>35.17%</td>
<td>46.51%</td>
</tr>
<tr>
<td>Behavior</td>
<td>8.14%</td>
<td>0.0%</td>
<td>91.87%</td>
</tr>
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