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Collaborative story-based *kanji* learning using an augmented tabletop system

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We present a novel augmented tabletop computer system to support collaborative story-based learning of Japanese kanji *characters by non-native students of the Japanese language. Our system is based on interactive use of physical and virtual media using Augmented Reality technologies. To investigate the effectiveness of this approach, we use Heisig's decomposition of complex* kanji *into simpler component parts and support constructionist learning by allowing tangible exploration and physical construction – analogous to construction of a jigsaw puzzle – of complex* kanji *shapes from simpler component shapes which are printed on physical cards. Cards can be associated with video content that is projected onto the card's location, thereby augmenting the physical* kanji *component with virtual media. A collaborative pen-based handwriting interface allows students to create mnemonic stories, in the form of pictures or words, to assist in mnemonic memorization of complex* kanji *as collections of simpler components. Experimental evaluation of the system compared user learning behavior between experimental card-using conditions and a control* GUI *condition. For card-using conditions, we observed increases in exploratory activity and pointing behavior; for the* AR *media condition, we observed increased exclamatory clapping. Our system demonstrates that story-based* kanji *learning – which is typically an individual learning process – can be realized as a collaborative, constructionist, and computer-assisted language learning activity. This points to the possibility of story-based* kanji *learning technologies being used in future classroom scenarios.*

Regular Paper

Introduction

Non-native students of Japanese as a second language (JSL) face the difficult hurdle of learning a large number of Japanese *kanji* characters. We propose a novel approach and an augmented tabletop computer system that allow collaborative constructionist *kanji*-learning activities. While many computer-assisted *kanji*-learning systems are aimed at individual learners working in isolation (Hsu & Gao, 2002; Li, 1996; Komori & Zimmerman, 2001; Lin & Mase, 2006; Lin, Kajita, & Mase, 2007, 2008; Kuo & Hooper, 2004), our system demonstrates the viability of computer-supported, synchronous multi-user *kanji* learning. In particular, our approach and system support constructionist exploration of *kanji* part-to-whole relationships and collaborative activities for making mnemonic stories. We believe that the multi-user aspect is important for encouraging wider, classroom adoption of story-based *kanji* learning methods and technology.

Broadly, our research questions are twofold. First, we ask if it is feasible to adapt a story-based *kanji* learning method for a group CALL scenario. We attempt to answer this question by designing and implementing a CALL system for the group scenario, described in detail below. Briefly, our system involves physical assembly of component parts, student creation of mnemonic stories to remember part-to-whole relationships, and projected video media to assist in the story creation process. Second, we are interested in the effects of our system on student learning behavior. To this end, we conducted a user study and compared student behavior between experimental conditions (using physical part-to-whole assembly and using video media) and a control condition (GUI with no video media). Our ultimate research goal, reaching beyond the scope of this paper, is to achieve increased acceptance of story-based *kanji* learning methods among JSL teachers and their classes, which we believe would bring both pedagogical benefits as well as new research opportunities for longer-term study of story-based *kanji* learning.

In the rest of this paper, we first explain and motivate the basic *kanji*-learning approach used by our system: using mnemonic stories to learn *kanji* (Heisig, 1986). Next, we review related work and observe how related research does not address the combination of learning parameters that we address: the combination of group learning, story-based learning, and computer-assisted learning. We then describe the design and architecture of our ARToolKitPlus-based tabletop system for collaborative, story-based *kanji* learning. We follow with an experimental evaluation of the effects of our system on collaborative learning behavior, as compared with a GUI. We conclude with a summary of results and directions for future research.

Story-based *kanji* learning

The approach we advocate for L2 *kanji* learning is to use mnemonic stories to assist with the tremendous memory load placed on the student, and to develop computer-assisted language learning systems that support this style of learning. Our previous research (Lin *et al.*, 2007) describes and motivates this approach in more detail; here, we only provide a brief summary of the story-based approach.

Students of Japanese as a Second Language (JSL) need to use some large-scale strategy to learn the thousands of characters needed for literacy; however, JSL learners encountering *kanji* for the first time may not have and may not know how to acquire such skills (Richardson, 2007). Many teachers rely on rote-learning methods (Shimizu & Green, 2002), even though the effectiveness of such methods is not certain (Gamage, 2003). An alternative is mnemonic-based learning, where students mentally connect external cues with characters during the learning process, in order to facilitate later *kanji* recall using those same mnemonic cues. Heisig's textbook (Heisig, 1986) presents a mnemonic method suitable for learning the large number of Japanese *kanji*. The method consists conceptually of three phases. The first phase, which is done for the student by Heisig's textbook, assigns to every *kanji* character a unique name in the student's L1 vocabulary, where the name corresponds as closely as possible to the meaning (or one of several meanings) of the *kanji* in Japanese. In the second phase, the student learns simple, non-decomposable *kanji* characters by using an ad-hoc mnemonic strategy, becoming able to associate each L1 meaning word with its corresponding *kanji* character. Since the *kanji* in the second phase are non-decomposable, the student must find some way of mapping the L1 word to the complete L2 *kanji* image; Heisig's recommendations are to search for particular nuances of the specific L1 word that can be associated with vivid mental images that facilitate recall of the non-decomposable *kanji*. Although the mnemonic strategy for phase 2 is somewhat unstructured, the number of *kanji* to be learned in the second phase is relatively small (less than 10%). The third phase uses a more structured mnemonic strategy and comprises most of the learning effort (90% of the *kanji* to be learned). Here, the student learns complex *kanji* characters – i.e. those that can be decomposed into simpler parts – by mnemonically associating the complex *kanji*'s L1 meaning with the L1 names of the simpler component parts comprising the complex *kanji*. As in phase 2, the student is again encouraged to use specific word nuances and vivid mental imagery, but in contrast to phase 2 additionally can benefit from the structured part-to-whole composition of the complex *kanji* and can use the part-to-whole relationship as the foundation of a structured mnemonic strategy (described in the next paragraph). In practice, phase 2 and phase 3 do not occur strictly in order but are interleaved; the student learns some simple components using ad-hoc mental imagery, then learns to mnemonically combine these component parts into larger wholes. This is again followed by further learning of further simple components, and further combination, and so forth. The principle is that before learning any complex character, first its simpler component parts must be learned and named in order to enable structured mnemonic learning. Figure 1 illustrates the method: simpler *kanji* (bottom of the figure) combine hierarchically to form more complex *kanji* (top of the figure), and each *kanji* has a unique L1 name.

The phase 3 mnemonic learning, which comprises the majority of the *kanji* to be learned and is our focus for the rest of this paper, thus requires learning one L1 word chain for each complex *kanji*, amounting to almost two thousand L1 word chains, where each word chain consists of a complex *kanji*'s L1 meaning and the L1 names of that *kanji*'s parts. For this method to have any benefit, the learning of word chains must be easier than a rote learning method. Mnemonic stories created by the student facilitate memorization of this large number of word chains. As an example of a mnemonic story, Figure 1 shows the *kanji* for husband, a combination of the simpler parts one and large, which could be remembered by the mnemonic story "a husband is just one half of a married couple, and traditionally he has the larger stature."

We say that such stories to facilitate recall are mnemonic because they introduce meaning into what is otherwise a meaningless information amalgamation; stories represent a "meaningful unitization of information that is essentially unrelated" (Richardson, 2007). Heisig (1986) also emphasizes the mnemonic nature of the story-making task, encouraging students to use mental imagery in combination with the structured hierarchical

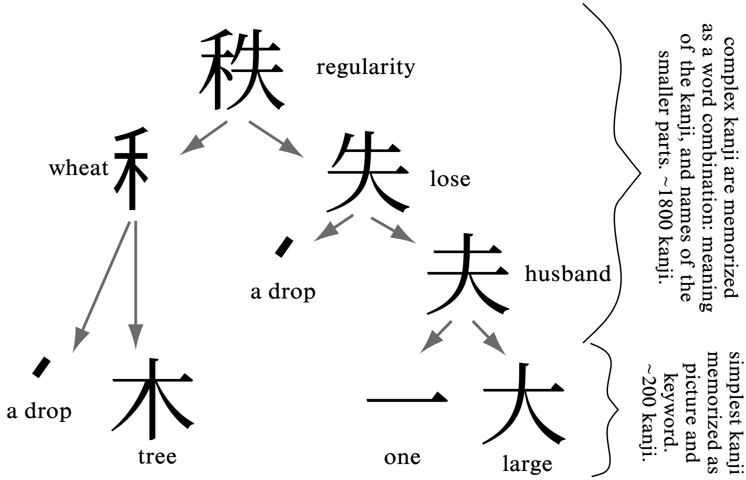

Figure 1. Learning complex kanji as combinations of simpler named parts.

organization of *kanji*. Richardson conducts a further analysis of mnemonic nature of the strategy, in terms of elaborational, organizational, and review components, which form three broad areas of cognitive learning strategies; for further analysis see (Richardson, 1998; Richardson, 2007; Richmond, 2005).

Our research interest is then in developing and evaluating the effect of computer-assisted language learning technology that can support some form of the above-described learning method. Before continuing, it may be helpful to examine possible objections to the method and responses to these objections that have been made by Heisig (1986), Richardson (2007), and other proponents of the method.

Perhaps the most immediate objection is that students are learning to connect L1 words and meanings with L2 *kanji* characters, which may seem counter-productive for L2 learning of Japanese. The main response to this objection (Heisig, 1986) is that if such an L1-to-*kanji* mapping indeed hinders progress, then we would expect Chinese JSL students, who already have such a mental mapping for the Chinese language, to be disadvantaged, or at least no better, than their uninitiated peers. However, the opposite is the case in practice: thorough knowledge of an L1-to-*kanji* mapping seems to greatly benefit students, who then can devote their study effort towards Japanese readings, compounds, and vocabulary.

Another objection is that this is not the way that native Japanese learn *kanji*. The response is that JSL students, in particular adults, have an entirely different background and learning style than native Japanese school children who are immersed in *kanji* from birth. To paraphrase Heisig (2006, personal communication): "The question is, how do you best learn *kanji*, if you've never seen one before?" The methods for native Japanese *kanji* education, which begins in childhood, do not necessarily address this question, and cannot necessarily be applied equally effectively to adult JSL students. Therefore, a learning style – the mnemonic story method – which eschews rote memorization in favor of abstraction and imagination might well be better suited to the unique needs of the JSL student.

A third objection is that by creating their own fictional stories to connect component *kanji* parts into a whole *kanji*, students are not learning the true etymological background of the Chinese characters. The response (Richardson, 2007) is that the "truth" about the etymological background of Chinese characters is in many cases incomplete at best, and the most pressing question is not how to teach students the background of the characters but instead is how to empower the student to remember the characters at all. Richardson (2007) mentions that if one must choose between between "etymological precision" and "relief for memory", that the beginning student is most in need of the latter. Therefore, regardless of its etymological accuracy, any strategy that helps students remember the characters is worth considering.

Finally, we would like to note that, in spite of such objections by some, Heisig's method is a popular one among JSL students: the textbook is in its 5th printing, has been translated into numerous languages (Heisig, 2008), and has positive reviews on amazon.com (Amazon.com, 2008); an independent website and active discussion forums are devoted to the method (Fabrice, 2008); and academic research has started to investigate the method (Richardson, 1998; Richardson, 2007; Richmond, 2005; Lin & Mase, 2006; Lin *et al.*, 2007, 2008).

Related work

Many PC-based systems for *kanji* learning exist, e.g. (Li, 1996; Grunewaldt & Rauther, 2008; KanjiPod, 2008; Van Aacken, 1999); mnemonic-based systems are described in (Kuo & Hooper, 2004; Matsunaga, 2003). These PC-based systems are aimed at single-user learning and use. Lin *et al.* (2006, 2007, 2008) develop mobile, but also single-user, systems for mnemonic story-based *kanji* learning. Fabrice (2008) supports asynchronous group-learning activities; a web forum allows discussion about and sharing of *kanji* mnemonic stories in text form. Wagner and Barakonyi (2003) support synchronous group review of *kanji* with augmented reality, but do not support mnemonic stories. Alprin (2002) presents an adaptation of the mnemonic-story method for classroom use, but does not use computer technology in doing so.

Our system differs from previous work in that we explicitly support synchronous group-learning of *kanji* through two kinds of collaborative learning activities: constructionist exploration of part-to-whole *kanji* relationships through an augmented tabletop interface, and collaborative written story creation through a pen interface.

System design and architecture

Previous experimental research (Lin *et al.*, 2007) indicated that students sometimes encounter difficulty when trying to create mnemonic story content on their own when using a single-user system. Therefore, for this research we created a group system where users could collaborate with a peer when learning *kanji* and creating stories.

Design considerations for group-oriented, story-based *kanji* learning

Heisig writes that story-based *kanji* learning is best when done individually and cannot be effectively used in classroom or group-learning scenarios (Heisig, 1986). If we accept this as true, then there is no place for story-based *kanji* learning in the classroom. Such a viewpoint would unfortunately limit both student and teacher exposure to the valuable learning method, and would likely limit future adoption of the method into future curricula. However, we believe that with suitably-designed activities and computer support, story-based *kanji* learning can be adapted for group learning. If we can demonstrate the feasibility of group scenarios and a collaborative computer system using a story-based method, this would be an important step towards future classroom acceptance and adoption of such methods and technology.

Heisig's objections to classroom use of the mnemonic story method can be summarized as follows (Heisig, 1986):

1. *All or nothing.* The method assumes that learning writing and reading skills for all daily-use *kanji* is the only meaningful goal with respect to *kanji* learning; it assumes that it makes no sense to aim for, much less stop at, intermediate levels of competency such as 25% competency, 50% competency, or the like. In contrast, JSL classes typically aim to demonstrate some measurable intermediate goal and structure the *kanji* part of the curriculum accordingly.
2. *Order of kanji.* Related to (1), the optimal order of learning the *kanji*, assuming one must learn them all, is hierarchical: first, learning of simple *kanji*, followed immediately by learning of more complex *kanji* that incorporate the previously learned simpler *kanji*. In contrast, typical JSL classes use a learning order based on frequency of use.
3. *Separation of tasks.* The method assumes that learning the writing and meaning of *kanji* is a skill that should be learned separately from, preferably before, but possibly in parallel with learning the rest of the language (e.g. pronunciations, grammar, vocabulary). In contrast, JSL classes typically teach *kanji* written forms, pronunciations, and other language aspects in an interconnected fashion.
4. *Pacing.* Students learn at different paces, which may be a problem for classroom adoption.

The reasons we decided to proceed in spite of these objections are twofold. The first reason we decided to proceed is that we feel that the core of the objections (1), (2), and (3) lie not with group usage of the method per se, but rather with the pragmatic viability of attempting to change existing classroom methods and gaining student and teacher "buy-in" for adopting the method including its assumptions. Indeed, increasing this viability is one of the goals of our research. Regarding objection (4), the same could be said of group study in any domain, yet classroom instruction still proceeds nonetheless. The second reason we decided to proceed is because we sense the potential of story-based *kanji* learning to improve the efficiency of the learning process, a potential which has to some degree been realized by the existing adherents of the method but which could have far greater benefits if adopted at institutional levels. Continuing demand for Heisig's book and examination of the method in academic research show that the idea, in its original individual-study form, has promise. Moreover, self-formed Internet-based communities like (Fabrice, 2008) indicate that CALL for groups of learners is already taking place in some form at an asynchronous level. We see a synchronous group learning system, with the potential for classroom deployment, as a logical next step. This raises questions about system design and system usage to facilitate group study, which we address below.

Approach: *kanji* component assembly as a collaborative jigsaw puzzle

Our approach to enabling collaborative story-based *kanji* learning is to create a group activity based on the idea of a jigsaw puzzle. Puzzle assembly can be a collaborative activity with people working together towards a common goal (Bullmer & Dew, 2002). Similarly,

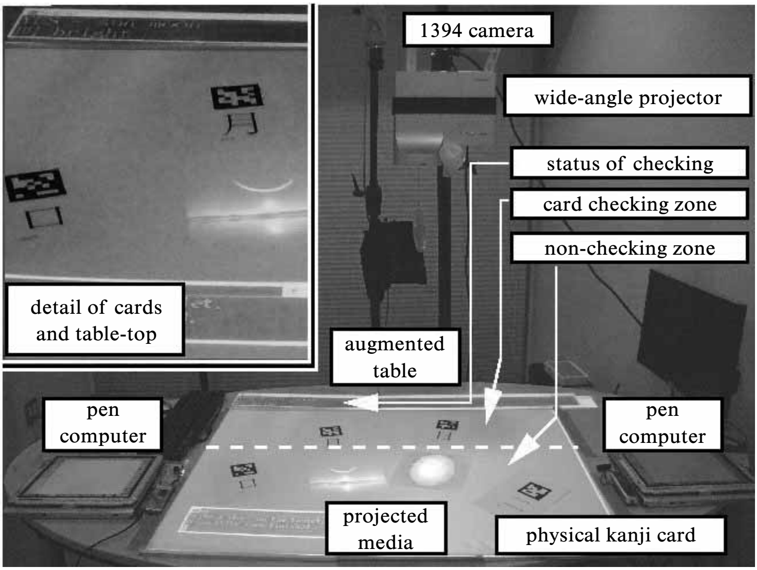

Figure 2: Augmented tabletop system.

we have chosen to view *kanji* part-to-whole relationships also as a jigsaw puzzle: certain simple *kanji* parts can fit together to form other more complex *kanji*; certain other *kanji* parts cannot fit together because the combination does not form any valid *kanji*.

We therefore designed a tabletop system (Figure 2) for collaborative exploration of *kanji* part-to-whole relationships, akin to collaborative exploratory assembly of a jigsaw puzzle. Our system is designed for two users simultaneously. We consider two users to be the minimum representative case for investigating group study as opposed to individual study, and for our experiment use the term "group" to refer to a pair of experimental subjects working together synchronously on a task. Combinable *kanji* parts are printed on cards (Figure 3) and are manipulated collaboratively by partners on a tabletop interface. Figure 4 in panel 1 shows the initial state of the system: cards are in random positions on the table and the users sort through them looking for valid combinations. The tabletop interface recognizes

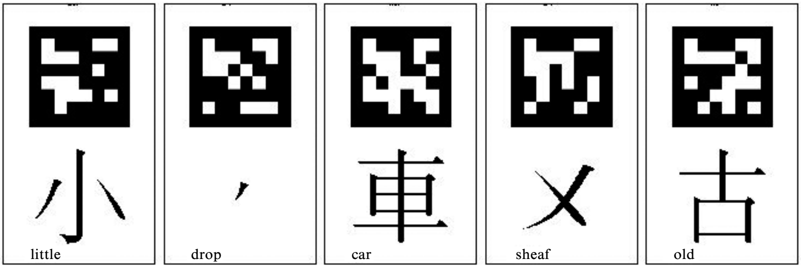

Figure 3: Example set of kanji component cards.

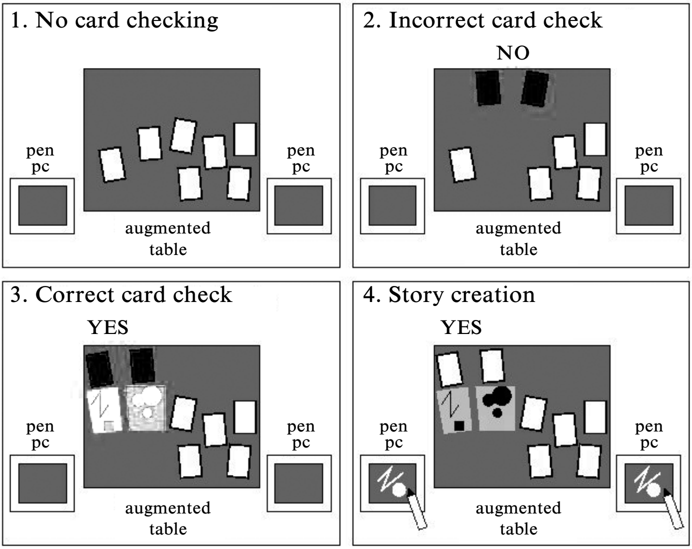

Figure 4: Typical user sequence of actions when using our system.

the positions of the cards and checks if the users have found a valid combination of components ("valid" means that the users' chosen combination of *kanji* component cards can be combined together to form a more complex *kanji* as per Heisig's textbook). Checking is done by sliding the chosen card combination to the top of the table (Figure 4, panel 2). An invalid combination causes display of a message with the word "NO." A valid combination (Figure 4, panel 3) causes the systems to display "YES" with an image of the composite *kanji* and its English meaning; also, the system augments the individual physical cards with virtual video imagery (which was selected manually before-hand). The augmented media attached to the component cards is intended to serve as inspiration to the users for the purpose of creating a mnemonic story. While viewing the component combination and the augmented media, the users collaboratively discuss how to form a mnemonic story to remember the *kanji* that they discovered as a collection of named parts. The story is written with a digital pen onto a pen computer (Figure 4, panel 4). (Although such a computer is usually called a "tablet computer," in this paper we call it a "pen computer" ; we avoid using the term "tablet" to avoid confusion with the semantically close terminology of "table" interface, which in our case refers to the augmented tabletop.) Each user has his/her own pen computer, and changes on one pen PC are immediately reflected on the partner's pen PC, allowing written collaboration.

For our current system design we chose to begin with a small number of *kanji* component combinations. We selected 59 *kanji* components that could be combined to form 43 different *kanji*. *Kanji* components were printed individually on separate paper cards; each card contained an image of a simple *kanji* component, its English keyword (as defined in Heisig, 1986), and a marker code that allowed optical tracking the position of the card with the ARToolKitPlus library (Wagner & Schmalstieg, 2007). We then divided these combinable components, printed on cards, into 21 sets. Each set contained between 5 and 9 cards of

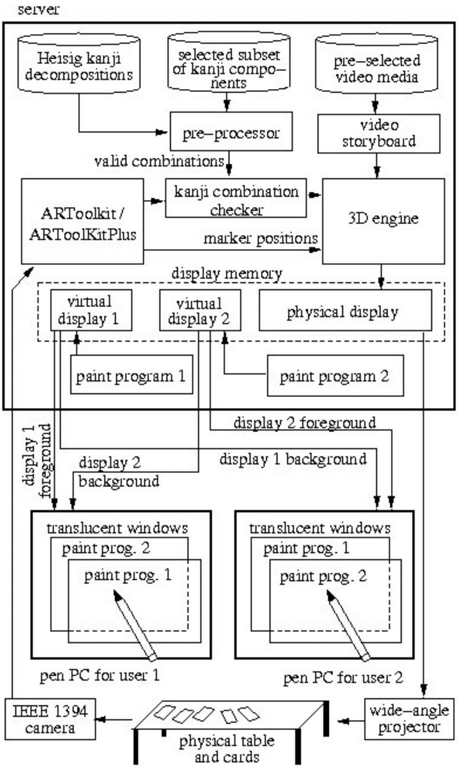

Figure 5. System architecture.

simple components that could be combined together to form between 1 and 3 more complex *kanji*. This division of components into sets reduces the combinatorial explosion that would otherwise result if all combinable components were amalgamated into one gigantic set; in such a case, users would spend almost all of their time futilely investigating invalid *kanji* component combinations. By dividing components into sets, each set combinatorially contains relatively few possibilities. This reduces the amount of time the students need to spend searching for valid combinations, while still requiring that they do in fact perform the act of combination themselves (a point discussed in more detail below).

System implementation

Figure 5 shows the system architecture; we now explain each part of the system.

Kanji *composition/decomposition database*

We created a text database of all Heisig *kanji* decompositions. Minor inconsistencies in Heisig's naming scheme (summarized in Richardson, 1998) were amended to ensure uniform naming of *kanji* parts. From this database, we selected a subset of 59 *kanji* components, divided these components into 21 separate sets, and wrote a preprocessor to list all valid combinations of the components in each set. The resulting list of valid combinations is used at run-time to check whether the users' chosen combination of cards is valid or invalid (Figure 4, panels 2 and 3).

Camera and marker detection

Checking of cards is done by sliding the chosen card combination to the top of the table; we therefore have divided the table into an upper "checking zone" and a lower "non-checking zone." Location of cards is tracked by the ARToolKitPlus BCH code (allowing up to 4096 unique markers) printed on each card. An IEEE 1394 camera provides 1024x768 images of the markers on the table surface; a third-party utility "Coriander" converts the IEEE 1394 stream to a Video4Linux stream, which is then captured by the original ARToolKit (Kato & Billinghurst, 1999) camera code and is then handed off to ARToolKitPlus for BCH marker recognition.

3D engine and video textures

A third-party 3D engine (a modified version of the "Nebula Device") places video-texture objects at the location of the tracked markers. Integration of ARToolKit and ARToolKitPlus into the 3D engine is done by a custom Nebula module. The video-texture objects are implemented by streaming the video off disk with the FFmpeg library and into texture memory.

A GUI-based video storyboard application written in Python allows drag-and-drop assignment of any video file on disk to any marker in any set of cards. The video storyboard application also allows spatial transformations (such as zoom or rotate) as well as temporal clipping of the video (i.e. cutting off the start or the end of the video if necessary). The video storyboard is currently not intended for use by the end-users of the tabletop interface; instead, the storyboard is used by the system administrator/operator to prepare video media beforehand.

Projection display of augmented media

Display of the augmented media (at the appropriate time, i.e. panels 3 and 4 of Figure 4) is done with a wide-angle Sanyo LP-XL40 projector that projects images directly onto the tabletop at the physical location of the marker (with a small offset to prevent "occlusion" of the marker by a projected image). This is different, for instance, than the *kanji* learning system of Wagner & Barakonyi (2003), which uses separate displays for the augmented media. We felt that integrating the physical cards and virtual media on a tabletop display would facilitate more natural collaboration than if separate displays were used (e.g. head-mounted displays or screens requiring users to direct visual attention away from the physical table space).

Collaborative drawing on pen PC

Story creation (panel 4 of Figure 4) is done with a collaborative drawing application on two pen PCs, one for each user. This allows a shared and synchronous electronic drawing space for the users to share story ideas and content. The drawing activity done by one user on his/her pen PC is immediately seen by the other user on the other pen PC. Also, both users can draw on the tablet simultaneously without interference. A VNC recording program records the drawing contents and activity of each pen PC.

Experimental evaluation

We were interested in evaluating the effectiveness of our tabletop system design in supporting collaborative story-based *kanji*-learning activities. In particular, do our system design choices of using physical cards and adding video media affect user behavior, and if so, how? We note that our interest is users' learning behavior, not the users' learning results. A thorough evaluation of learning results would require collaboration with JSL classrooms and a long-term study of students' retention rates when using our system. Unfortunately, our attempts to collaborate with JSL teachers were met with skepticism that the basic story method itself has merit, an objection Heisig himself encountered (Heisig, 1986, and personal communication). Without the possibility of studying long-term retention, we instead choose to focus on the learning process and the effect our system has on that process as reflected by user behavior.

To evaluate our system, eighteen volunteer subjects (12 male, 6 female, ages 23–40) were recruited by means of flyers around our university. Subjects were self-described beginning-to-intermediate *kanji* learners with good knowledge of English. Subjects were divided into groups of 2 based on schedule availability. Subjects filled out a demographic pre-questionnaire, used our tabletop system for approximately 90 minutes, then filled out a post-questionnaire on usability. Subjects were paid 1000 yen for their time. IC recorders and clip microphones recorded user speaking activity. A video camera in front of the table recorded user activity. Computer log files recorded card activity (checking operations) and writing activity on the pen tablet.

As stated earlier, we divided 59 *kanji* components printed on cards into 21 sets of between 5 and 9 cards each (components could be re-used among sets leading to a total number of cards greater than 59). Each set contained cards that could be combined to form between 1 and 3 composite *kanji* shapes. Subjects proceeded through all 21 sets in order, trying to find all valid *kanji* combinations in each set. If subjects failed to find all valid *kanji* in a set after 3 minutes, the system would display the remaining answers automatically. After finding each valid *kanji*, subjects collaboratively created a mnemonic story and wrote the story on the pen PC. Subjects were asked to use their imagination to create a memorable story. Subjects were not required to finish all 21 sets.

For evaluation purposes we divided the 21 sets into three different conditions, equally distributed among all 21 sets. Condition 1 was the "cards-only" condition: the tabletop interface was used to check students' combinations of *kanji* cards, but no augmented media was displayed. Condition 2 was the "cards+AR media" condition: after finding a valid card combination, video media was projected onto the locations of the cards as incentive material for story-making (see Figure 6). Condition 3 was the "GUI" condition: numbered images of all candidate component parts were printed on a single piece of paper (preventing physical combination or assembly), and subjects would click corresponding numbered checkboxes in a GUI on the pen PC to signify their choice.

Figure 6. Two users consider the augmented video media.

User checking activities: support for exploration

We compared the frequency of checking activity – i.e. how frequently the users tried to check if a combination of components was valid – between the card conditions and the GUI condition. This is a measure of the interface's support for exploratory activities. If an interface (GUI or cards) supports or encourages exploration of various *kanji* part-to-whole relationships, we would expect a higher frequency of checking operations indicating the users' exploration of the possible *kanji* relationships.

Table 1 shows the mean frequency, computed as the number of checking operations per second for each *kanji* that was found, for the two conditions cards vs. GUI. (Due to technical reasons group 1's log file was not properly recorded and is omitted from consideration.) A one-tailed t-test (null hypothesis no difference in means; alternative hypothesis that card checking frequency is greater than GUI checking frequency) reveals statistically significant ($p<0.05$) differences between the means for each group individually and for all groups considered together.

We interpret this result as evidence that the the card interface supports user exploration of part-to-whole relationships better than the GUI interface. Further qualitative evidence to support this view was offered by the spontaneous comments of one subject after completion of the experiment. Unfortunately these verbal comments were not recorded, but they were transcribed from memory immediately after the subject had left the laboratory: *"When the system says 'wrong,' I have a negative feeling. When the system says 'you are right,' I have a positive feeling. When I try to write* kanji*, I think I will make some mistakes. But then I can remember: no,* ***I tried this*** *combination with the system, and it said 'wrong,' and I can remember*

Table 1: Mean frequencies of user checking activity (number of check activities per second).

Group	**Cards**	**GUI**	**t-test** (h_a: $f_{card} > f_{GUI}$)
1	–	–	–
2	0.745	0.158	$p<0.01$
3	1.183	0.156	$p<0.05$
4	0.738	0.109	$p<0.01$
5	1.283	0.147	$p<0.01$
6	0.590	0.119	$p<0.01$
7	1.250	0.112	$p<0.01$
8	0.988	0.103	$p<0.05$
9	0.747	0.110	$p<0.01$
All	0.956	0.131	$p<0.01$

the ***combination that I tried*** *when the system said 'right.' So* ***I can remember what I did*** *and remember how to write the* kanji.*"* (emphasis added)

Notable is the subject's repeated reference to the importance of checking the *kanji* combinations himself and receiving immediate system feedback based on his own actions. We believe that the physical exploratory action of assembling smaller *kanji* components into larger *kanji* composites – and the immediate yes/no feedback provided by our augmented tabletop – is an important constructionist learning activity not supported by existing *kanji* learning systems. Users can tangibly build and discover both valid and invalid *kanji* compositional structures; and constructionist learning theory advocates that a construction activity, especially a physical construction activity, strengthens the learning (Papert, 1991; Strohecker, 1999). Our system supports physical construction and supports exploration better than a GUI, so we believe our card and tabletop interface supports the learning process in a collaborative environment.

Story creation times and pen activity

To see if the presence or absence of augmented video media had an effect on the story-making process, we performed two analyses. Our hypothesis was that the augmented media might lead to more ideas and thus to longer story creation times and more activity on the pen PC as users discussed and explained possible stories.

The first analysis compared the amount of writing activity (number of pen events) on the pen PC among the three conditions cards, cards+AR, and GUI. We performed a two-tailed t-test (alternate hypothesis: means not equal) to determine if the condition (cards, cards+AR, GUI) was associated with differences in pen activity; the t-test revealed no significant differences among conditions.

The second analysis considered the total length of time spent creating the story, measured starting from the time that a correct *kanji* combination was found and ending when the subjects pressed a key to indicate they had finished writing their story. Our earlier research with a mobile *kanji* learning system (Lin *et al.*, 2008) indicated that story creation times were not normally distributed but instead were positively skewed, and we suspected this might be the case with our new system as well. We plotted histograms of

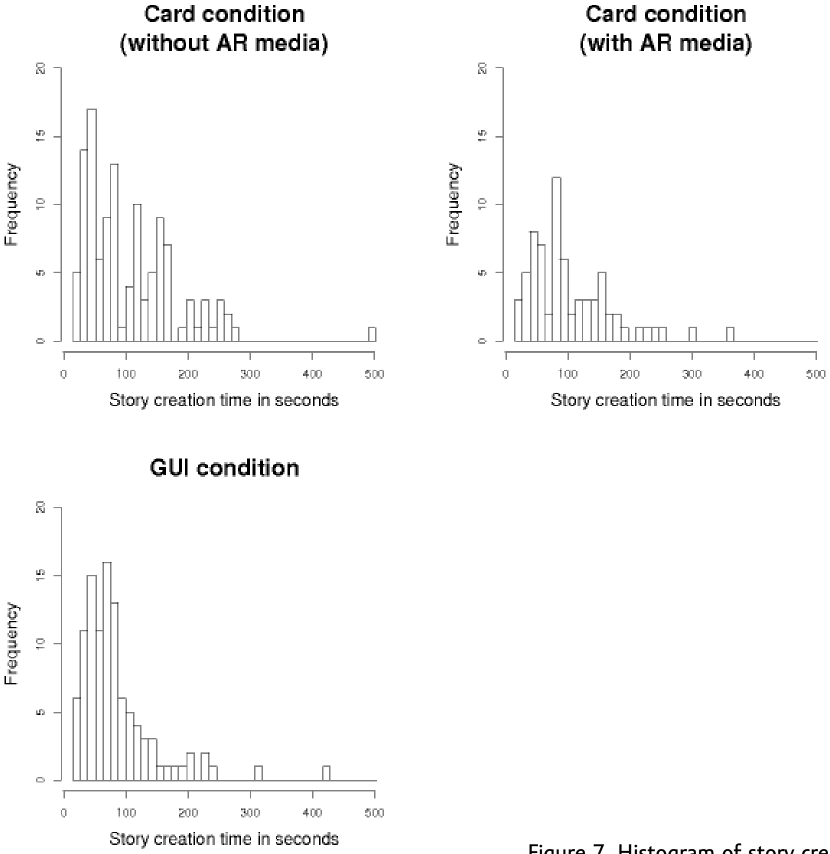

Figure 7. Histogram of story creation times by condition.

the story creation times for each condition and again observed positively skewed distributions (Figure 7); therefore we looked at the median and used a non-parametric one-tailed Wilcoxon rank-sum test to test if distribution differences were significant among conditions. Median story creation times were as follows: cards-only condition 83s; cards+AR condition 85.5s; GUI condition 69.5s. One-tailed Wilcoxon rank-sum tests reported that the differences between the cards and the GUI condition distributions were significant: for cards-only vs. GUI condition, $p<0.02$ ($W = 7177.5$, $n_1 = 119$, $n_2 = 104$); for cards+AR vs. GUI condition, again $p<0.02$ ($W = 4366.5$, $n_1 = 70$, $n_2 = 104$). No significant difference was found between the cards+AR condition and the cards-only condition. This suggests that the card conditions, either with or without AR media, are associated with longer median story creation times; the effect of using cards seems significant, not the effect of having AR media. The spatial nature of the cards may stimulate the discussion process by allowing *kanji* components to be discussed and manipulated more easily than in the GUI.

Returning to the subject of pen activity, another observation is that the qualitative usage style of the pen PC varied among groups. Some groups used the pen PC for collaboration,

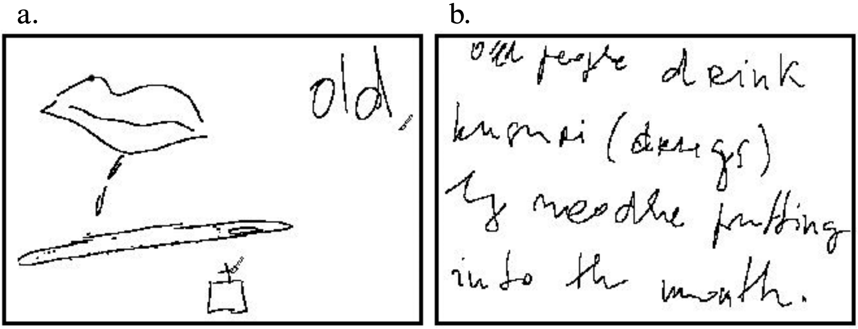

Figure 8. Different pen PC usage modes: picture story (a) vs. word story (b).

where one user would illustrate a possible story idea on his/her pen PC while the other user used his/her pen PC to embellish or comment on the story idea under consideration. Other groups did not use the PC for collaboration, performing all story discussion verbally and only using the pen PC to commit the final result of the discussion to written form. One factor that likely influences this difference in usage style is the preferred story representation modality of the persons in the group. Some subjects represented mnemonic stories mainly as pictures (e.g. Figure 8a); other subjects represented mnemonic stories mainly as words (e.g. Figure 8b). We suspect that pen PC collaboration with a picture-style story is easier than with word-style stories due to the relative ease of annotating a partner's picture compared with the relative difficulty of annotating a partner's sentence. Also, the fact that the pen PC display was separate from the augmented tabletop display certainly affects the usage style of the pen PC during story creation. If users could draw story contents with a digital pen directly onto the augmented tabletop, it is possible that more collaborative behavior overall would result due to the unification of digital pen content, AR content, and physically manipulable *kanji* cards into one coherent interactive surface.

Video analyses

The previous analyses were all done based on time-stamped information in log files recorded during the experiment. To understand more deeply the effect of our experimental conditions on user behavior, we transcribed and labeled video footage from six of nine experimental sessions. These six sessions were chosen because the subjects spoke English during the experiment, facilitating transcription. The other three sessions unfortunately consisted of groups that spoke their native tongues, making transcription of the contents impossible. We transcribed the spoken dialog as well as certain non-verbal actions that were easily detectable: pointing activities, exclamatory clapping, and spatial rearrangements of cards. In total, 9 hours of video were transcribed and labeled, with a total of 29,294 words and 969 actions.

During transcription of the videos we observed some behaviors and formed hypotheses; we then used statistical testing to confirm or deny the hypotheses. To begin with, let us consider the hypotheses which found insufficient supporting evidence. First, we hypothesized that the cards-only and cards+AR conditions would, compared with the GUI

Table 2: Mean count c of instances of pointing at kanji components during exploratory phase.

Group	**Cards-only**	**Cards+AR**	**GUI**	**t-test (h_a: $c_{\text{cards-only}} < c_{\text{GUI}}$)**	**t-test (h_a: $c_{\text{cards+AR}} < c_{\text{GUI}}$)**
1	0.462	0.143	0.727	$p = 0.33$	$p = 0.17$
3	0.5	0.286	3.091	$p = 0.06$	$p = 0.04$
5	0.067	0	2.533	$p<0.01$	$p<0.01$
6	1.429	0.429	1.273	$p = 0.56$	$p = 0.04$
7	1.2	1.9	10.133	$p<0.01$	$p<0.01$
9	0.125	2.25	6.833	$p<0.01$	$p = 0.04$
All	0.675	0.756	4.159	$p<0.01$	$p<0.01$

condition, increase dialog and mean spoken word counts per *kanji*; however, t-tests found no significant difference across conditions. Second, we formed a hypothesis about subjects' body gestures during story creation. We observed that subjects would use concrete body gestures while proposing or discussing story ideas with their partners. Here we define concrete body gestures more narrowly than just any gesture; the gesture should be related to the content of the story being discussed. An example of a gesture we would not count would be moving one's hand abstractly and repetitively while trying to think of a suitable story idea. An example of a gesture we would count would be forming one's hands into the shape of a story item under discussion. Having observed the occurrence of such concrete body gestures, we hypothesized that the cards-only condition or the cards+AR condition, because they involve the physical space of the subjects, might be more conducive than the GUI condition in encouraging subjects to use physical space in the form of increased mean concrete body gestures per *kanji* during story creation. However, the means for the cards conditions were found not to be greater than that of the GUI condition.

Next, let us consider the hypotheses where supporting evidence was found.

Coordinative pointing at kanji *during exploration*

We observed on video that during the exploratory phase, when students were searching for valid *kanji* component combinations, subjects seemed to point at *kanji* elements more during the GUI condition than in the cards-only or cards+AR conditions. Recall that the GUI condition used a single sheet of paper with candidate parts printed on it; subjects then clicked the corresponding numbered elements on the pen PC to indicate their choices. Subjects were observed to point frequently to the shared piece of paper in the GUI condition. Based on this observation, we hypothesized that pointing at the *kanji* elements during the exploration phase would be greater than that of the cards-only and the cards+AR conditions. We measured the count of occurrences of such pointing for each *kanji* and took the mean over the number of *kanji* that subjects completed. One-tailed t-tests confirmed that the mean counts for the GUI condition were greater than those of the cards-only and cards+AR condition at the $p<0.01$ level (Table 2). Based on observations of the subjects' pointing activities within the context their spoken dialog, we interpret these pointing gestures as coordinative activities and take this to mean that the GUI requires more explicit coordination of activities among partners. With the GUI, subjects tended to signal their intention

Table 3: Mean count c of instances of pointing at complete kanji image during story-making process.

Group	**Cards-only**	**Cards +AR**	**Combined cards (both with and without AR)**	**GUI**	**t-test (h_a: $c_{cards} > c_{GUI}$)**	**t-test (h_a: $c_{cards+AR} > c_{cards\text{-}only}$)**
1	0	0.143	0.05	0	p = 0.16	p = 0.18
3	0.25	0	0.158	0.182	–	–
5	0.133	0.2	0.16	0.133	p = 0.42	p = 0.38
6	0.286	0.143	0.238	0.182	p = 0.37	–
7	0.2	0	0.12	0	p = 0.04	–
9	1.125	0.5	0.917	0.333	p = 0.06	–
All	0.273	0.133	0.221	0.116	p = 0.06	–

to their partner by pointing and/or speaking, before clicking on the corresponding item on the pen PC. On the other hand, with the cards condition, the shared physical nature of the space and the cards makes such coordinative pointing less necessary.

Explanatory pointing at kanji *during story making*

We also observed that students would sometimes point at *kanji* elements or the image of the composite *kanji* during the story-making process. We interpret such pointing as a non-verbal indicator of subject's mental engagement in the story-making process. If subjects did not care about making a memorable story or did not care about convincing their partner of the merit of their story, we would expect few *kanji*-pointing gestures due to lack of interest. On the other hand, if subjects are trying to explain or convince each other of the suitability of a particular mnemonic, we would expect subjects to use pointing gestures to explicitly include the *kanji* components in the discussion and the story-making process.

We hypothesized that the cards-only and cards+AR conditions, considered together, would elicit more *kanji*-pointing behavior than the GUI condition, and also that the cards+AR condition would elicit more than the cards-only condition. Pointing behavior was divided into two types, pointing at the complete *kanji* image and pointing at the component parts of the *kanji*. We measured the number of occurrences of such pointing that occurred during the story-making process for each *kanji*, and took the mean of the number of occurrences over all *kanji* that were completed by the subjects. For both *kanji*-pointing and component-pointing behavior, mean pointing counts were higher with card-only and cards+AR conditions than with the GUI condition, and one-tailed t-tests reported the difference to be statistically suggestive ($p<0.10$). However the cards+AR condition did not elicit more mean pointing behavior than the cards-only condition. Similar to the earlier comparison of story creation times, again the differentiating factor seems to be the cards themselves, not the additional video media. Having physically distinct and manipulable cards may encourage subjects to make more physical references to the *kanji* components in the form of pointing during their story-making. Tables 3 and 4 show the mean occurrences of pointing and results of the t-tests. In the tables, a dashed (–) entry indicates that the corresponding one-tailed t-test was not performed because the data already contradicted the alternative hypothesis. Note in the tables that the mean over all groups is not

Table 4: Mean count c of instances of pointing at kanji component parts during story-making process.

Group	Cards-only	Cards +AR	Combined cards (both with and without AR)	GUI	t-test (h_a: $c_{cards} > c_{GUI}$)	t-test (h_a: $c_{cards+AR} > c_{cards-only}$)
1	1.23	0.286	0.9	0.091	$p = 0.02$	–
3	0.917	0.143	0.632	0.091	$p = 0.06$	–
5	0.333	1.1	0.64	0	$p = 0.05$	$p = 0.21$
6	0.714	0.286	0.571	0.727	–	–
7	0.8	0.4	0.64	0.933	–	–
9	5.75	0.2	4.5	2.5	$p = 0.25$	–
All	1.299	0.622	1.049	0.565	$p = 0.08$	–

the mean of the individual group means, since the number of samples (completed *kanji*) differs between groups.

Pointing at AR story media during story making

The AR video media, intended to spark or support the story-making process, did not have an observed effect on the story creation times, pen activity, number of words, or the occurrences of *kanji*-pointing behavior. We did, however, observe that students to some extent used the video media, when present, in their story making. Students would sometimes gaze at, discuss, or point at the video media (Figure 6). Of these behaviors, pointing at the video media was the easiest behavior to identify and count. Over all groups, out of 61 samples of the cards+AR condition, we counted a total of 47 times that subjects pointed to the AR media. From this we can say that the pointing is evidence that students took notice of the media. The media also had an effect on exclamatory clapping behavior (see below). Future linguistic analysis of story-making dialog may yield more insight into how the media affects the story-making process.

It may be the case that the effect of AR media is subtle and not directly incorporated into the content of stories. Nevertheless, qualitative observation of the video leads us to believe that AR media may still have a positive effect in encouraging discussion. Especially in cases where subjects were strangers, there sometimes were conversation gaps with silence, when the subjects either had no story idea to discuss or lacked the confidence to propose their idea to their partner. We think that the concrete images provided by our AR media may encourage discussion in such strained situations. By providing a focal point for attention and a specific image, the additional media can direct or focus the discussion space, which could provide at least a starting point for a stalled discussion process.

Spatial rearrangement of cards

The previous findings that the cards conditions, independent of the AR media, affected subject behavior led us to try making further observations about subjects' tendency towards using spatial affordances of the physical cards. In contrast to a GUI, and in accordance with our jigsaw-puzzle analogy, physical cards allow but do not force the students to arrange the cards in spatial configurations in the 2D space of the tabletop interface. If the cards offer no usage benefits over a GUI then we would expect no purely spatial manipulations to take place. On the other hand, if the spatial aspect of the cards is useful to subjects, we would expect them to spontaneously arrange or rearrange cards spatially.

During the exploration phase, we observed that subjects sometimes would tentatively spatially rearrange a set of cards, placing cards in different positions relative to one another and apparently using the spatial configuration to mentally gauge the likelihood of that combination being a valid *kanji*. We thus defined a spatial rearrangement to have occurred when an already-checked set of cards was spatially re-ordered and checked again, or when subjects spatially placed two or more cards in physical proximity outside of the checking area as a sort of "what-if" scenario before checking. In both cases the action indicates that the subjects are using the spatial configuration of the cards. Additionally, we observed that no spatial rearrangements occurred during the story-making phase, perhaps because during the story-making phase, the correct answer in the form of a complete *kanji* image is already shown, eliminating the motivation or the need for the students to explore different spatial configurations.

We counted the occurrence of spatial rearrangements. Over 92 cards-only and 61 cards+AR samples, we found a total of 28 spatial rearrangements. Because all such spatial arrangements occurred during the exploratory phase, which takes place before any AR media is displayed, there could have been no possible effect of AR media on the number of occurrences of spatial arrangements. It was therefore not possible to compare the spatial arrangement frequencies among conditions, but we can say that the emergence of spatial rearrangements indicates that the cards conditions encourage or allow an observably different usage style than that of the GUI, and that this different usage style seems to be characterized by the other cards-condition effects noted earlier.

Exclamatory clapping

Exclamatory clapping behavior refers to sudden spontaneous clapping by a subject, often accompanied by a verbal exclamation, upon successfully finding a valid combination of component parts during the exploratory phase. We observed occurrences of this on the video and hypothesized that the cards+AR condition would yield more clapping than the both the cards-only and the GUI conditions. We measured the number of times either subject clapped upon successfully finding a valid combination, and took the mean over the number of *kanji* completed. Over all groups, a one-tailed t-test revealed that mean clapping occurrences with the cards+AR condition were greater than the GUI condition at the $p<0.02$ level (Table 5). Comparing cards+AR against cards-only, the mean was again greater for the cards+AR condition, at a statistically suggestive ($p<0.10$) level. We interpret this to mean that subjects enjoyed more satisfaction with the cards+AR condition upon successfully finding a valid combination. In the cards+AR condition, subjects were rewarded upon successful combination not only with the image of the *kanji* but also with images of the AR media. Displaying the AR media in this way thus seems to have a positive effect on subjects' enjoyment.

Table 5: Mean count c of instances of exclamatory clapping.

Group	Cards-only	Cards +AR	GUI	t-test (h_a: $c_{cards+AR} > c_{GUI}$)	t-test (h_a: $c_{cards+AR} > c_{cards-only}$)
1	0.077	0	0.091	–	–
3	0.083	0	0	–	–
5	0.133	0.6	0.067	p=0.02	p=0.04
6	0	0	0	–	–
7	0	0	0	–	–
9	0.25	0.5	0	p=0.09	p=0.24
All	0.078	0.178	0.029	p=0.02	p=0.09

Table 6: Questionnaire responses.

Item	Mean	Std. Err
Tabletop interface was useful	5.222	0.358
Using stories was useful	5.889	0.342
Technology will be useful in future classrooms	5.944	0.347
Japanese teacher would be excited about this technology	5.5	0.364
Japanese teacher would be excited about story-based learning	5.5	0.364
Discussing with partner helped new story ideas	6.056	0.318
Watching table-top videos helped new story ideas	4.111	0.484
Would like to use this technology in the future	5.889	0.361
Other students would be excited about this technology	5.944	0.318
Other students would be excited about story-based learning	5.722	0.351
Using cards helped discuss how kanji shapes fit together	5.333	0.388

Questionnaire results

Results from our post-questionnaire are shown in Table 6; responses are on a scale of 1 to 7, where 1 indicates strong disagreement and 7 indicates strong agreement with an item. The results indicate that users generally had a positive opinion of our system. One interesting exception is the subject who gave low scores on all questions. His free-response written comment indicated "I think it's forcing to make stories, which make people irritated." This subject's self-reported *kanji* knowledge was tied for the highest rank among our subjects (knowledge of about 500 *kanji*). We suspect, therefore, that this user already had his own effective *kanji* learning strategy and saw no benefit to the mnemonic story method. Another user with high *kanji* knowledge of around 500 characters gave our system positive ratings and reported that he liked the story-based method. Just as teachers (Shimizu & Green, 2002) and textbook authors (Richmond, 2005) have differing philosophies on *kanji* instruction, so do students as well.

Towards a corpus of story-making activity

Previous work on story-based *kanji* learning (Richmond, 2005; Lin & Mase 2006; Lin *et al.* 2007, 2008; Richardson, 1998; Richardson, 2007; Fabrice, 2008) frequently focuses on the end-result of the story-making process, but not on the process itself; when the process itself is considered (Richardson, 1998; Richardson, 2007), it is done so without empirical data. Our experiment helps fill this gap by recording and analyzing the story-making process during story-based *kanji* learning. Our initial data set contains transcribed dialog and activity labeling. While it is perhaps still too small to yet be called a corpus, we believe that data sets such as ours represent what could be the start of a corpus of *kanji* story-making activities. We feel that such corpora would allow deeper understanding of and better support for story-based *kanji* learning, and that this area represents a fertile ground for future research.

Conclusion and future work

We presented a novel tabletop system that addresses the need for group support of story-based *kanji* learning activities. We designed a collaborative activity and a collaborative system based on the analogy of a jigsaw puzzle. Users can explore *kanji* part-to-whole compositions in a constructionist way by physically assembling cards whose locations are tracked with augmented reality marker technology. Physical cards are augmented with virtual media to assist in mnemonic story creation for learning *kanji*, and stories are written collaboratively on pen computers with synchronized displays. Although our current system only implemented a subset of *kanji* needed for literacy, we could show: the feasibility of our approach; that our technology supports exploration and story-making; and that users generally accepted our system. As compared with a GUI control condition, we observed increased exploratory activity, greater pointing activities, and longer story creation times with the card interface; with the addition of AR media, we observed increased exclamatory clapping. We interpret these to mean that our system increases user engagement and enjoyment during the learning process.

In the current system, the constructionist exploration task and the story creation task take place on different interfaces – the tabletop interface and the pen PC, respectively. A possible future improvement would be to allow students to write with a digital pen directly on the tabletop, thereby adding their own written/drawn story contents directly onto the assembled *kanji* components. Additionally, it would be useful if end-users could, by using the tabletop interface, assign their own augmented video media content to the *kanji* component cards; such video assignment is currently done beforehand by the system operator with a mouse-driven storyboard GUI. Designing a multi-user tabletop storyboard interface is a challenge and a research project in its own right.

Additional data analyses of story-making activities would be interesting. In particular, collaboration patterns while using the cards and linguistic analyses of the story-making spoken dialog seem worth investigating to gain a deeper understanding of the *kanji* story-making process, which has gone largely unstudied.

It would also be interesting to try using this technology as part of a formal educational curriculum. Our (admittedly limited) direct experience with JSL teachers has been that they are reluctant to introduce story-based methods into their classrooms. However, we hope that systems such as ours that can support group activities may lead to a greater willingness to try story-based *kanji* learning in the classroom.

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