Original Article

**Acquisition and Expansion of Kanji Vocabulary
through Computer-Based Teaching in a Student
with Mental Retardation: Analysis by
Equivalence Relations**

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The purpose of the present study was to examine whether an arbitrary matching-to-sample procedure with a differential outcome in a computer-based teaching method would be effective for establishing equivalence relations for three stimuli (visual picture, visual kanji word, and spoken word) and for expanding kanji vocabulary for a student with mental retardation. We developed a computer-based teaching program that the student could use without adult assistance. The program allowed the student to make progress in accordance with his present learning level. The results showed that the computer-based teaching developed in the present study was effective for establishing equivalence relations in the student with mental retardation and that the transfer of selection-based responding on the computer to topography-based responding, such as reading and writing with ordinary paper materials, did emerge. The results showed that the use of a daily teaching program in the home setting, in which the student spontaneously used the computer, had a remarkable effect on the student's kanji vocabulary. These results are discussed in terms of the necessary conditions for establishing linguistic skills and the applicability of computer-based teaching in special education.

Key Words: computer-based teaching, kanji vocabulary, equivalence relations, home setting, student with mental retardation

Equivalence relations are one of the basic conditions of language acquisition (Sakagami, Yamamoto, & Jitsumori, 1994; Saunders, 1989; Sidman, 2000; Sidman & Tailby, 1982; Stromer & Mackay, 1996; Yamamoto, 1992). Equivalence relations are

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established through an arbitrary matching-to-sample procedure. When Stimulus A1 (the spoken word /inu/) appears as a sample stimulus, the student is required to select B1 (a picture of a dog), and when A2 (the spoken word /neko/) is the sample, the student is required to select B2 (a picture of a cat). Also, when B1 (the picture of a dog) appears as a sample, the student is required to select C1 (the kanji character for dog “犬”), and when B2 (the picture of a cat) is the sample, the student is required to select C2 (the kanji character for cat “猫”). Arbitrary matching-to-sample teaching may generate derived stimulus relations. That is, when A1 appears as a sample, the student may select C1 without any teaching, and when A2 appears as a sample, the student may select C2 without any teaching. Such derived stimulus relations established by arbitrary matching-to-sample tasks have been called “stimulus equivalence” (Sidman & Tailby, 1982) or “equivalence relations” (Sidman, 2000). Since students with developmental disabilities have difficulty producing equivalence relations (Devany, Hayes, & Nelson, 1986; Yamamoto, 1994), recent studies have investigated what kinds of teaching methods would facilitate the emergence of equivalence relations and improve linguistic skills (Eikeseth & Smith, 1992; Saunders, 1989; Stromer & Mackay, 1996; Yamamoto, 1994; Yamamoto & Tokutake, 1997).

To comprehend the meaning of words and establish reading of those words, the three stimuli employed (visual picture, visual word, and spoken word) should be equivalent and two kinds of ordinary matching-to-sample teaching (e.g., “spoken word→picture” and “picture→visual word”) should be used. On the other hand, when we present the differential outcome stimulus (spoken word) to the correct selection of the comparison stimulus (visual word) in the presentation of the sample stimulus (visual picture), we can establish 3 stimulus relations at one time among the sample, comparison, and differential outcome stimuli (Dube, McIlvane, Mackay, & Stoddard, 1987; Dube, McIlvane, Maguire, Mackay, & Stoddard, 1989; Dube & McIlvane, 1995). This procedure would be efficient, because one arbitrary matching-to-sample lesson would produce 5 derived relations among 3 stimuli without further teaching. We must empirically examine whether these three stimuli are equivalent when applying the arbitrary matching-to-sample procedure with a differential outcome (Sidman, 2000).

In the present study, we developed a method for teaching the modified matching-to-sample procedure with a differential outcome, applied it to a student with mental retardation, and evaluated whether equivalence relations emerged. Since equivalence relations are the basis of the acquisition of linguistic skills, we need to develop an effective and efficient teaching program for applying the paradigm of equivalence relations in an educational setting (Stromer, Mackay, & Stoddard, 1992). Recent studies showed that, for students with developmental disabilities, computer-based teaching is effective for establishing various linguistic skills, such as spelling (Stromer & Mackay, 1992), vocabulary acquisition (Stromer, Mackay, McVay, & Fowler, 1998), listening (Merzenich, Jenkins, Johnston, Schreiner, Miller, & Tallal, 1996), comprehension (Tallal, Miller, Bedi, Byma, Wang, Nagarajan, Schreiner, Jenkins, & Merzenich, 1996), sentence construction (Yamamoto & Miya, 1999), and

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grammatical development (Tallal et al., 1996).

Introducing computer-based teaching to an educational setting has the advantage of allowing students to learn by themselves. Also, such teaching can enhance students' on-task behavior by providing consistent and direct presentation of discriminative and feedback stimuli (Jones, Torgenson, & Sexton, 1987). Using computer-based teaching, students can automatically progress through the curriculum in accordance with their individual learning level, having fun in the classroom and at home for a relatively long time without any assistance from adults. Such everyday intensive teaching can contribute to the drastic improvement of linguistic skills (Merzenich et al., 1996; Tallal et al., 1996).

The learning of kanji vocabulary is often difficult for students with mental retardation. The purpose of the present study was to examine whether employing a procedure for arbitrary matching-to-sample with a differential outcome in computer-based teaching would be effective for establishing equivalence relations for three stimuli (visual picture, visual kanji word, and spoken word). We evaluated the emergence of equivalence relations for comprehending, naming, and reading skills both in computer-based responding and the transfer of such skills to paper-based responding. We developed a computer-based teaching program that students could learn by themselves that would allow them to progress at their own speed. We also examined the effect of home-based computer teaching on expanding kanji vocabulary.

We attempted to answer the following research questions in the present study:

- (1) Did the arbitrary matching-to-sample procedure with a differential outcome establish the equivalence relations among three stimuli (visual picture, visual kanji word, spoken word)?
- (2) Did the systematic teaching procedure of the matching-to-sample materials promote errorless learning?
- (3) Was the daily teaching with a computer in a home-based setting effective for expanding kanji vocabulary?
- (4) Did the student spontaneously use the computer every day?
- (5) Did the student make correct responses when paper materials were presented?
- (6) Did the parents have a positive impression of changes in the student and for using home-based computer teaching?

1. Method

1-1. *Participants*

A student with moderate mental retardation participated in the present study. His chronological age was 8 years 4 months at the start of the study. His IQ score on the WISC-R was 40, his vocabulary age on the Picture Vocabulary Test was 4 years 3 months, and he could follow simple instructions from an adult. He often talked to adults, but using a limited vocabulary, so he often repeated the same sentences. He was enrolled in a special education class at the public elementary school. He came to the laboratory at the university once a week to receive special

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Stimulus Set				
Visual Picture
	(bamboo)	(sky)	(shell)	(grass)
Visual Kanji	竹	空	貝	草
Spoken word	/take/	/sora/	/kai/	/kusa/

FIG. 1 An example of stimulus set. Each stimulus set consisted of 4 items. Each item consisted of 3 stimuli (visual picture, visual kanji word, and spoken word).

instruction in communication and academic skills.

The student could read and write all the hiragana syllables (Japanese phonograms), but he could not read any kanji (Japanese ideograms), except for his name. Though he had been taught reading and writing kanji by his teacher and at home by his parents, he could not learn new kanji. When he had difficulties in accomplishing an academic task, he escaped from the situation or showed no response to the task. He often looked at the teacher's face to get cues about the desired answer. His errors were often the result of position or stimulus preference.

1-2. Apparatus

An Apple Macintosh computer (a Power Macintosh 8500/150[®] at the university and a Performa 5440[®] at his home) with an Apple desktop bus mouse was used to present stimuli, detect responses, and record data automatically. Computer program for the teaching and testing in the present study was developed using Hyper Card 2.3J[®].

1-3. Materials

We used 194 kanji characters, 194 pictures, and 194 spoken words as stimuli, which represented nouns. Each stimulus set consisted of 4 items (e.g., 竹(bamboo), 空(sky), 貝(shell), 草(grass)). An example of a stimulus set is presented in Fig. 1. Each item consisted of 3 stimuli, that is, a picture (e.g., a picture of bamboo), the corresponding kanji word (e.g., 竹), and the corresponding spoken word (e.g., /take/). Stimulus sets consisting of 2 items were used in the beginning of teaching sessions, because matching-to-sample performance should be established through an easy task. We used 7 stimulus sets with two items for the 2-choice procedure. After the

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FIG. 2 Paradigm of the equivalence relations in the present study. The student was taught by arbitrary matching-to-sample (picture→kanji) with differential outcome (spoken word). And equivalence relations were evaluated in ① Picture→Kanji Selection (comprehension), ② Picture→Vocal Response (naming with vocal response), ③ Kanji→Vocal Response (reading with vocal response), ④ Picture→Writing Response by Hiragana (naming with written response), and ⑤ Kanji→Writing Response by Hiragana (reading with written response).

2-choice procedure was completed, we used 45 stimulus sets with four items for the 4-choice procedure.

Pictures and kanji were presented on a 4 cm×4 cm portion of the computer display. Spoken word was presented from the speaker of the computer; it was the voice of a male adult sampled at the level of 16-bit 44 kHz. All of the computer programs were stored on a CD-ROM.

1-4. Teaching Procedure

In each trial of the computer-based teaching, simultaneous matching-to-sample with a differential outcome was conducted in a 2-, 3-, or 4-choice procedure. A choice response was defined as occurring when the student moved the mouse to one of the comparison stimuli and clicked it. When a sample picture was presented in the upper part of the computer display, the student was required to choose one of two (or three or four) comparison stimuli (kanji) that were presented in the lower part of the display. When the correct kanji was chosen, the corresponding spoken word was presented from the computer as the differential outcome stimulus and also the a fanfare sound was presented. For example, in each trial, immediately after the student chose the correct comparison (犬) in response to a picture of a dog, the

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FIG. 3 Examples of the stimulus arrangement in the computer display in 2-, 3-, and 4-choice procedure. When a sample picture was presented in the upper part of the computer display, the student was required to choose one of two (three or four) comparison stimuli (kanji) which were presented in the lower part of the display. When the correct kanji was chosen, the corresponding spoken word was presented from the computer as the differential outcome.

corresponding spoken word /inu/ was presented as the differential outcome (Fig. 2).

When the incorrect kanji was chosen, a buzzer sound was presented and the selected stimulus disappeared. Then, the same trial was conducted, with the sample stimulus remaining in the display until the correct response occurred. Examples of the stimulus arrangement in the computer display are presented in Fig. 3. The response to the comparison stimulus was automatically recorded by the computer.

1-5. Teaching Steps

Teaching of arbitrary matching-to-sample with a differential outcome progressed from a 2- to a 4-choice procedure (Fig. 3), as follows:

1) 2-choice procedure: In each trial, one sample picture (A1 or A2) and 2 kanji (B1 and B2) were presented in the display, and one spoken word (C1 or C2) was presented when the correct choice response occurred. The student was taught to choose the corresponding kanji from two choices. One block consisted of 16 trials of the random presentation of 2 stimuli. Each item was presented for 8 trials. When the student responded correctly for 15 trials in one block, the 3-choice procedure was conducted.

2) 3-choice procedure, part 1: In this procedure, one new stimulus from the same stimulus set was added, that is, three comparison stimuli (B1, B2, and B3) were

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used. One block consisted of 18 trials of the random presentation of 3 stimuli. Each item was presented for 6 trials. When the student responded correctly for all 18 trials in one block, the second part of the 3-choice procedure was conducted. When the student made more than one incorrect response in each block, the teaching program returned to the 2-choice procedure and the student was allowed to work through that procedure again.

3) 3-choice procedure, part 2: In this procedure, the alternate new stimulus from the same stimulus set was added, so three comparison stimuli (B1, B2, and B4) were used. One block consisted of 18 trials of the random presentation of 3 stimuli. Each item was presented for 6 trials. When the student responded correctly for all 18 trials in one block, the 4-choice procedure was conducted. When the student made more than one incorrect response in each block, the 2-choice procedure was again conducted as the next block.

4) 4-choice procedure: In this procedure, all four comparison stimuli (B1, B2, B3, and B4) from the stimulus set were used. One block consisted of 16 trials of the random presentation of 4 stimuli. Each item was presented for 4 trials. When the student responded correctly for more than 12 trials in one block, the same 4-choice procedure was conducted. When there were fewer than 12 correct responses, the 3-choice procedure, part 1, was again conducted as the next block.

1-6. Phase 1: Weekly Teaching at the University Laboratory

Computer-based teaching was conducted once a week at the laboratory of the university for 17 months. Each weekly session lasted 20 minutes. In the beginning, arbitrary matching-to-sample was taught subsequently for 6 stimulus sets, each of which consisted of 2 items. Equivalence relations were taught directly only for 2 stimulus sets with 2 items. After the student met the learning criterion for these stimulus sets, the teaching for one stimulus set with two learned and two unlearned items was conducted by the teaching steps outlined above (from the 2- to the 4-choice procedure). After that, a new stimulus set with four new items was taught using the same teaching steps.

1-7. Phase 2: Daily Teaching at Home

After the completion of Phase 1, laboratory-based testing (pretest and posttest) and home-based teaching were conducted in a weekly cycle for stimulus sets with four items in Phase 2. The weekly cycle of teaching and testing (Fig. 4) was as follows:

- (1) The pretest was first conducted at the laboratory of the university for 2 stimulus sets.
- (2) The parents took the CD-ROM with the tasks for 2 stimulus sets home and conducted at-home sessions every day.
- (3) At the next weekly session in the laboratory, a posttest was conducted for these two stimulus sets. At this laboratory session, a pretest for next two stimulus sets was also conducted.

Before parents were introduced to the home-based teaching program, they were

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FIG. 4 A weekly cycle of laboratory-based testing and home-based teaching in Phase 2. Pretest was first conducted at the laboratory of the university for 2 stimulus sets. And then, the student took the CD-ROM home which included the teaching tasks for 2 stimulus sets and conducted the task every day at the home. At the next weekly session in the laboratory, posttest was conducted for these two stimulus sets. At this laboratory session, pretest for next two stimulus sets was also conducted.

taught how to start, stop, and use the computer via verbal instruction, manuals, and telephone consultation. In the beginning of the home-based computer teaching, the parents taught the student how to start and end the computer program. After that, the student could start the program, conduct the task, and quit the program by himself, so the parents had only to deliver the CD-ROM to the student.

1) *Pretest*. For 2 stimulus sets, the following five tasks (Fig. 2) were evaluated regarding the emergence of equivalence relations without differential reinforcement at the laboratory as a pretest. No feedback was given for “correct” and “incorrect” responses, and the next trial began after any response from the student. Each task consisted of 16 trials or stimulus presentations in each stimulus set.

- (1) Picture→Kanji Selection (comprehension): The student was evaluated regarding whether he could select the correct kanji from four comparisons when presented with one of the pictures as the sample stimulus.
- (2) Picture→Vocal Response (naming with vocal response): The student was asked to name the picture with a vocal response when presented with one of the pictures in the display.
- (3) Kanji→Vocal Response (reading with vocal response): The student was asked to read the visual kanji word with a vocal response when presented with one of the pictures in the display.

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- (4) **Picture→Writing Response by Hiragana** (naming with written response): The student was presented a piece of paper on which four pictures in each stimulus set were printed. He was required to identify the picture and write in hiragana in parentheses at the side of each picture.
- (5) **Kanji→Writing Response by Hiragana** (reading with written response): The student was presented a piece of paper on which four kanji in each stimulus set were printed. He was required to identify the kanji word and write in hiragana in parentheses at the side of each kanji word.
- 2) *Home-based teaching.* The student conducted the arbitrary matching-to-sample teaching program with a differential outcome at home every day for a week, using 2 stimulus sets on the computer. Teaching procedures were as described above in the Teaching Procedure and Teaching Steps section.
- 3) *Posttest.* For 2 stimulus sets that were taught at home in a week, the five stimulus relations were evaluated without differential reinforcement at the laboratory. The procedure was the same as in the pretest.

1-8. *Social Validity of the Computer-Based Teaching*

Before the present study, we explained to the parents of the student the purpose, procedure, and expected results of this study. After obtaining consent from the parents, we started the study. Six months after introducing the home-based teaching, a questionnaire was provided to the parents to assess the social validity of the computer-based teaching. We asked them to answer 21 questions by checking one of four choices on Likert-type items: “I completely agree” earned 3 points, “I agree” earned 2 points, “I don’t agree” earned 1 point, and “I completely disagree” earned 0 points.

Twenty-one questions for the assessment of the social validity of home-based teaching were categorized as follows: positive change of the student (e.g., Did the student enjoy participating in computer learning?), negative change of the student (e.g., Was the student so absorbed by using the computer that other activities decreased?), load of parents (e.g., Did it take too much time to prepare the materials?), and support materials for conducting the computer program (e.g., Is it easy for you to understand the operation manuals of the computer?).

2. Results

Figure 5 shows the cumulative number of acquired kanji words for which the student could give the correct response in the “picture (sample)→kanji (choice)” task. The criterion for the acquisition of kanji in each stimulus set was a correct-response rate of more than 90%.

During the weekly teaching in the laboratory, the student acquired only 18 kanji words in 17 months. In the daily teaching at home, he acquired 176 kanji words in 7 months. The student learned 1.05 kanji words in weekly-based teaching and 25.14 kanji words in daily teaching in the home setting per month. The acquisition of kanji words was drastically increased by introducing home-based computer teaching in the

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FIG. 5 The cumulative number of acquired kanji words that the student could give the correct response to on the "picture (sample)→kanji (choice)" task in each month.

FIG. 6 The percentage of correct responses of five tasks in pretest and posttest in home-based teaching for the assessment of equivalence relations.

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daily setting.

Figure 6 shows the percentage of correct responses for five tasks in pretest and posttest in home-based teaching for the assessment of equivalence relations. Data were from 40 stimulus sets. In pretesting, the mean percentage of correct responses was 31.1% in Picture→Kanji Selection (comprehension), 24.7% in Picture→Vocal Response (naming with vocal response), 15.6% in Kanji→Vocal Response (reading with vocal response), 10.0% in Picture→Writing Response by Hiragana (naming with written response), and 7.5 % in Kanji→Writing Response by Hiragana (reading with written response). In posttesting, the mean percentage of correct responses was 99.7% in Picture→Kanji Selection (comprehension), 98.8% in Picture→Vocal Response (naming with vocal response), 98.8% in Kanji→Vocal Response (reading with vocal response), 90.6% in Picture→Writing Response by Hiragana (naming with written response), and 87.7% in Kanji→Writing Response by Hiragana (reading with written response).

The arbitrary matching-to-sample procedure with a differential outcome established the equivalence relations among three stimuli (visual picture, visual kanji word, spoken word). The student could read 194 kanji characters without direct teaching. He could also make correct responses of reading and writing using ordinary paper materials, as well as when using a computer. Initially, for home-based teaching, his mother set up the computer and instructed the student in using the teaching materials. One month later, he could spontaneously start the computer, run the task, and end the program by himself. The mean time of engaging in the computer task for 7 months in the home was 15.3 minutes in a day.

Mean scores in the Likert-type items (wherein the largest score is 3 and the smallest score is 0) that assessed the social validity of home-based teaching were as follows: positive change of the student was 3, negative change of the student was 1, load of the parents was 0.6, support for the home-based program was 2.3.

3. Discussion

3-1. *Equivalence Relations and Expansion of Kanji Vocabulary*

Teaching of arbitrary matching-to-sample with a differential outcome was effective for establishing the equivalence relation of three stimuli (picture, visual kanji word, and spoken word) in a student with mental retardation. This result supports the notion that three types of stimuli, that is, a sample stimulus, a selected stimulus, and a feedback stimulus, are equivalent, a subject about which some theoretical (Sidman, 2000) and empirical studies of typical children (Dube et al., 1987) have argued.

From a practical point of view, the arbitrary matching-to-sample procedure with differential outcome is efficient, because we can teach a student three arbitrary stimulus-relations at one time, while two kinds of teaching (e.g., “visual picture→visual Kanji word” and “spoken word→visual Kanji word”) are needed in the ordinary matching-to-sample procedure.

Since the student could select correct kanji when presented with picture and could name the presented picture for more than 98% trials in the posttest for

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equivalence relations, he could comprehend the meaning of the kanji. Also, the student could emit the correct vocal response to the presented kanji for more than 98% trials, showing that he could read kanji. The present study showed that we could apply the arbitrary matching-to-sample procedure with differential outcome to establish and extend the linguistic skills of comprehending meaning, reading, and writing.

The present study showed that daily teaching using a computer had a drastic effect on the expansion of kanji vocabulary. Since learning of kanji is often difficult for students with moderate mental retardation, the weekly interval between the teaching sessions in a laboratory reduced the effectiveness of the teaching. Daily use of a computerized teaching program can assist students with mental retardation in acquiring difficult tasks.

3-2. *Errorless Learning in Computer-Based Teaching*

With the development and implementation of our computerized errorless learning program, the performance of our participating student was consistently reinforced and on-task behavior for the task was maintained. The student could engage in the computer task for a relatively long time by himself and be reinforced by the stimuli provided, so that additional reinforcement from teachers and parents was not needed for maintaining the on-task behavior. Since the student could conduct the computer-based teaching program and learn by himself, we could easily apply it to both school and home settings. The student could use the computer and learn by himself, so the load of parents and teachers for teaching would be reduced (Breiner, 1989; Marcus & Schopler, 1989).

In the present study, the computer automatically helped the student progress through the teaching steps in accordance with the level of the student's learning performance. The number of stimuli used in the teaching increased from 2 to 3 or from 3 to 4 in each stimulus set when the student consistently made correct responses. When the percentage of correct responses did not increase or was not stable, the number of stimuli for the teaching decreased from 4 to 3 or from 3 to 2. This program would minimize errors, facilitate "errorless learning," and maintain the rate of reinforcement for on-task behavior.

The student could utilize an "exclusion" strategy to successfully proceed through the program, as follows: Even though the relation of "A1→B1" was established and the relation of "A2→B2" was not established in the matching-to-sample procedure, the student could select the correct comparison (B2) using the rule "not B1" when presented with A2. Through the "exclusion" strategy, children can easily acquire new vocabulary (Markman & Wachtel, 1988; Stromer, 1986; Yamamoto, 1996). In the program of the present study, the student could easily learn the correct response for two stimuli by the exclusion strategy in the 2-choice procedure and minimize the position or stimulus preference strategy as the first step of the task. The 3-choice procedure could also facilitate new learning by exclusion (McIlvane, Kledaras, Munson, King, De Rose, & Stoddard, 1987; McIlvane & Stoddard, 1981).

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3-3. *Transfer of Learning from Computer to Paper Materials*

Computer-based teaching involves selection-based responding to stimuli on the display. Ordinary teaching in the classroom setting, on the other hand, often requires topography-based responding (such as vocal responding and hand-writing) for using paper materials. In the present study, the student made correct naming and reading in paper materials without receiving direct teaching after the computer-based teaching.

Before the start of the study, the student often rejected paper materials and could not learn kanji. This might be because students with mental retardation often have difficulty writing because of the fine motor skills needed. If attempting to use paper materials, students must both learn kanji vocabulary and work on the fine motor skills needed for writing. It is to the student's benefit if we separate the two kinds of learning process; that is, learning for the acquisition of vocabulary and learning for a stable sort of response topography such as handwriting or vocal responding.

A computer-based teaching procedure, in which the selection of appropriate kanji is taught, could help students with mental retardation learn basic kanji vocabulary. After that, topography-based responses such as vocal responding and handwriting can be integrated with knowledge of kanji vocabulary through the equivalence relations. At the onset of a teaching program, vocabulary should initially be established with selection-based responses by computer-based teaching, and the program should then progress to topography-based responses to extend the linguistic skills to be maintained in ordinary educational situations.

3-4. *Social Validity of the Present Program and Future Direction*

The student spontaneously used the computer every day. Initially, his mother started the computer, instructed the student in the use of the software, and stopped the computer. After that, the student learned how to start the software, to conduct the learning program, and to quit it. He spontaneously took the CD-ROM and inserted it into the computer and ran the program. This spontaneous involvement can be encouraged by successful learning of the presented tasks. The assessment of social validity showed that parents felt that the load of teaching in the home was quite small and that the student's positive change was large. We felt there was sufficient consumer satisfaction with the computer-based teaching in the home.

From the application point of view, we clarified the conditions under which a student with mental retardation could acquire and expand the kanji vocabulary. The necessary conditions would be the emergence of equivalence relations and the acquisition of errorless learning. Applying computer-based teaching into the learner's everyday life situation can contribute to a drastic expansion of vocabulary. Future research is needed to apply the program developed in the present study for students with developmental disabilities with various kinds of deficits in learning of linguistic skills.

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