THE EFFECTS OF HANDHELD NETWORK SERVICE "LOOK" ON THE ACQUISITION OF COMMON GROUND

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Dissertation submitted to faculty of the Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
In
Computer Science and Applications

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January 12, 2007
Blacksburg, Virginia

Keywords: Human-Computer Interaction, Computer-Supported Cooperative Work,
Computer-Supported Collaborative Learning, Ubiquitous and Pervasive Computing,
Handheld Devices

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ABSTRACT

Constructing common ground and the associated convergent conceptual change is critical to cooperative work and learning. Convergent conceptual change is achieved as participants in a conversation update common ground through presentations, repairs, and acceptances of utterances (Roschelle, 1992). People employ available techniques that utilize the least collaborative effort for current purposes (Clark and Brennan, 1991). Although sharing physical co-presence of interlocutors’ facial expressions doesn’t make grounding more efficient even in more open-ended and less task-focused dialogues (DiNardo et al., 2005), visual co-presence of the addressee’s workspace is essential to work-related tasks, such as information transmission and collaborative problem-solving (Clark and Krych, 2004). However, handheld-mediated collaborative activity makes sharing the workspace challenging, especially when we consider that handhelds possess small screens and permit activities of a distributed nature. In a handheld-mediated classroom, a teacher must be able to check students’ work for various reasons (e.g., grading, checking whether they are following directions correctly or paying attention) and at various phases of the activity. Gazing into the small screen of a handheld over someone’s shoulder is a tricky task at best. The teacher may misread the information on the screen and thus provide incorrect feedback. Another challenge involves the difficulty inherent in latecomers joining the collaborative activity when each student is involved with his or her individual and small screen. This exclusion from joining on-going activity can reduce the chance of student’s vicarious and serendipitous learning. Although such events may occur naturally in the learning environment, they become important concerns when one attempts to focus collaborative activities with handheld devices. I therefore created a new handheld network service called “Look,” which is designed to facilitate the acquisition of common ground and allow a latecomer to do meaningful monitoring of ongoing conversation about the workspace. I tested empirically the value of this shared physical/virtual context in the task of creating common ground by examining task performance and conversation quality.

To my parents, 김용선, 이영희, and my sisters and brother.

Acknowledgements

At the point of submitting my dissertation, the last five-and-a-half years at Virginia Tech (VT) seem like they have flown by. Most of my colleagues who started the study with me are not here any more (although Con Rodi is still here and is my good colleague in the HCI Center).

However, I can say that these years have been the most fruitful and keen period in my life so far. I came to VT with no sense of Human-Computer Interaction (HCI) research. Now, I dare say that I understand the idea of what HCI research is and how interesting it is. This growth in my mental and academic ability would not have been achievable if I had not had the good fortune to meet several great people. Dr. Carroll and Dr. Rosson taught me how to have a broad point of view toward challenges and how to approach answers in an important way. Their guidance in my early studies will be a cornerstone for my attitude for future research. I had also the great chance to work with Dr. Patton during my stay at SRI. He is a pleasant and knowledgeable, but humble person. I am lucky to have had him on my committee. Dr. Perez and Dr. Quek are very active debaters, too. Whenever I visited them, I always came back with new, interesting ideas.

Also, my research group mates, Sirong, Jamaika and Meg, are good companions. Seonho and Dong Kwan are good Korean friends to talk with. Ann Hess and John Hess are my host family parents who fed me during holidays every year. I am also thankful to all those who provided support throughout my graduate study, including Dr. Dunlap, Dr. Zin, Dennis Neale, Philip Isenhour, Dr. Kavanaugh, Dr. Hartson, Dr. Capra, Dr. Rode, Jon Howarth, Pardha, Yonca, Xiaoyan, Laurian Vega, Youngyun, Dr.Weon, Yoon-Soo, Albert, Pilsung, Ji-Sun, Seungwon, Chewoo, Si-Jung, Joon-Seok, Jaehoon, Yongju, Chang-Geun Ali Ndiwalana, Craig Ganoe, Dr. Schafer, Gregorio Convertino, Umer Farooq, Lu Xiao, Dr. Perugini, Mayur, Michael, Kathleen Stoeckle, Joung-Eun, and my roommate Jason.

However, this dissertation and what I am now could not been made unless I had met Deborah Tatar and Steve Harrison. They are my advisor, supporter, mentor and my academic parents. All of the valuable time I had with them will never be forgotten and their influence will go with me forever after I graduate. I just want to say “Thank you.”

Finally, this dissertation is dedicated to my parents who always believe in me.

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Chapter 1: Introduction

Wireless connecting of computers to the Internet from a variety of everyday locations—from coffee shops to libraries, from airports to hotel rooms—has become so commonplace that it no longer attracts special attention. New, increasingly common opportunities for ubiquitous wireless connectivity exist, and so it seems only logical that many schools have begun adding wireless network capabilities to their traditional classrooms. By creating wireless "hotspots" on the fly, a teacher can set up an instant computer lab, auditorium, and virtual classroom, even outside of buildings. The import of wireless technology to K-12 education is meaningful because it saves money, provides flexibility, and supports expandability on the already-made wired infrastructure. However, many current mobile classrooms are still semi-mobile in some sense: in order to create her "wired" classroom, the teacher must wheel a cart with a set of wireless laptop computers along the hallway. Additionally, once she arrives at her room, the teacher must spend valuable class time setting up the laptops and creating access. For fully ubiquitous network access in the traditional classroom, one must look beyond this solution to handy mobile devices such as Palm OS handhelds, Pocket PCs, and Smartphones equipped with communication technology like Bluetooth, Wi-Fi, and infrared (IR). Following the trend toward increased availability of wireless handhelds, I will present a new handheld network service, "Look," which accomplishes pedagogically-useful transmission of the data and also examine the effects of its potential use in collaborative learning activities.

The proposed handheld network service "Look" is designed to enable the capturing of objects or workspaces from other handheld screens by beaming or signaling to them. In handheld-based collaboration, voice, eye gaze, facial expression, gesture, and physical environment are naturally available because such collaboration is based on synchronously collocated face-to-face interaction. However, the focal objects or workspaces on the handheld and the user's activities on the screen are not easily shared among collaborators. Because of device glare and size, ordinary glancing is insufficient. Prior empirical evidence suggests that when people can see where each person is looking, it is easier to establish common ground. For example, incorporation of the shared video for a workspace proves valuable when partners are expected to collaborate on task-oriented discourse (Kraut, Miller et al. 1996; Fussell, Kraut et al. 2000; Kraut, Gergle et al. 2002; Kraut, Fussell et al. 2003; Gergle, Kraut et al. 2004). Although monitoring an addressee's face did not lead to measurably greater efficiency, providing a visual context of a workspace makes discourse participants perform tasks much effectively and quickly (Clark and Krych 2004). To augment face-to-face communication in handheld mediated joint activity, "Look" enables participants to share indicatory objects (i.e., visual context) during collaborative activities. The value of shared visual context with handhelds in the task of creating common ground is empirically tested in the experiments reported here.

Many current computer-supported collaborative learning (CSCL) or computer-supported cooperative work (CSCW) tools focus on supporting central participants such as speakers or addressees in a communication; however, not many of these tools focus on peripheral participants—that is, those who are attending to the conversation overtly or covertly but are not current addressees or responders. Considerable evidence exists that such participants have different access to information and different cognitive burdens than do central participants (Schober and Clark 1989; Clark and Schaefer 1992; Clark and Schaefer 1987; Clark and Carlson 1982). However, very little is known about how to support peripheral participants' needs. Designing a system for peripheral participation as well as for central participation is a complicated task that likely requires different perspectives from those adopted for existing CSCL and CSCW theories. In this dissertation, I will explore the challenges faced by peripheral participants, introduce a possible solution to overcome those challenges, and report experimental results showing the proof-of-concept of the suggested solution, "Look."

The experiments reported here focus on three different types of peripheral participants in the context of task-oriented discourse processes with handheld computers; an early side-assistant, a late overhearer and a late side-participant. The side-assistant is the helper for central participants, such as a teacher or a peer commentator. The overhearer is an *"unratified inadvertent participant"* in a conversation (Goffman 1976). During the experiment, s/he cannot join the process of coordinating between a speaker and an addressee but may try to get oriented. Lastly, the side-participant is a ratified but not central participant. S/he can takes part in the conversation but s/he is not currently being addressed, like a student trying to enter the conversation.

Peripheral participants also differ by virtue of when they join a conversation. They may become latecomers. The other effective use of “Look” is to support latecomers to group activity. With regard to collaboration, such a latecomer traditionally would be at a disadvantage in grounding, the joint process of establishing mutual belief. However, there is no generic way for groupware tools to handle latecomers (Roseman and Greenberg, 1996). To catch up with the accumulated understanding in a discussion, a latecomer perhaps enters into a conversation about a particular object by merely observing the interaction until she can make an informed contribution. With “Look,” the latecomer can be brought up to date by capturing the existing state of other handheld screens. Therefore, people seeking to join an activity can understand the context of the discussion quickly and easily and can participate in conversation without paying too high a price in grounding.

From various networking options, the experiments in this study will explore two different distributed communication platforms, infrared (IR) technology (i.e., beaming) and radio-frequency (RF) technology (i.e., Bluetooth) to address whether different forms of implementing shared visual context affect how well peripheral participants can use shared visual context. IR machines are less expensive and solve a raft of classroom management problems. Point-to-point beaming allows localized control, with no need for the system to know who is working together. Also, the limited range and angle of the infrared allows each person to aim her or his device at the intended recipient with ample security and no interference. On the other hand, any success of “Look” with IR would be amplified with RF-based communication. Since, unlike IR, RF communication is omni-directional and need not be directed at a particular other person, overhearing or monitoring can be accomplished less intrusively. The standard RF network protocol is a strong candidate for seamless connectivity regardless of the device, service, network, or location.

In addition to providing students with cutting-edge technology, handhelds can empower them to become more engaged in what otherwise might be routine classroom activities. Handhelds permit students to move around the classroom or learning environment rather than restricting students’ collaboration to those on the computer beside them, which increases students’ potential for interacting with others. This active, collaborative engagement promotes high levels of student learning and increases educational effectiveness. The proposed handheld network service "Look" is designed to enable a coherent activity in which peripheral participants understand what other are talking about (in other words, what they are learning), and thus increases the chance that peripheral participants' vicarious and serendipitous learning takes place.

Dissertation outline

This dissertation addresses how sharing visual context affects the creation of common ground between participants in different conversation roles during a handheld-based collaborative activity. It focuses especially on peripheral participants' understanding the conversation. Three experiments were conducted to test three different roles of peripheral participants; early side-assistant, late overhearer, and late side-participant. The study also examines how providing a shared visual context affects the learning of peripheral participants. Learning the pronunciation of Korean characters has been introduced as an experimental task in addition to the main task of achieving common ground.

To explore the benefits of the shared visual context while using handhelds, a new handheld network service, "Look," was devised using two different forms of implementation; infrared beaming and Bluetooth communication. By implementing the network service with different technologies, this study investigates how different forms of implementing shared visual context affect the rapid creation of common ground of peripheral participants. Although these different design options of wireless local area network (WLAN) architecture are not the main purpose of this study, the findings are discussed generally for future ubiquitous classrooms.

Table 1 shows how experiments in this study are designed via different WLAN and participatory status.

Table 1: Experiment design by technology and participatory roles.

WLAN / Participation	Infrared Beaming	Bluetooth Communication
Early Side-Assistant	*Experiment 1*	
Late Overhearer		*Experiment 2*
Late Side-Participant		*Experiments 3a, 3b*

Chapter 2 looks at past research on the use of handhelds for educational purpose, addresses shared visual workspaces, and discusses restrictions faced by peripheral participants. Chapter 3 describes the role of context in learning theories, human-computer interaction theories and cognitive psychology theories. Context is the key consideration for facilitating mutual understanding and collaborative learning in handheld-mediated communication. Chapter 4 describes the methods used to test the general hypothesis that the "Look" network service (as contrasted with its absence) facilitates the creation of common ground between discourse participants and enhances their understanding of conversation in handheld-mediated collaborative learning. Chapter 5 presents the experiment results about the effect of "Look" on the early side-assistant. Chapter 6 presents the experiment results about the effect of "Look" on the late overhearer. Chapter 7 shows the experiment results about the effect of "Look" on the late side-participant. Chapter 8 discusses general findings from all three experiments. The final chapter, Chapter 9, discusses the main contributions and conclusions of this research, and suggests areas for further study.

Chapter 2: A Review of Previous Work

In this chapter, I survey previous work showing how handheld devices can be used for collaboration in a classroom and the issues of sharing visual workspaces for cooperative work. Lastly, I discuss previous findings about restrictions faced by peripheral participants.

The use of handhelds in the classroom

Over the last few years, many researchers have been interested in devices for educational technology. They have been investigating a small handheld as a classroom delivery mechanism with both pragmatic and transformative functionality. The pragmatic component comes from the device's much-reduced price, which by itself solves a number of problems in adoption and usage (Norris and Soloway 2003; Fishman, Soloway et al. 2001; Tatar, Roschelle et al. 2005). The transformative component comes from the small, mobile form factor as a generator of pervasive, ubiquitous activities. The last couple of years have been exciting ones for the development of classroom-based activities at all levels of realization, from products such as clicker systems and graphing calculators, to classroom demonstrations of learning affects, to laboratory demonstrations of possibilities. As shown in Table 2, these systems have already been used in many ways to produce a multiplicity of good effects.

In two previous projects using participatory design, Tatar and her colleagues have produced a series of activities to support formative assessment in middle school science learning (Tatar, Roschelle et al. 2005; Roschelle, Penuel et al. 2004; Penuel and Yarnall 2005) and targeted "games" for middle school math (Vahey, Tatar et al. 2004; Tatar, Roschelle et al. 2003; Tatar, Roschelle et al. 2005; Roschelle, Tatar et al. 2005). The outcomes of these projects include various design patterns, particular implementations, and classroom use experiences. The first project has thus far been pursued to the point of demonstrating that teachers can more effectively use the activities than the original teacher-collaboration. The second project has demonstrated profound and impressive classroom impact, including that 8^{th} grade students at the beginning of their algebra learning sequence showed improvement in scores and achievement on qualitative advanced placement (AP) calculus problems. The class-wide consequences of the study were overwhelmingly positive; therefore, arguably, the time that students spent struggling with the problems was well spent. However, at the same time, when compared to the use of manipulatives, worksheets or desktops, the project revealed that the teacher's ability to gauge the nature and seriousness of problems was curtailed. Even given this difficulty, wirelessly-connected handheld PDAs hold great potential for the classroom (Soloway, Grant et al. 1999; Tatar, Roschelle et al. 2003). While it might be too expensive to provide a desktop computer for every student or too much of an interruption to leave a traditional classroom for a trip to the school's computer lab, handhelds simplify the collaborative learning environment; they are portable, easy-to-maintain and relatively inexpensive and so, they do away with the need for a centralized lab.

Handhelds can be used in many ways in the classroom. For example, by employing both handhelds and a large screen display, Wilensky and Stroup (2000) used a distributed programming language, StarLogo, to allow students to explore complex distributed systems. Kaput and his colleagues (Kaput and Hegedus 2003; Kaput, Roschelle et al. 2003) also emphasized aggregation activities, highlighting the individual's contribution to the whole class. In these situations, a relatively close relationship exists among the involvement of the teacher, the acts of individuals, and the publication of their work for the whole classroom. Such publication provides an opportunity for formative assessment.

Students can also develop complex and sophisticated idea-networks using handhelds. The Picomap project (Luchini, Quintana et al. 2002), the Sketchy tool (www.goknow.com) and the elaboration in ImageMakers (www.projectwhirl.org) allowed students to produce animations of science processes and concept-maps before uploading them to a desktop or large screen format. Indeed, ImageMakers had formative assessment as a goal; nonetheless, it primarily supports uploading at the end of the activity, using HotSync. While the participating students had a clear idea when they had finished the tasks, there were barriers to fine-grained formative assessment (Davis 2002). Successful formative assessment using handhelds that involves minimal disruption and communicates contextual data in a continuous process is critical.

On the other hand, Shields and Poftak (2002) brought up some problems involved with bringing handhelds into the classroom. Handhelds are originally built for business purposes, not educational use, so that they are still a bit pricy for schools and their design is not perfectly danger-proof for kids. Their glass LCD screens are breakable when dropped. In some respects, beaming is also very controversial for schools. It can be misused to disrupt the class, such as changing channels on a TV monitor during class, sending personal email during the class time, and playing games. In addition, beaming can slow down some tasks; for example, when many students all try at once to upload their works to a teacher's PC, logistical problems become clear. A more troubling aspect is electronically-enabled cheating with beaming, although it may not be common because of line-of-sight alignment and a fairly limited range of communication. Handheld technology for schools is still in its infancy, much like laptop technology in the mid-1990s. Although interesting research needs to be done dealing with the ubiquitous learning which handheld devices offer, we are on the right track with the idea of portable small devices for one-to-one computing for every student.

Table 2: A partial list of handheld projects classified by classroom functionality and technological status.

	Personal / Background Tools	Central Representational Devices	Controllers of Other Devices	Communicators	Teacher Management Devices
Clicker Systems	Boomerang (Tatar, Roschelle et al. 2003)	ClassTalk (Dufresne, Gerace et al. 1996)	PUC (Personal Universal Controller), CPoF (Command Post of the Future) (Myers, Nichols et al. 2004)	I-Guides (His 2002)	EduClick (Liu, Kiang et al. 2003)
Graphing Calculators	PIGMI (Portable Information Technologies for supporting Graphical Mathematics Investigations) (Hennessy 1999)	Gridlock (Wilensky and Stroup 2000)	LabWorks (Morgan and Amend 1998)	Match-My-Graph, Slot Machine (Tatar, Roschelle et al. 2003)	HubNet (Wilensky and Stroup 2000)
PartSims	Cooties (Soloway, Norris et al. 2001)	Chemation (Bobrowsky, Vath et al. 2004)	Thinking Tags (Colella, Borovoy et al. 1998)	HEARTS (Harness for Education And Research Testing System) (Jipping, Dieter et al. 2001), Geney (Danesh, Inkpen et al. 2001)	MathWorlds (Hegedus and Kaput 2002)
System Sims	CritterVille (Soloway, Norris et al. 2001)	NetCalc (Tatar, Roschelle et al. 2003)	MRSCL (Mobile Robotic Supported Collaborative Learning) (Mitnik, Nussbaum et al. 2004)	Sketchy (Bobrowsky, Vath et al. 2004)	Environmental Detectives (Klopfer, Squire et al. 2002)
Awareness Devices	StudySpace (Schnase, Cunnius et al. 1995)	Data Doers (Tatar, Roschelle et al. 2003)	Symbiotic Environment (Raghunath, Narayanaswami et al. 2003)	Awarenex (Tang, Yankelovich et al. 2001)	Information Aware System (Wang, Liu et al. 2003)

Focused Practice	VeGame (Belloti, Barta et al. 2003)	Who's who? (Moher, Ding et al. 2003)	Probeware (Tinker and Krajcik 2001)	Electronic Guidebook (Bannasch 1999)	Code It! (Goldman, Pea et al. 2004)
Active Document Exchangers	FreeWrite (Bobrowsky, Vath et al. 2004)	Plantations Pathfinder (Rieger and Gay 1997)	Campus Mobile (Demeure, Faure et al. 2005)	NERTS (Networked Exchange for Remote Teaching Systems) (Jipping, Dieter et al. 2001)	Quizzler (Penuel and Yarnall 2005)
Formative Assessment	WHIRL(Wireless Handhelds Improving Reflection on Learning) project (Roschelle, Penuel et al. 2004)	Palm sheets (Soloway, Norris et al. 2001)	SLiC (Science Learning in Context) project (Soloway, Grant et al. 1999)	ImageMap (Roschelle and Pea 2002)	Gradebook (Penuel and Yarnall 2005)
Information Delivery / Storage	Fling-It (Soloway, Norris et al. 2001)	MCSCL(Mobile Computer Supported Collaborative Learning) (Zurita and Nussbaum 2004)	Cornucopia (Rieger and Gay 1997)	PiCoMap (Luchini, Quintana et al. 2002)	NotePals (Davis, Landay et al. 1999)

Shared visual workspaces

As Clark and Brennan long ago noted (Clark and Brennan, 1991; Brennan, 1998; Brennan, 1990), different communication media put different constraints on the grounding of information. Clark and Brennan (1991), Kraut, Fussell, Brennan and Siegel (2002), Clark and Krych (2004), and Kraut, Gergle and Fussell (2002) provide both theory and experimental evidence that a shared visual space helps efficient communication and grounding of information between discourse participants. The underlying theory describes the need that participants have to create and maintain joint focus on the mental and physical objects of collaboration and the processes that they go through to maintain this state (Clark, 1996). Clark and Krych (2004) show that monitoring an addressee's workspace during a task involving referential communication is associated with an eighth of the errors, and half the time needed for the work as opposed to no monitoring the workspace. The findings from previous experiments investigating the benefits of sharing visual context can be summarized as follows (Kraut, Fussell et al. 2003; Fussell, Kraut et al. 2000; Kraut, Fussell et al. 2002; Monk and Gale 2002; Clark and Krych 2004):

Shared visual context can facilitate the grounding process between discourse participants by improving communication quality. When there is external evidence of visual information, discourse participants can achieve grounding with fewer conversational turns. There is little need for addressees to state explicitly their understanding of instruction, since the speaker can use the video to observe whether the addressees' performance is correct. Also, when participants have shared visual workspaces, they use more frequently such deictic references as *this*, *that*, *these*, or *those*. Without a shared visual context, participants must work harder and more frequently to describe their states.

Shared visual context can give discourse participants the ability to maintain consistent awareness of the task state. Through the shared visual context, participants can have up-to-date views of the task state and maintain their awareness of how the current state moves toward a goal. For discourse participants, such awareness not only reduces ambiguity and coordinates formulation of subsequent utterances but also allows them to achieve their goal with the least amount of joint effort.

Shared visual context permits enhanced monitoring of comprehension. It provides evidence about collaborators' understanding of the language used for coordination and permits collaborators to remedy specific mistakes. With the benefit of shared visual context, they can mutually assess what each other knows at any moment and use this information to carry on their conversation.

Shared visual context can produce greater benefits when tasks are visually complex or when there is no simple vocabulary for describing the task state. Otherwise, if tasks are simple enough or discourse participants have well-practiced vocabulary to describe the state of task, visual context does not provide any new information.

Another class of previous research suggests that the sharing of computer screens provides certain advantages for collaborative learning endeavors (Inkpen, Booth et al., 1995). Sharing a single display provides a shared artifact, which between collaborators initiates discussions and enhances attention. However, handhelds do not naturally support the sharing of a single display among collaborators. As a result, collaborative activities that rely upon handhelds face greater challenges with regard to the maintenance of shared attention (Roschelle and Pea, 2002).

Restrictions faced by peripheral participants

The challenge for a peripheral participant is peculiar: The peripheral participant needs to understand what central participants are doing with as little impediment to them as possible. Previous research, motivated by the theoretical base in joint action of discourse processes, shows that there is a cost to being an outsider or an overhearer to the ongoing conversation (Clark and Schaefer 1992). When two people were engaged in a referential communication task, a third person connected by video was at a substantial disadvantage across the repeated trials in decoding what the central participants were talking about (Schober and Clark 1989). In actively collaborating to reach common ground, central participants possess an advantage over a peripheral participant because central participants, unlike peripheral participants, engage in a process of gathering the moment-by-moment evidences necessary to ensure that what is said is understood. For example, a speaker might periodically check the understanding of addressee before proceeding with his conversation, and also the addressee might occasionally respond to the speaker to clarify points of her confusion. However, the peripheral participant does not interact actively with either a speaker or an addressee.

According to psycholinguistics, in such a collaborative view of language usage, the peripheral participant faces several disadvantages in understanding what is said. First, peripheral participants have limited resources in grounding the mutual beliefs, knowledge and assumptions required for current purpose of understanding the conversation (Wilkes-Gibbs and Clark 1992). Grounding refers to the interactive exchange of evidences by discourse participants regarding what is understood. Peripheral participants cannot actively join the process of such coordination between a speaker and an addressee. Instead, they receive only what is given by central participants (i.e., speaker and addressee). Second, peripheral participants cannot control the pace of the conversation, and once they lose track of the content, their misunderstandings can accumulate easily (Schober and Clark 1989). Peripheral participants must contend with each speaker's next utterance while trying to complete understanding of the last one. They do not have an opportunity to keep the speaker informed of the state of their confusions or to clarify misunderstandings. Third, although the addressee can determine what the speaker means from conclusive evidence of their common ground, peripheral participants can only conjecture about what the speaker means using inconclusive evidence (Clark and Schaefer 1992). This problem grows worse if peripheral participants are not present to witness the buildup of common ground between central participants. Without knowing what constitutes the speaker's and addressee's common ground, the peripheral participant finds it difficult to determine exactly what their discussion means. In most if not all cases, peripheral participant's only recourse is to conjecture based on his/her own assumption of common ground.

Two gaps in theory follow from prior work. The first has to do with the relationship between the cost of being a peripheral participant as compared to a central participant, and the cost of no sharing a visual context. Earlier research shows that both situations present problems, but it leaves open how the problems are related: are they (for example) cumulative or does one dwarf the other? The second question is the relationship between the findings about overhearers, who are completely isolated from participation, and side-participants, who may participate but neither interrupt nor distract the central participants. Together, the lack of theory in these areas leaves open design questions. This study will not attempt to answer these questions at the level of basic theory; however, it casts light on them by investigating whether a particular design solution suffices.

Chapter 3: A Review of Related Theories

Context is important for facilitating mutual understanding and collaborative learning in handheld mediated communication. The "Look" handheld network service provides a visual context to facilitate a peripheral participant's understanding of the conversation. This chapter presents the literature of context in theories concerning learning, human-computer interaction, and cognitive psychology, among other relevant areas to this study.

Learning theories

Two major figures in developmental psychology, Jean Piaget and Lev Vygotsky, offer a foundation for contemporary study in the entwined fields of education, sociology, and philosophy. In particular, much research on the topic of Computer Support for Collaborative Learning (CSCL) has plumbed Piaget's and Vygotsky's theories as frameworks for empirical development as well as for theoretical understanding.

Although both Piaget and Vygotsky were certainly concerned with the development of children's cognition, they had different views regarding the core of children's intellectual growth. Piaget was a biology-oriented individualist whose child development model was interior and private; thus, it placed primary emphasis on individual psychogenesis. On the contrary, Vygotsky was a socio-cultural constructivist whose intellectual development model for children was exterior and public. Sociogenesis of mind was much more important to Vygotsky.

In Piaget's psychological explanation of intellectual development theory, the gradual establishment of *equilibrium* between *assimilation* and *accommodation* plays a critical role. Equilibrium is the compensation resulting from subject's activities in response to external intrusion; it is not an extrinsic or added characteristic but rather an intrinsic and constitutive property of natural life. When the fundamental interaction between mental and environmental factors is taken into account, all behaviors are considered as assimilations of reality to the prior schemata (i.e., conceptual model). At the same time, the schemata can accommodate to the actual situation (Piaget 1964). The result is that learning is neither a plain copy of reality nor merely transmitted. Instead, learning is much more meaningful because it is knowledge constructed through a child's interiorized action against an external experience, which requires the dual process of assimilation-accommodation for the attainment of equilibrium (see Figure 1). In other words, learning is possible only when there is active equilibrium or voluntary self-regulation of behaviors, what Piaget calls *internal reinforcements* (Piaget 1972).

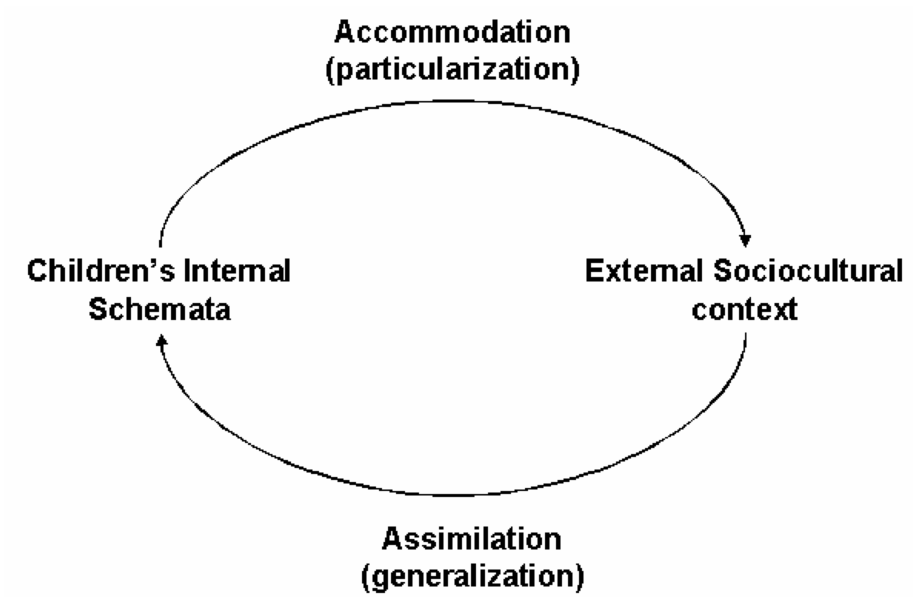


Figure 1. Piaget's circular reactions of equilibrium in intellectual development through assimilation and accommodation.

While Piaget argues that the child's learning process starts from the deeply egocentric self in the process of becoming gradually socialized, Vygotsky argues, on the contrary, that the true direction of children's intellectual development starts from the social aspect in the process of progressively individualizing themselves. Vygotsky considers the decisive factor in children's development of mind to be social, and he states that learning presupposes a specific social nature and is a process by which children grow into the intellectual life of those around them (Vygotsky 1978).

Vygotsky theorizes that the state of children's intellectual development can be explained by the zone of proximal development. This zone involves the distance between the level of actual development as determined by independent problem solving and the level of potential development as determined through problem solving under adult's guidance or in collaboration with more capable peers (Vygotsky 1978). Once this process of creating the zone of proximal development is appropriated, it becomes part of children's independent developmental achievement. Learning awakens various internal developmental processes, which then are able to operate when children interact with others in their environment. Thus, learning is a necessary collective process of developing culturally organized psychological functions.

Socio-culture-historical context in Piaget's and Vygotsky's theory

Despite the differences that exist between Piaget's and Vygotsky's approaches to the learning processes of children, there also exists between them a noticeable similarity: the effects of the cultural and socio-historical contexts in which children act dynamically to shape their intellectual development. Both Piagetian and Vygotskian state that cultural and socio-historical contexts influence the ways in which children interact with, learn from, and demonstrate an understanding of physical features of their environment.

Piaget shows that with progressive socialization through contexts (i.e., maturation, equilibrium), the egocentric character of a child's thinking gradually leans toward collaboration and cooperation (Piaget 1962). Children construct meaning from their experience within the context of, and in relation to, their physical and psychological environments. Piaget's dual process, assimilation-accommodation, can be characterized as circular reactions in which the child repeatedly tries out assimilation (generalization) of a specific situation to his or her internal preexisting schemata, as well as accommodation (particularization) of his schemata or skills to activity within a context (see Figure 1). Piaget defines children as active agents cooperating within their own worlds with the dynamic role of environmental affordances, and he recognizes the contribution of socio-cultural contexts to children's cognitive development. Piaget explains that because knowledge is an internalization of experience, learning activity is, in a certain sense, the function of the environment and the product of internalization of external society. In his opinion, from the cradle to the grave, social experience is pervasive: *"human intelligence is subject to the action of social life at all levels of development from the first to the last day of life*" (Piaget 1995). Cooperation between a child and socio-cultural contexts in his environment provides the basis for the development of intelligence by voluntary self-regulation of behavior.

For the intellectual development of the child, Vygotsky also emphasizes the importance of socio-historical contexts. He describes the development of higher mental processes is socially rooted and historically developed: every function of the child's development appears first on the social level (interpsychological) and, later, transforms into the individual level (intrapsychological) (Vygotsky 1978). Children's minds are shaped by the particular social and historical contexts in which they live and by their interactions with adults and peers. Therefore, the development of children's intelligence must be studied with respect not only to intrapsychological progress, but also to interpsychological progress. In Vygotsky's view, represented by the zone of proximal development (see Figure 2), there are at least two developmental levels. The first level is called the *actual developmental level*; this level defines functions that have already been achieved by the completion of the developmental cycle. The other level is the *potential developmental level* (i.e., proximal development level), which defines functions that have not yet matured but are in the process of doing so under socio-historical contexts. The actual developmental level characterizes mental development retrospectively, but the potential developmental level characterizes it prospectively.

The zone of proximal development requires a complex dialectical process between children and social environment: Children personally influence their relations with the environment, and through that environment they change their behavior personally. For example, if children can do such-and-such independently, that means they achieve a level of actual development. However, if children can solve a problem only after a teacher offers leading questions or initiates the solution, or after collaboration with other peers, then they are in the zone of proximal development. This joint construction of knowledge requires creating a process of cognitive, social, and emotional interchange. Learning in the zone of proximal development involves the shared contexts in which participants are interpersonally engaged. Therefore, socio-historical contexts are central to the creation of the zone of proximal development (see Figure 2).

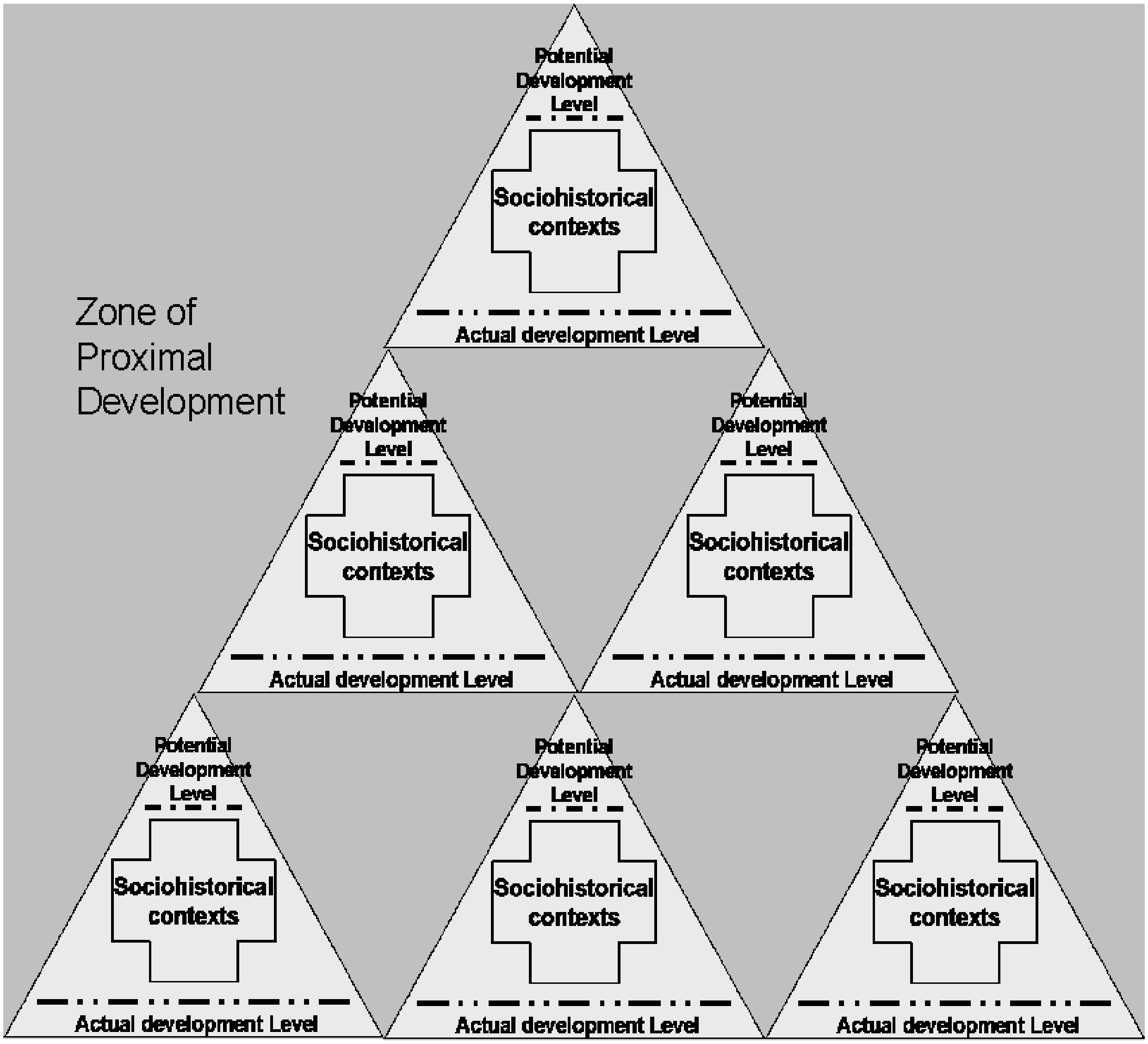


Figure 2. Vygotsky's zone of proximal development.

Context in human-computer interaction (HCI) theories

Context is a powerful and time-honored concept in human-computer interaction research. New technology paradigms—ubiquitous computing, pervasive computing, augmented reality, tangible interface, wearable computers, and cooperative buildings, among others—broaden the scope and style of interaction beyond the desktop and extend into the real world, where ever-changing contexts of use are encountered. Context-aware technology increasingly will become a part of our lives and shape the fundamental way we interact with the artifacts it creates. The concept of context has been interpreted in various ways in traditional HCI theories—as activity theory, distributed cognition, and situated action models—but all interpretations emphasize the important role it plays in everyday life.

Activity theory has served as an analysis framework for characterizing mutual relationships between subject, object, and community. This theory implies that the outcome of human actions and interactions cannot be understood as the simple collection of individual artifacts. Rather, we must consider the complexity of the activity in its entirety.
This theory proposes that activity itself provides internal and external contexts (Nardi 1996). Internal context involves a specific subject (a person or group engaged), object (the aim or reason which directs the subject to a specific path), and community (in which such activity is embedded or constituted). On the other hand, external context involves mediated artifacts such as tools (instruments, signs, languages, etc.), rules of the community (laws, accepted practices, etc.), and division of labor in the community (roles, communication procedures, etc.). The relationship between subject and object is mediated by tools, the relationship between subject and community is mediated by rules, and the relationship between object and community is mediated by the division of labor (Engeström 1987).

Activity possesses a hierarchical structure; activity, action, and operation (Kuutti 1996). The top level activity requires long-term formation and does not change on a moment-by-moment basis. Activity is the result of a sequence of actions, which turns into a series of operations again. Action is similar to task in other HCI literature (Payne and Green 1989), which is a process directed toward the goal of fulfilling activity. The different motive of activity creates different individual goal of action. Through operations, action is actually carried out. If the goal remains the same and only the condition changes, then only the operational level of activity will change. Each constituent of activity (i.e., motive, goal, and condition) changes dynamically with the external context (i.e., tool, rule, and division of labor) and internal context (i.e., subject, object, and community) of activity.

The distributed cognition approach concerns not just an individual's internal cognition but also the context in which an individual's cognition can be structured with the artifacts they use. Distributed cognition emphasizes as a central unit of analysis a *cognitive system* composed of individuals and artifacts (Hutchins 1990; Flor and Hutchins 1991; Hutchins 1995). The cognitive system is comparable to the activity in activity theory. Distributed cognition moves the boundary of analysis beyond each individual, and extends it to the context level, a process that reveals the functioning of socio-cultural systems under which individual cognition is constructed.

According to Hollan (Hollan, Hutchins et al. 2000), distributed cognition conducts three kinds of processing:

- Cognitive process is distributed across the members of a social group. It is phenomenon emerging in social interactions as well as interactions between people and social structures in their environments.
- Cognitive process involves coordination between internal (memory, attention, executive function) and external (artifacts, materials, environment) structure. The human and the work materials are embodied rather than take on peripheral roles, just as happens with a blind person's cane or a cell biologist's microscope.
- Cognitive process is distributed through time in such a way that the products of earlier events can transform the nature of later events. Culture (in the form of a history of material artifacts and social practices) shapes cognitive process.

Distributed cognition focuses not only on individual cognition, but also on the cooperation of people and artifacts within the context. It emphasizes that shared goals and plans, as well as the particular characteristics of the artifacts in the context, are important determinants of the interactions and the qualities of collaborations (Nardi 1996b).

In *Plans and Situated Actions: The Problem of Human-Machine Communication*, Lucy Suchman (1987) pays attention to the dynamic aspect of context and activity. She argues that, in real life, plans are naturally vague and incomplete, thus inadequate for accomplishing the goal(s) of action. Because the particularity of each situation is hard to predict in advance, plans are often reclassified as goals retrospectively if the actual outcomes of actions are found to be acceptable. Suchman's situated action model has a significant effect on standardizing ethnographically-driven design and participatory design as contemporary engineering practices in HCI.

Situated action has been connected with the situated learning model of Lave and Wenger (1991). Suchman's critique of the emphasis on situatedness of action was used to point out the inappropriateness of overwhelming lesson planning for the classroom. The actions through which the lesson is enacted to conform to the plan often distract students' engagements in learning. A lesson is a situated action, which a teacher and students always co-construct. Situated learning model assumes that cognition is in fact a complex social phenomenon. Lave and Wenger (1991) asked what kinds of social engagements provided the best contexts for learning. The fact is not so much that knowledge is the set of prescribed context-independent teacher-proof procedures or materials in lesson planning, but that it is knowing-in-situated-action, which classroom participants socially co-construct in such a way that "takes it into being" (Green and Dixon 1993).

Common ground as intrinsic context

A broad range of work in developmental cognition and cognitive psychology has long referred to the notion of context by such names as *letter*, *acoustic*, *extra-linguistic*, *syllable*, *deictic*, *sentence*, *semantic*, *mood*, and *pharmacological*, as well as by the terms *contextual relations*, *frames*, *scripts*, *schemata*, and *story grammars*. Although the term *context* has long been used in psychology, and is a particular favorite of experimental cognitive psychology, its denotations vary considerably (Clark and Carlson 1992). For psychologists, the experimental approach to the meaning of context is useful because such a broad sense of the concept is general and abstract enough to encompass many different definitions. However, for the purpose of some research, such as that involving language and communication, generality and vagueness can be detrimental. For psycholinguists, a precise characterization of context is vital for analyzing how people produce and understand the sentences of their language. In the study of language and communication, context has been used in a narrower sense as relevant or appropriately activated knowledge for the understanding of conversation. Herbert Clark, who has been long interested in the social foundation of language use, along with his colleague, Thomas Carlson, originated his own analytic approach to context that is intrinsic to language comprehension (Clark and Carlson 1992).

According to Clark and Carlson, context possesses several essentials and common features: context is information that is available to a particular person for interaction with a particular process on a particular occasion. Furthermore, Clark and Carlson identify two kinds of contexts: *intrinsic* and *incidental context*. For example, imagine John trying to understand the intention of a speaker who says, "Yes, but take it off." What is "Yes" for? Why "but"? What is "it"? Are we talking about discounting a price or removing a hat? In determining the meaning of the sentence in that specific occasion, two kinds of contexts are available to John. One category includes his (and the speaker's) identification of his hat, his (and the speaker's) cultural knowledge that wearing a hat in a particular location (such as a church) is impolite, and his (and the speaker's) understanding of the purpose of the church building. Another category of context includes John's awareness of today's date, his recognition of the beautiful lady whom he met yesterday, and his recollection of an appointment this afternoon.

Technically, both categories are part of John’s context in determining the speaker’s intention. However, these two categories have different relations to the task. The first category would be considered *intrinsic* to the process of determining the meaning of the sentence and the one that John must consult in order to successfully comprehend the speaker’s intention. However, the second category would be generally considered *incidental* to the process as carried out on that occasion, and it might not directly affect the process of understanding what the speaker meant. In comprehension of conversation, intrinsic context is necessary for its success, while incidental context does not need to be consulted. Clark and Carlson (1992) propose that *the intrinsic context for a listener trying to understand what a speaker means on a particular occasion is the common ground that the listener believes holds at that moment between the speaker and the listeners he or she is speaking to*. When a listener tries to understand the intention of a speaker, the listener must engage in the process of going through his or her limited memory to access any information that is relevant to the particular instance of comprehension (Clark and Wilkes-Gibbs 1992; Clark 1996). At the very least, intrinsic context should be kept separated from incidental context.

Chapter 4: Methods

This dissertation tries to verify how a new handheld network service which allows sharing visual workspace among members of a social group can facilitate the effective creation of common ground in face-to-face communication and enhance collaborative learning in handheld-based activity. In particular, the following research questions are examined.

(1) Can different kinds of peripheral participants benefit from a shared visual workspace while using handhelds in the performance of a task?

(2) How does a shared visual workspace affect the learning of peripheral participants?

In the collaborative view of conversation, a speaker doesn't just speak and an addressee doesn't just listen. Instead, discourse participants go beyond the autonomous actions of uttering, decoding, and interpreting words as individuals. They must also work jointly moment by moment to make sure that what is heard is correctly understood. They depend not only on the form of the signal and the circumstance of its use, but also on its uptake and validation (Clark 1996). Nonetheless, peripheral participants have difficulty engaging in this grounding mechanism. The collaborative process between central discourse participants and the peripheral participant is weak if it exists at all (Schober and Clark 1989; Clark and Schaefer 1992; Clark and Schaefer 1987; Clark and Carlson 1982). When the peripheral participant is also a *latecomer* to the on-going interaction and does not witness the creation of common ground between the speaker and the addressee, understanding of the conversation by the peripheral participant becomes more difficult.

To overcome this difficulty, the "Look" handheld network service makes it possible to capture referential context during the collaboration. The literature reviewed above shows evidences that a shared visual context helps efficient communication and grounding of information among discourse participants (Kraut, Fussell et al. 2003; Fussell, Kraut et al.

2000; Kraut, Fussell et al. 2002; Monk and Gale 2002; Clark and Krych 2004). Therefore, the following specific hypotheses should hold true:

- H1: “Look” functionality, compared to its absence, will help early side-assistants learn Korean characters, as evidenced by naming and recognition of Korean characters.
- H2: The nature of early side-assistants’ experiences—whether positive or negative—will be more favorable if “Look” is available to early side-assistants.
- H3: “Look” functionality, compared to its absence, will help late overhearers gain common ground, as evidenced by accurate placement of the icons.
- H4: “Look” functionality, compared to its absence, will help late overhearers learn the Korean characters, as evidenced by naming and recognition of the Korean characters.
- H5: “Look” functionality, compared to its absence, will help late side-participants gain common ground, as evidenced by accurate placement of the icons and the use of less time to complete the task.
- H6: “Look” functionality, compared to its absence, will help late side-participants communicate efficiently, as evidenced by fewer turn-takings and overlappings in conversation.

Three experiments will test the general prediction that providing “Look” network service facilitates the creation of common ground among discourse participants and enhances their understanding of conversation in a handheld-mediated collaborative learning. Through experiments, the outcomes of three different kinds of peripheral participant roles (i.e., early side-assistant, late overhearer, late side-participant) will be manipulated by the presence or absence of a form of “Look.” Note that particulars of the different peripheral participant roles determine which outcome measures (such as icon placement, naming, recognition, time, turn-taking and overlapping speech) are relevant to each experiment. For example, the side-assistant does not place icons at all, so placement cannot be an outcome for experiment 1.

Experiment 1 examines the effects of “Look” on early side-assistants’ learning as well as a specific hypothesis that relates the side-assistants’ favorable comments on their experience with “Look” during the activity. For this experiment, “Look” is implemented with infrared beaming, which allows overt monitoring. Experiment 2 examines the effects of “Look” on late overhearers. Task outcomes and learning results are collected. Experiment 3 examines the effects of “Look” on late side-participants. Experiments 3a and 3b replicate the experiment by changing the difficulty of the task. Task outcomes and communication efficiency are measured. For experiments 2 and 3, “Look” is implemented with Bluetooth technology, which allows nearly-synchronous screen-capture from other handhelds as well as covert monitoring.

Table 3 and 4 summarize the experiment design space by technology (table 3) and participatory status (table 4).

Table 3: Qualities of technology used in experiments.

		EXPERIMENT 1	EXPERIMENT 2	EXPERIMENT 3
Interruption of Central Participants	Covert		✓	✓
	Overt	✓		
Peripheral Participant Updated	Nearly Synchronous		✓	✓
	Short Delayed	✓		
Information Seen by Peripheral Participant	Character Text	✓		
	Screen Image		✓	✓
Connection	Infrared Beaming	✓		
	Bluetooth Communication		✓	✓

Table 4: Kinds of peripheral participation.

	From the beginning	Latecomer
Side-assistant: helps out (like a teacher or peer commentator)	Experiment 1	
Overhearer: not ratified, can't participate (trying to get oriented)		Experiment 2
Side-participant: ratified but not central (like a student trying to enter)		Experiment 3

Chapter 5: Experiment 1 - the Effect of "Look" on the Early Side-Assistant

In Experiment 1, I compared the performance of side-assistants learning Korean characters when working with "Look" and without it. When a side-assistant worked with "Look," s/he could see relevant data because infrared (IR) beaming connected her/his handheld with handhelds of the director and the matcher (i.e., central participants). On the other hand, a side-assistant who worked without "Look" was unable to see the data. I examined two main research hypotheses that emerged from this experiment:

- **H1**: "Look" functionality, compared to its absence, will help early side-assistants learn Korean characters, as evidenced by naming and recognition of Korean characters.

- **H2**: The nature of early side-assistants' experiences—whether positive or negative—will be more favorable if "Look" is available to early side-assistants.

The following section describes the experiment in detail. It includes discussions regarding the choice of participants, the experimental apparatus and procedure. It concludes with an extended discussion of results.

Participants

Via announcement on mailing lists, sixty students and human-computer interaction (HCI) researchers were recruited to participate in the experiment. Most of them were volunteers, while some of them received *Professionalism in Computing* course extra credit. Participants' ethnic backgrounds were multi-cultural: the group included participants from Nigeria, Germany, Bangladesh, Uganda, France, Egypt, Kuwait, Russia, Turkey, Bulgaria, Myanmar, Sri Lanka, the Philippines, India, China, and America. None of them had prior knowledge of how to read Korean characters, were familiar with Korean culture, or had traveled to Korea. Participants' ages ranged from 20 to 56, with a mean age of 28 (SD: 7.19). Twenty-three percent of the group was females. Most of the participants were graduate students studying computer science but other majors also took part, including students of industrial system engineering, educational technology, sociology, finance, and agriculture. All of the participants use computers in their everyday lives but only a few of them had prior experience using handheld computers.

Apparatus

For the experiment, I created an electronic variant of the Tangram game, which is widely used to explore the creation and maintenance of common ground in computer-supported cooperative work (CSCW) and psycholinguistic literature (Clark 1996; Clark 1996b). Indeed, so popular is this game that NetCalc project's Match-My-Graph's activities were based on the structure of the Tangram game (Tatar, Roschelle et al. 2003). In my game, Korean Character Matching (KCM), the images were Korean characters (see Figure 3). The game runs on a Palm OS handheld computer: participants use a stylus to drag and drop characters from one place to another and to initiate task actions, such as "shuffling" the image order.

Additionally, this game implements the infrared communication functionality "Look," which supports visual co-presence by allowing the side-assistant to capture objects from other screens simply by beaming to them. Instead of having the owner of the information stop an ongoing activity to give her/his handheld to the side-assistant, the side-assistant simply requests data directly from other students' handhelds by beaming without much disruption. This process guarantees that central participants can maintain focus on their discussion or project.

Traditionally, beaming is used for one-way communication, as in the sending of a signal by a TV remote control device. However, my "Look" network service supports a two-way roundtrip signal, a characteristic that enables retrieving information from remote companion handhelds to beaming handhelds. "Look" was implemented using *Exchange Manager* in the Palm OS API, which provides a high-level interface using the *exchange* socket structure. I embedded and tested this "Look" function as a component for the KCM game (see Figure 4).

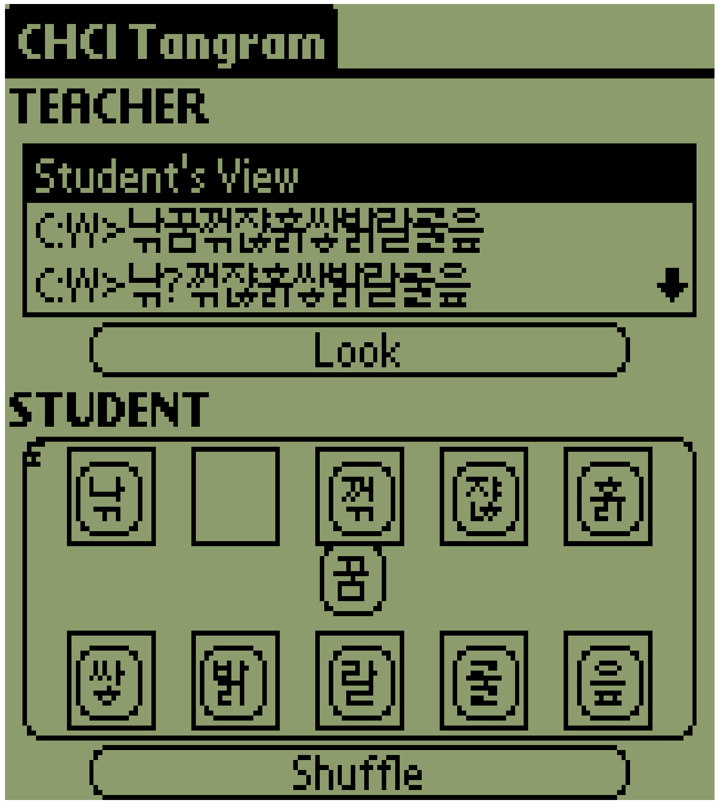


Figure 3. Korean Characters Matching (KCM) game.

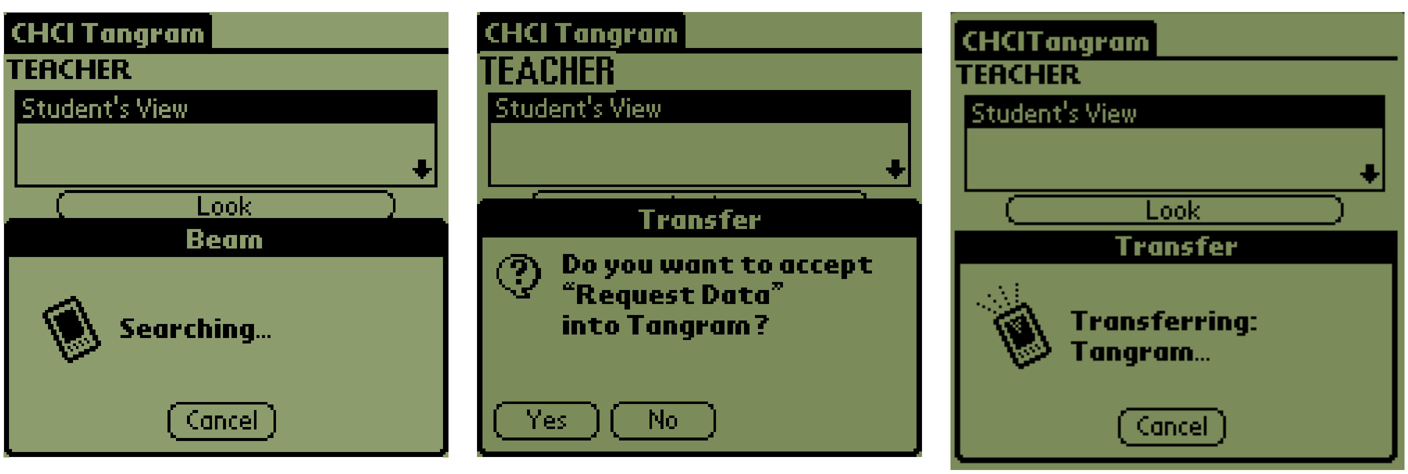


Figure 4. Pop-up windows notifying the user that IR communication has been initiated.

System design considerations

The small screen size of handhelds is not a technical limitation, but a key factor in their usefulness (Kamba, Elson et al. 1996). However, on account of small display screens, user interface design for the application on handheld devices has significant differences with GUI (Graphical User Interface) design on the desktop computers. Few of traditional WIMP (Windows, Icons, Menus and Pointing) interfaces models for desktop computers are incorporated into handheld system. A likely reason is that integrating WIMP interfaces techniques into small-screen devices is challenging for both (1) effective direct manipulation techniques with limited input devices and (2) the presentation of the data to fit small display.

Input device

Compared to multiple input-devices for a desktop computer (such as a mouse, a keyboard, a joystick, a keypad, and a track ball), most PDAs have only a stylus as input devices limiting the user actions. This restricted artifact challenges the adoption of existing interaction techniques of a desktop computer, which were mainly designed for indirect input devices, such as a mouse and a keyboard. Rather, it is more natural to exploit direct manipulation technique for the interaction with the objects of interest, because the stylus can provide the intuition of physically picking up and moving a computer object.

Direct manipulation can provide users with comprehensible, predictable and controllable interfaces that give them a feeling of accomplishment and responsibility. In the KCM game, users should move objects (i.e., Korean character Tangrams) to solve the problem. To support this interaction, I considered two possible stylus-based direct manipulation techniques that can be used for moving regular objects: *Select-and-Put* and *Drag-and-Drop*.

Select-and-put is a direct manipulation technique with which a user first “selects” an object by clicking once on the object to pick it up (a click refers to tapping with a stylus) and “put” it into a desired position on the screen by clicking again to place the object at that position on the screen. This technique is especially suitable for a mouse button click and enables a rapid movement of objects. However, simply applying the select-and-put to a stylus-based user interface presents a problem. It is often the case that a user accidentally confuses the tapping for selection and the tapping for placement, and forgets to pair "select" and "put" interactions, particularly when distracting by other activities.

Drag-and-drop method is more useful alternatives for overcoming this problem. Drag-and-drop is a generic instrument for transferring or copying information, while avoiding the use of a hidden clipboard. A user first grabs an object by touching a stylus on it, then "drags" it towards a desired position on the screen with the stylus, and "drops" it on that location by releasing the stylus. Since the object follows the movements of the stylus, drag-and-drop supports continuous representation of the object, physical interactions, and rapid, incremental reversible movements whose impact on the object of interest is immediately visible. The KCM game supports drag-and-drop techniques to move Korean Tangrams (See Figure 5). However, we have still much room for improvement from the viewpoint of user interactions for the KCM game. It is rather error-prone to drag an object with a stylus without failing to continuously keep the stylus tip contacted on the display surface. Also, it is often the case that a stylus hides the selected object. How easily objects need to be moved should be investigated more.

Figure 5. A user drags a character in the Korean Character Matching (KCM) game.

Limited screen real estate

In the KCM game, the successful representation of "looked" central participant's view on the side-assistant's screen is another major requirement for the interface design. To meet this requirement, I considered two possible options of displaying the beamed data: using pop-up (overlapping) windows and using tiled windows. If an overlapping window system is used, a side-assistant can maximize the visibility and see a full screen's worth of contents on the newly opened window. However, side-assistants might be distracted by management over moving, resizing, and overlapping windows anywhere on the screen. On the other hand, tiled system aids a side-assistant not to worry about additional window management but to proceed directly with the task (Bly and Rosenberg 1986). In addition, in my task, the tiled window system can reduce the cognitive load of memorizing previous views for the purpose of comparing central participants' works. Therefore, I decided to use the tiled windows approach instead of using the overlapping windows approach.

Once I decided to use the tiled windows approach, there was another issue, how to share the limited space available for the display of both the beamed central participants' views and the side-assistant's own working area. Previous work on the interface for mobile devices has explored changing the representation of the data, such as creating summaries of documents that fit more easily on the small screen (Buyukkokten, Garcia-Molina et al. 2000). Techniques that rely on alternative views of information content can maximize usable screen space.

In the KCM game, I use the "List" interface component to abstract two-dimensional space information into one-dimensional line in order not to take excessive screen display space but to maximize the available space for display of contents. Because the goal of the KCM game is to put the Korean characters on matcher's screen into the same order as those of the director, the "List" representation of ordering is enough to provide the side-assistant the appropriate information for the purpose of the task. The "List" is also ideal for representing multiple rows of sequentially beamed data, which can exhibit the history of central participants' trials. The side-assistant may scroll "List" vertically to see central participant's previous trials. Scroll indicators (small arrows) are automatically drawn in the corners of a "List" to indicate if the "List" may be scrolled up or down to display hidden items.

In Figure 6, “List Representation of Ordering” in “Looked View” shows ten Korean characters of “Working Area.” The first five Korean characters in the list represent the matching characters inside top five boxes in working area. The other five Korean characters inside bottom five boxes follow in the list. Notice that, in this example, “?” mark shows up as the second element of the list because no matching Korean character is found inside the top second box in “Working Area.”

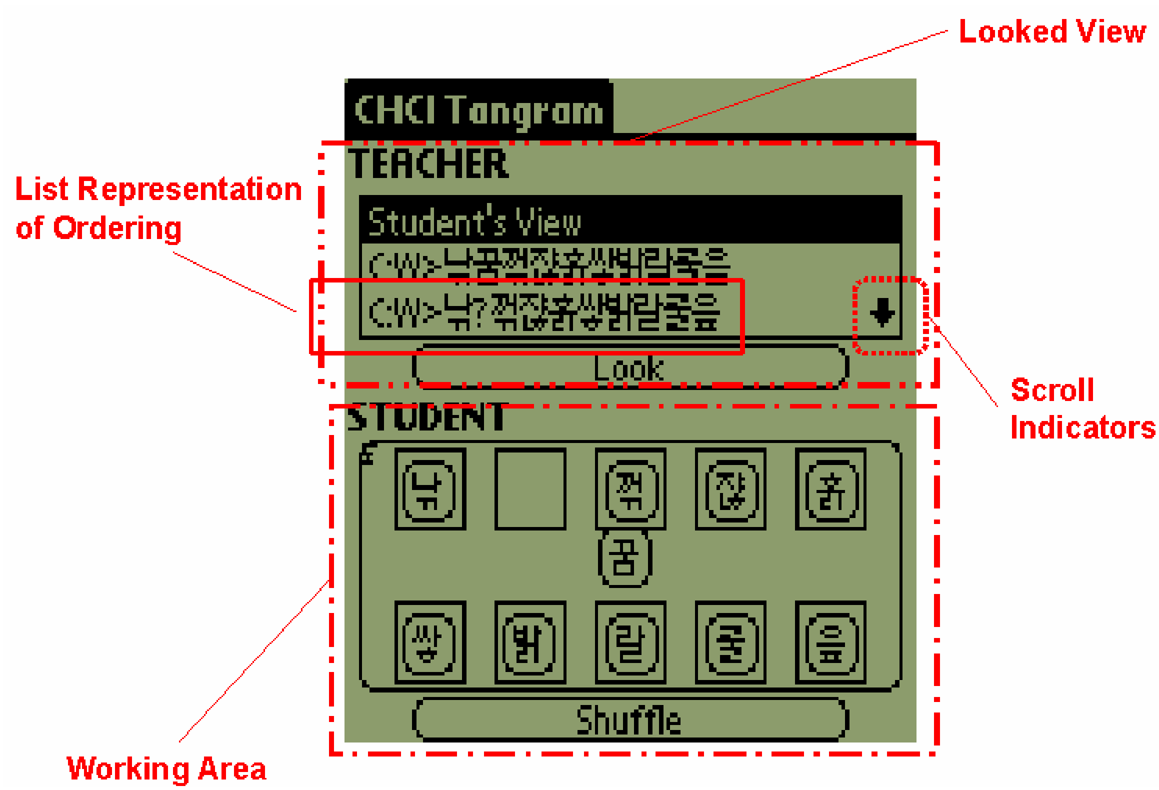


Figure 6. User interface of Korean Character Matching (KCM) game.

The "Look" feature

In this first experiment version of "Look," I employ connectivity based on infrared (IR) beaming. At a user level, this means that the side-assistant specifies the central participant by physically aligning her/his PDA with the central participant's and tapping the "Look" button. The side-assistant is relieved from the need to know or specify who the central participant is in abstract terms, such as by machine name, as s/he might need to with a radio frequency (RF) form of connection. The central participant is notified by four messages in quick succession: "Receiving: Chat" "Searching…." "Transferring: Tangram…." and "Disconnecting". The side-assistant also receives four messages: "Searching…." "Sending: Chat" "Disconnecting" and "Receiving: Tangram." Both must maintain the alignment of machines until the transfer is complete, about 4 seconds. Because of the relationship between "pushing" and "pulling", the side-assistant sees a "Disconnecting" message before the transfer is actually complete, and must learn that this disconnection will be followed by the receiving message.

Thus, compared to the non-mechanized version of the Tangram game, this mechanized version involves a little longer delay. On the other hand, it also involves a mutuality of the interruption between side-assistant and central participant, which might cause subtle alignment in their behavior, especially compared to the complete disassociation between overhearer and matcher seen in previous overhearer experiments (Schober and Clark, 1989).

Procedure

Like the Tangram game (Clark and Wilkes-Gibbs 1992), the KCM game involves two participants, a matcher and a director. For each round, the director places a new sequence of Korean character images in random order. The matcher also starts with the same sequence of images in random order. By discussing each image in turn, the matcher is able to put the images on his/her screen into the same order as those of the director. The game is complete when the matcher and the director agree that they have all images in the same order.

Additionally, one participant is instructed to play the role of the “teacher” (i.e., side-assistant) and is assigned the task of determining whether the matcher-director group is making progress. In addition to normal interaction, the “teacher” has two extra mechanisms or components by which she can assist the director and matcher (i.e., central participants). First, her handheld exhibits the names of the characters. Second, she can use the “Look” button to find out what is on a particular participant’s screen.

Before beginning the experiment, all participants completed a form listing demographic information and identifying their familiarity with the Korean language. The experiment was conducted in a large meeting room with tables set in a U-shape. Director and matcher sat facing each other or around a corner of the table, while teacher either stood next to one of them or moved from person to person.

From the sixty participants who had been recruited, twenty groups of three were organized by their schedules. Half of those groups were equipped with the “Look” functionality, while the other half was tested without it. Each group conducted the KCM game twice. In each round, participants changed their roles and this rotation of roles resulted in forty data for each role. However, I decided to use just the first round result because rotating participants’ roles in the second round might pollute the effect of “Look” in the analysis.

To document the interaction, an observer videotaped the activity and also recorded notes, both of which focused on whether and how the “Look” function was used. Participants were asked to engage in a think-aloud process and articulate what they were doing at each step in the game process, a procedure that enabled observers to identify potential usability problems. Afterwards, participants were asked to indicate both the positive (good) and the negative (bad) aspects of the experience.

After the experiment, a questionnaire was administered, which gathered two kinds of quantitative learning measurements: from a list of the complete twenty Korean characters, participants were asked to pick out ten characters with which they had worked and to match these characters with their English names. Finally, to seek as much detailed information as possible, a number of open-ended positive/negative comments were requested.

Results

As presented in this section, results of the experiment suggest that students whose handhelds were equipped with "Look" exhibited better performances than those without "Look."

Naming and recognizing quizzes

The principal test for the benefits of sharing visual context during collaborative learning provided by the new handheld network service "Look" was based on the number of user errors in quizzes involving naming and recognizing. According to the hypotheses, the teachers whose handhelds were equipped with the "Look" functionality should better understand the conversation and thus should be better able to offer improved instructional judgments. As a result, in a "Look"-equipped group, students' (i.e., directors and matchers) learning should show improvement. This is precisely what occurred. Regardless of which role they played, participants in the group that had access to "Look" experienced significantly fewer errors than those who were not supported with "Look" did. Results indicated an average of 3.28 (Standard Deviation (SD): 2.74) errors per 10 questions among those students who used "Look," compared to an average of 4.55 (SD: 3.19) errors for students without the "Look" functionality: F (1, 118) = 5.46, p = .021 (see Figure 7).

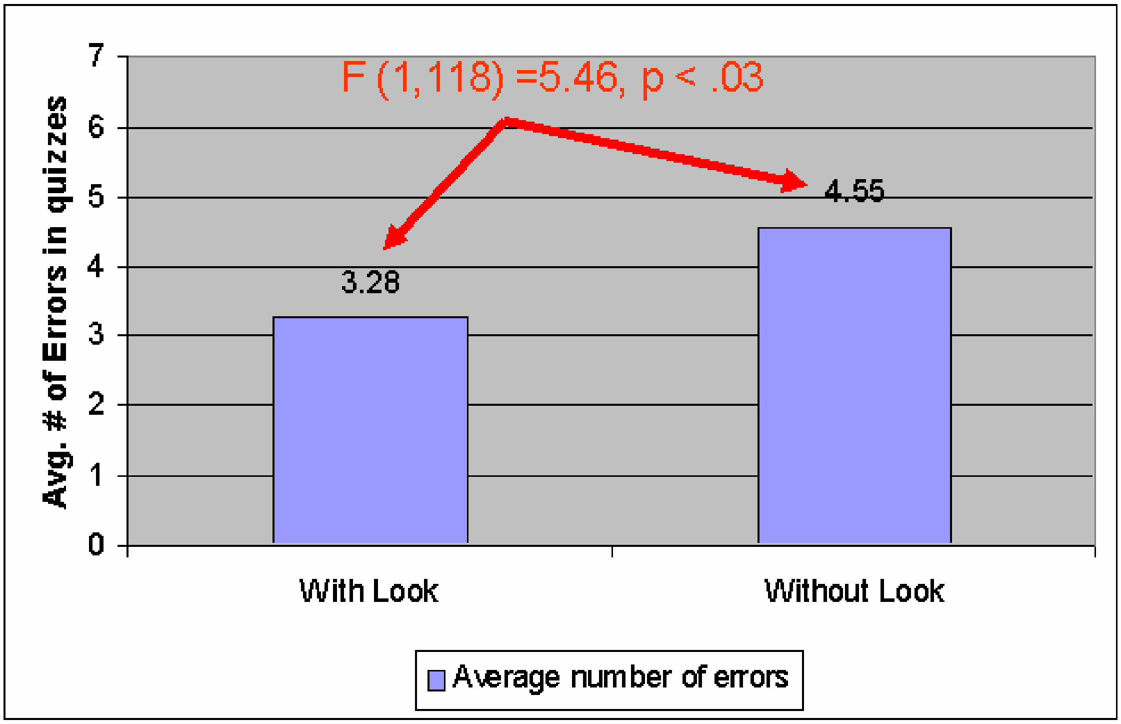


Figure 7. Average errors on quizzes. With “Look” (left bar), students experienced fewer errors.

Of particular importance, the number of errors recorded by each side-assistant in the naming of Korean characters was significantly smaller for the groups who had access to "Look" when compared to the results of those who did not. With "Look," side-assistants made errors fewer than half. Specifically, the mean number of errors in the naming quiz among side-assistants who used "Look" was 3.0, while the mean number for those without "Look" was 6.3: Analysis of variance (ANOVA) yielded a significant main effect of "Look" with F (1, 18) = 7.65, p = .0127 (see Figure 8). The graph shows that the director and the matcher of the group whose side-assistant was equipped with "Look" also exhibited fewer errors.

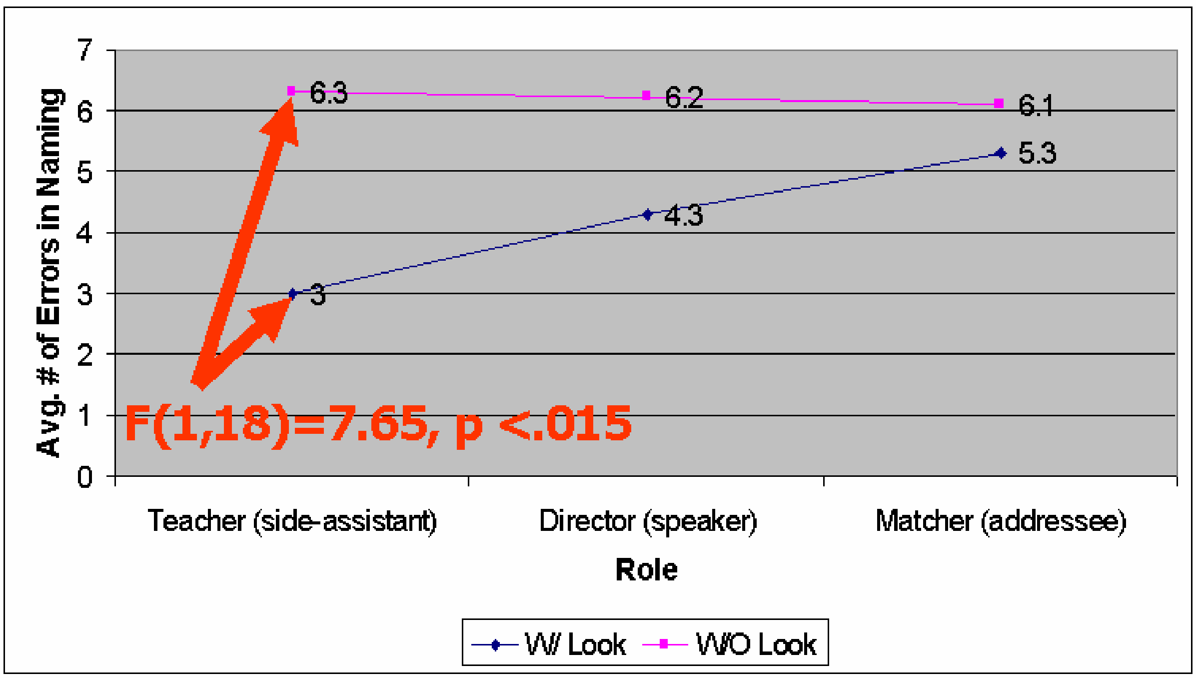


Figure 8. Average number of errors in naming Korean characters. The reduction in errors for the side-assistant with "Look" as compared to one without "Look" is significant (F(1, 18) = 7.65, p < .015).

The other test used for accuracy involved a recognizing quiz, administered after the experiment, which asked participants to correctly identify ten Korean characters viewed during the activity from a list of twenty. This test was designed to measure participants' level of attention to task. The difference between "Look" users and non-users was not significant. All participants with "Look" recorded an average of 2.4 (SD: 1.79) errors vs. 2.9 (SD: 2.16) for those without "Look." Figure 9 shows the mean number of errors in the recognizing quiz for each role assumed by participants. The graph indicates that the greatest difference in the number of errors occurred among the overall matcher group. Table 5 summaries naming and recognizing quiz results for each role.

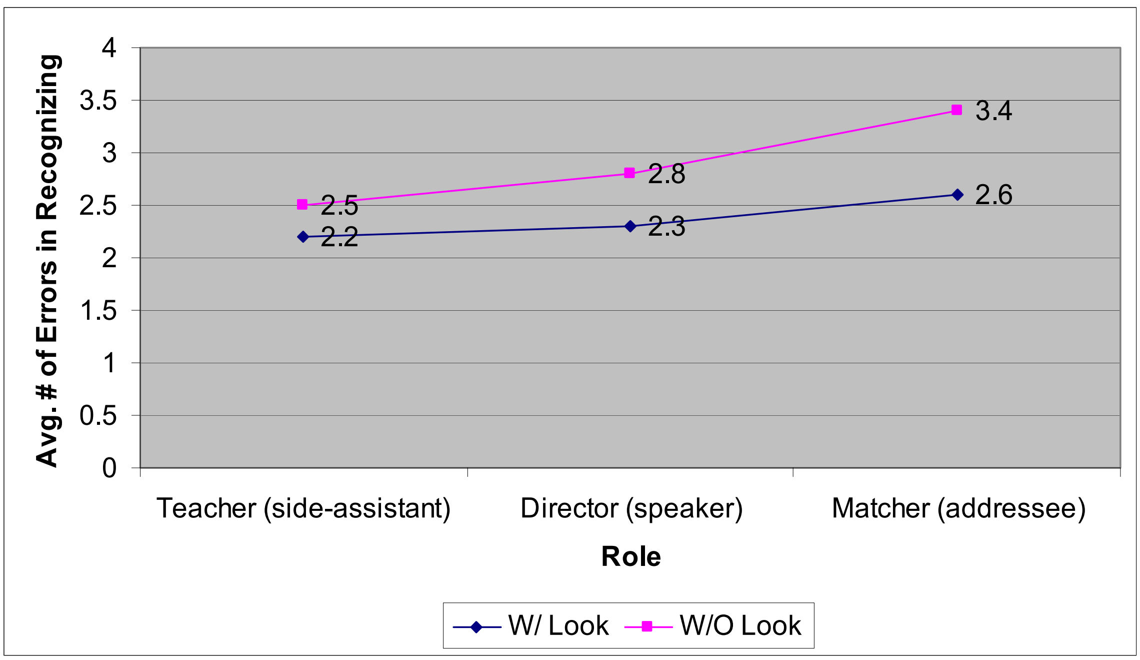


Figure 9. Average number of errors in Korean character recognizing quiz for three different roles. There is no significant difference in performance.

Table 5: Errors in naming and recognizing quiz.

(The numbers in each cell represent mean (*standard deviation*))

With Look / Without Look	**Teacher**	**Director**	**Matcher**
Naming Quiz	3.0(*3.09*)* / 6.3(2.*16*)*	4.3(*3.23*) / 6.2(*3.82*)	5.3(*3.20*) / 6.1(*3.75*)
Recognizing Quiz	2.2(*1.55*) / 2.5(*2.22*)	2.3(*1.89*) / 2.8(*2.04*)	2.6(*2.07*) / 3.4(*2.32*)

* $F(1,18) = 7.65$, $p < .0127$

Subjective comments

Responses to the questionnaire provide much insight into participants' experiences. For example, many individuals responded favorably to the use of "Look" and believed that "Look" helped establish common ground among group members. Other responses measured the value of formative assessment with the "Look" function.

Favorable responses to the handhelds

On the questionnaire administered after the experiment, participants commented favorably on their experience with using handheld devices during the activity. As one respondent noted, *First, I like the use of portable computing devices for teaching and learning (in/out of the classroom)*; *The PDA for this experiment was good*; *The good thing was that the characters were on my screen, and I could see them for as long as I wanted, until I was comfortable with them.* Many participants also noted that the experiment was interesting: *The experiment itself was interesting/fun at the beginning, a little bit challenging and it turned to (be) a surprise for me at the end*; *It feels like some sort of charade, quite challenging and fun. I like the game flavor to the experiment*; *It is an interesting project.* Participants were also aware of the collaborative nature of the experiment: *This may be a good way to learn how to recognize characters*; *People could exchange knowledge by different explanation*; *It could be useful as a team building enterprise*; *It was an interesting experiment that required a lot of focus. It was also a good test of someone's memory and communication skills*; *We had a common language to describe the letters*; *It was a good experiment. Made me realize teaching patterns*; *(With) back and forth communication between director and teacher, (I) worked well in a group.*

Importance of common ground

Creating common ground for collaborative work involves incorporation of individual and social process. To succeed in their collaborative work, participants should carry out not only autonomous actions as individuals but also joint actions as members in an ad hoc social group. Many teachers, directors, and matchers recognized the very process predicted by the common ground model. One claimed that *the teacher's direction that allowed more input from the matcher was good, because it let us confirm what was going on with the matcher. This occurred at a pivotal moment, about half way through the set. Up to that point, in my role as "director," I had mostly been giving commands. After opening up to listen more, I felt that our cooperation improved. This was a result of more 2-way communication.* Another participant noted that *I like the way the two players quickly established a common ground with a common vocabulary of shapes and the way they re-affirmed their decisions every now and then or (we) define terms first then we can go more quickly to match, (and) use common language between director and matcher to quicken the process.*

Advantages for side-assistants having "Look" functionality

Most side-assistants whose handhelds were equipped with "Look" realized that they were at an advantage due to the fact that they could easily share indicatory context: *Good things about the teacher's action is that the teacher can help students to identify the mistakes without sit beside*; *I like that the teacher can easily communicate with both the director and the matcher*; *It ("Look") helps to see both people's work. Teacher was able to say when we were correct*; *To learn the characters' names, it was almost necessary to put them in the same order, sync views, so that you could be sure that everyone was seeing the same thing*; *The teacher could be more involved to help reenforce the learning*; *Even though I could not get the idea for the experiment, it was fun to do it. I learned some Korean letter's pronunciation. The teacher's actions were so good to explain the matcher the correct configuration. He (teacher) just made him (matcher) engage in it and made him (matcher) to think more critically*; *Teacher let us know when we were doing something right. Teacher let us know when we're done or successful. Teacher did not interrupt our interactions*.

Disadvantages for side-assistants not having "Look" functionality

On the other hand, side-assistants working without "Look" condition pointed out the limitation of their interaction with students: *Students did not give enough feedback*; *Student need(s) to give more feedback. Not sure if the student got the correct placement*;

Teacher should act as a helper for the communication between matcher and director. In this experiment, teacher worked only as a judge. Teacher might take more functionalities to help communication; *I would like students to listen to teacher's conventions. But the students spent that time developing their own conventions*; *I used my own memory and walked back and forth.* One argued that *it's harder to be the teacher than I thought! It was difficult to go back and forth and try to look over their shoulders and to remember the shapes. I tired to remember the names ("oop, lar, bah"…) but could only remember 3 in sequence. I could not remember more than 3 shapes or names in sequence, so even though I checked the matcher's game after each row of 5 shapes, I was not completely sure that the matcher had the correct answers.* Another participant claimed that *he (teacher) had more of a "checking" role than a teaching role, double-checking my (matcher's) guesses*; *It can be difficult to express visual data in a form comprehensible to someone who is not also seeing the (same) visual data*; One also said that *associating pictographs with names is not as easy as it looks, especially when pictographs have not seen before. As far as the teacher's action, it was minimal actually non-existent when I was trying to match the pictographs*; *Teacher's action is fairly limited in first pass while we are playing the game and trying to match characters*. Another echoed a comment sometimes heard from students in project-based classes that *teacher did not have to help in solving the puzzle. We just did it ourselves.*

Formative assessment with "Look"

Although there was no reason to believe that the participants had any familiarity with pedagogical theory, and no instructions were given to the participants about the kind of pedagogy or pedagogical results desired, participants in both conditions commented on the side-assistant's role. One side-assistant from the "Look" group said; *in my role as a teacher, most of my input was given up-front (at beginning). I tried to be sensitive to what they were saying and incorporated it into the "lesson." During experiment, I tried to remain passive and give minimal direction*; *I tried not to give away too much with my expression, although early on I was aware of smiling and nodding slightly (around the 3rd match). I felt it was important to stay impartial so that I didn't influence the outcome (by giving away answers). By holding back, I knew I could jump in if director and* *matcher got stuck.* Another participant commented that *the teacher must not help the students until the last minute. Extensive help from the teacher will reduce the learning*; *Teacher does not play much role till the director and the matcher have misunderstanding.*

To determine whether the nature of participants' experiences—whether positive or negative—was related to the availability of "Look," a statistical test was administered to measure specific inferences. Table 6 breaks down the subjective comments by classifying participants as either "Look" or "No Look." Using the collected comments in Table 6, a chi-square test of independence was conducted. The calculated test statistic value of $\chi^2 = 6.568$ exceeds the critical value of 5.991 in a chi-square distribution for $\alpha = .05$, df = 2. Therefore, we can conclude that the participants' positive and negative experience varied depending on the availability of "Look."

Table 6: Number of participants' positive, negative, and neutral comments with and without "Look." (χ^2 (2) = 6.568, p < .05)

	Positive	**Negative**	**Neutral**
Look	35	15	10
No Look	21	23	16

Video analysis

Videotapes recorded during the experiment were able to provide more detailed, post-experimental coding of the conversation. This section presents analyses of those video recordings.

Episode 1: Are you talking about the one with like…?

One of the most important benefits of "Look" in collaboration is the ease with which it permits a side-participant (such as a teacher or a latecomer) to enter into an ongoing conversation. This seamless entrance can be achieved through indicating or identifying the specific objects under discussion. According to Clark's common ground theory, visual co-presence of the objects creates the indicatory context (Clark and Carlson 1992). By literally seeing what is being discussed, the side-participant can create common ground and participate in conversation more easily.

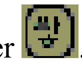
The "Look" network service makes it possible to capture the indicatory context during handheld mediated collaboration. The following transcript from the experiment reveals such an occurrence of seamless entry into a conversation using indicatory context. In this episode, when the director and the matcher had a hard time in matching their Tangrams, the teacher (i.e., side-assistant) could quickly and efficiently provide advice simply by accessing their views. This help was possible because "Look" enabled the teacher to capture data from director's and matcher's handhelds into her handheld without disruption. Table 7 presents a detailed transcript of the episode.

Table 7: Transcript of an episode wherein “Look” provided assistance to the teacher.

(With pairs of asterisks, overlapping speech is marked. Gesture acts are enclosed in parentheses.)

Seq. #	Person	Transcript
1	Director (D)	Umm, so there is one last one that has a circle in it, it’s got a circle with those same two lines right above and that is the only thing in the bottom half of the character. And above it, it has got some kind of a U.
2	Teacher (T)	(“Look” by beaming to Matcher)
3	Matcher (M)	Umm, the bottom is a circle?
4	D	Yeah.
5	M	And then there is like a U, but like a line down it. (motions hand)
6	T	(“Look” by beaming to Matcher)
7	D	The U has kind of some territory.
8	M	Another one, with kind of a vertical line on it, another circle? Or uh huh, square? Uh huh.
9	D	Square?
10	T	Yeah, It looks like a square.
11	D	Well it’s umm, kind of like the same circle that was in the last two, a circle with a straight line on top of it and then a little bitty line in the center.
12	M	Oh, uh huh, where should I put it?
13	D	Umm. That goes in the bottom left corner.
14	T	(“Look” by beaming to Matcher)
15	M	(hesitantly) I am not so sure about this one. (laughing)
16	D	(laughing)
17	T	(with looking down her screen and raising her head to the director) Are you talking about the one with like a circle on the bottom and then two lines between the top part and the bottom part? There are two lines between the shoulder line and the bottom line (with hand gesture). Is that the character you are talking about? *The character should be...*
18	D	*The one I am talking about* doesn’t have a line separating the top and bottom half of the character (oppositely). Umm…
19	T	You said there is a circle and then what’s on top? ...

20	D	The circle is kind of wearing… The circle has connected to it a line and a little tick mark in the center… It kind of looks like the circle is wearing a hat…
21	T	Umm. I didn't see that character (with watching her own palm pilot). Can you describe that for me, again? (silently)
22	D	Umm. Well, the top half of the character looks like…, it is the Greek character μ. A μ, with little tails on the side.
23	T	Oh, okay, so, it kind of looks like a letter T? (with watching director)
24	D	Umm…, there is a sideways T?… Yeah!
25	T	There is a sideways T. Umm, like tail. Well, yeah, it is like a T and a U, share *a line*.
26	M	*They share a line.*
27	T	So that's the character you're talking about?
28	D	T… and U... share a line?? Oh, are both on the top half of the same line of the character?
29	T	*Aha.*
30	M	*Yes.*
31	D	Okay, yes, yes! (nods)
32	T	And then, the bottom, there is actually a square from the formal writing, It is…*Yeah, it is a square or uh huh, circle, so yeah?*
33	M	*Yes, it is rectangular.* (silently with watching director)
34	D	I think that could be a square.
35	T	Yes, I think that's why I and she (matcher) have misunderstood. Yeah, it looks like a circle, but actually, from the formal writing here I got it looks like a square.
36	D	Okay.
37	M	So that should be on the left of the bottom?
38	T	("Look" by beaming to Matcher)
39	D	Left of the bottom… Yeah, one that has the top half of it has like a Greek μ, and then a sideways T, that goes on the bottom left corner.
40	M	Okay. I got it.
41	T	("Look" by beaming to Matcher)
42	D	Okay, so I think we have four of the characters the same.

This interaction shows how the teacher helped the director and matcher (i.e., students) work through their confusion, which originated from the fact that they had slightly different views of the same object. As indicated in turn 35, the director had his own slightly different interpretation for the character . This confusion began in the conversation that occurred between turns 3 and 13. In fact, in turns 15 and 16, students explicitly expressed their uncertainty. In turn 17, we can see how the teacher entered the students' conversation promptly and appropriately. The teacher used the evidence of shared visual clues to propose assistance. Turns between 18 and 25 show the interactive cycles of conversational turn-taking between the teacher and the director. They acted jointly toward a convergence of meaning (Roschelle 1992). When the director indicated "the Greek character μ" (#22), the teacher added a new metaphoric explanation—"like a letter T?" (#23)—as evidence that provided a scaffold for students' understanding. The director's expression in turn 24 demonstrated that a conceptual change had been initiated.

Between turns 25 and 33, we find another example of how visual co-presence of objects can easily create common ground among participants. Turns 26, 30 and 33 show that the matcher was following correctly the discussion between the teacher and the director. The matcher could do so because she was watching the same object. She even validated the teacher's description by displaying her understanding: "They share a line" (#26) and "Yes, it is rectangular" (#33).

Finally, in between turns 34 and 42, all participants were successful in creating convergent concepts and were able to complete the first portion of the task. In turns 38 and 41, the teacher beamed to the matcher's handheld to formatively evaluate that student's work.

Episode 2: Teacher, you will tell us, yeah?

In activity-based classroom environments, a teacher will act most effectively as a "side guardian" or an observer whose primary job is to provide weak guidance. This recommendation is based on the concept that if students learn to depend heavily and consistently on the teacher as a source of information, then they will not develop the capacity for independent or creative thought; hence, they will not learn as effectively. Static instructions or directives from a teacher simply do not support the new knowledge creation that is vital to individual creativity. Students who participate more, contribute their time helping each other with problems, and mutually engage in problem-solving, are more likely to acquire knowledge and be creative both in the classroom and in the "outer" world. Therefore, as a teaching strategy for promoting new ideas and innovations, as well as for increasing individual creativity in classroom activities, weak guidance seems preferable. These properties can be seen in the interactions captured by the excerpt introduced in Table 8. In this episode, members of a student group tried to solve the problem by themselves, while the intervention of the teacher who had access to "Look" was minimal but efficient.

Table 8: Transcript of an episode using the “Look” functionality.

(With pairs of asterisks, overlapping speech is marked. Gesture acts are enclosed in parentheses.)

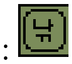
Seq. #	Person	Transcript
1	Director (D)	OK, umm the position number 4, you have like “N” on the top and a zero (with hand gestures) on the bottom with a “T” (motions with hand gestures) in between them.
2	Matcher (M)	Say that again.
3	D	How about a letter “N”, small “N”, at the top? (with hand gestures).
4	M	Yeah?
5	D	And you have an “O” at the bottom, but in between, there is like a “T”.
6	Teacher (T)	You (pointing to the director with a hand but keeping eyes on his own palm pilot) mean more like a “Seven” on top, it’s like “seventy seven”?
7	D	Yes, it’s like “seventy seven”.
8	T	“Seventy seven”, and then “T”, and then an “O” (gesture of writing characters on the air).
9	D	“T” and then an “O”
10	T	So like that one is, a “KUM ” (pointing to the director with hands and keeping eyes on his own palm pilot).
11	D	“KUM”. Ah, okay “KUM”. (with scratching his head)
12	M	Ok, now I got it. Alright, teacher, can you tell me if I’m good so far or missing something? (with watching the teacher)
13	T	(“Look” by beaming to the matcher)
14	D	Okay, You have *confirmed till...*
15	M	*Hold one second*, I want teacher to address us whether they are good for 1, 5, and 6.
16	T	So…
17	D	It’s like…
18	T	1…
19	D	5 and 6 (with watching the teacher). Okay, but the teacher just keeps on watching and we don’t need to hassle the teacher (with watching the matcher). Teacher, you will tell us, yeah? (with watching the teacher)

:	:	:
:	:	:
:	:	:
20	M	*I have*, I have two “seventy seven”…
21	D	Uh huh?
22	M	There are, there are two “seventy seven”, there is one which I can see like an “LT” at the top
23	M	Do you, do you see which one I am talking about? (with watching the director)
24	D	Two “seventy seven”? *Okay*
25	M	* You have… two “seventy seven”* on the second line, you have two items like that?
26	D	“Twenty seven”? Not “seventy seven”? (with watching the matcher)
27	M	No. there are “seventy sevens”, (with watching the director) there are two items like that.
28	D	*Aha.*
29	M	*And one of them* has like a “LT” at the top.
30	D	Okay. And the other one has like a... what? What would you call the other one? That one is like a “seventy seven” and a “four”?
31	T	(“Look” by beaming to the director)
32	M	Yeah, where would you put . . .?
33	D	Ok, the “seventy seven” and “four” one is in position 2.
34	M	OK.
35	T	(“Look” by beaming to the director)
36	D	The one that has, like “seventy seven” and “four” squashed together (with the gesture of squashing hands together).
37	M	Yeah.
38	D	Ok, and the other one is in position…, The other one is (counting the positions on his handheld) 5, 6, 7, The other one is in position 8.
39	T	(“Look” by beaming to the director)
40	M	Eight? I should have a “twenty seven” here.
41	T	(“Look” by beaming to the matcher)
42	D	No, the “twenty sevens” are in position 9 and in position…7
43	M	Okay.

44	D	Okay?
45	M	Well, one, one second…
46	T	(“Look” by beaming to the matcher)
47	T	So, do you want me to confirm one of the second row at number 2? (shows 2 with hand)
48	D	No. Just leave it. Keep looking. You just keep watching.
49	M	Hold on, so, you said that “LT” “seventy seven” is going in position ten? Or position seven?
50	D	“LT”?
51	M	“LT” “seventy seven”?(with watching the director)
52	D	It is in position eight.
53	M	Eight, okay.
54	D	And then the other one (with watching the matcher) the “seventy seven” is in position two.
55	M	I got it

The first activity of this episode (i.e., until turn 5) shows how the director and the matcher tried together to identify the Korean character . In turns 6 and 8, the teacher indicated the shape of the character by using the number 77. In response, in turns 7 and 9, the director accepted the teacher’s presentation (i.e., signaling through describing-as) by repeating a part of the teacher’s description (i.e., validation through displaying understanding). In turn 10, the teacher introduced a new piece of knowledge, while the students created common understanding (turns 11 and 12).

The student comment in turn 19—“Okay, but the teacher just keeps on watching and we don’t need to hassle the teacher. Teacher, you will tell us, yeah?”— supports my argument that the teacher’s ideal role is that of side guardian. In this instance, students expressed a desire to consider the teacher as a side guardian who could provide help to them whenever they needed it or requested it. By considering the teacher as a helper instead of a commander, students could challenge and extend their own levels of creativity, as expressed by the statement, “Ok, now I got it. Alright, teacher, can you tell me if I’m good so far or missing something? ” (turn 12).

In another activity of this episode (i.e., turns from 20 to 55), the speaker and the addressee worked toward the solution of a problem involving two similar characters:  and . Up to this point, the teacher has watched the students' progress using the "Look" function, without stopping or disrupting them (turns 31, 35, 39, 41, and 46). Finally, the teacher entered the conversation at the point where he determined students might need help. He asked "So, do you want me to confirm one of the second row at number 2?" (turn 47). However, students could resolve the problem by themselves without the teacher's assistance (turns from 48 to 55).

Episode 3: Wow, there's like a glare. So, I couldn't see it.

Previous research suggests that sharing of computer screen provides certain advantages for collaborative learning endeavors (Inkpen, Booth et al. 1995). Sharing a single display between collaborators provides a shared object, which initiates discussions and enhances their attentions. However, a handheld—with its small and truly individual screen—does not naturally support the sharing of a single display among collaborators. As a result, students' collaborative activities that rely on handhelds face greater challenges with regard to the maintenance of shared attention (Roschelle and Pea 2002).

My expectation is that the "Look" network service makes it easier for participants who use handhelds to share the focused objects and thus to develop and maintain equal levels of attention. Further, I expect that participants without access to "Look" are stymied in the truly collaborative nature of their educational endeavors because they are denied the potential for "sharing" the focused objects. To test this expectation, I have investigated ten groups of thirty participants, none of whom had access to the "Look" network service. The following excerpt (see Table 9) illustrates the problematic situations that participants confront when attempting to share objects without the assistance of "Look."

Table 9: Transcript of an episode without "Look."

(With pairs of asterisks, overlapping speech is marked. Gesture acts are enclosed in parentheses.)

Seq. #	Person	Transcript
1	Director (D)	Okay, yeah, that one is between the twenty-seven and the zero over the pi on the bottom.
2	Matcher (M)	I Gotcha.
3	D	Okay, and then the other, which is divided by something over the two. It is on the other side of the lower twenty-seven.
4	M	Umm... So…
5	Teacher (T)	(keeps watching her own handheld)
6	D	(To the teacher) Can you see his…., please see his response? *because…*
7	T	*Yeah, let me see.* (teacher walks over to the director in order to check which character he is trying to explain)
8	M	I've got the Roman numeral two on the lower right corner.
9	D	Yeah.
10	T	(teacher leans to director's handheld screen over the director's shoulder)
11	M	And then, the one, like divided by the number two, just to the left of that… two divided by like two.
12	T	No…
13	D	Yes!! (with watching the teacher)
14	T	Yes. (correcting her response)
15	D	*Okay, how's...?*
16	T	*Wow, there's like a glare.*(covering her forehead with her hand) So, I couldn't see it. (laughing)
17	D	*Yes, okay.* (laughing)
18	M	And then, next to that is an upside down A on *top of the twenty seven.*
19	D	*Yeah, yeah.*
20	M	Okay.

21	D	And then, next to that… *is like a two minus something over two almost…*
22	M	*No, what?*
23	D & T	(watching the matcher)
24	M	Alright, so that is in the lower left area, not the corner but next to the lower corner?
25	D	Yeah, yeah.
26	T	(walks over to the matcher)
27	D	So, we really only have three things left.
28	M	Right.
29	T	(teacher leans to the matcher)
30	D	And they all involve…, two of them have like these sevens, two of them have seventy-seven on the bottom, one of them has seventy-seven on top.
31	M	Yeah, okay. Right.
32	D	The one with seventy-seven on top is on the bottom left hand corner.
33	M	Okay, that's right there.
34	D	Ok, cool! So we are dealing with the two upper right spots.
35	M	Yeah, upper right spot and the right next to it.
36	T	(back to her position and pick up her own handheld)
37	D	Umm, it's hard not to gesture some.
38	M	Yeah
39	D	Ok, so you've got the two seventy-seven, so one kind of them looks like a seventy-seven anyway… with a kind of a thing attached to it.
40	T	Yeah, like on the top. (with watching her own handheld)
41	M	There is… I see one with an L and then…
42	D	Yeah, the L one? That is all the way to the right.
43	M	Ok, then I think… I think, we are done.
44	D	Yeah, I think we are done.
45	T	So, can I now check theirs, can I hold both of theirs? Because I can't memorize. (She moves to the matcher and grabs matcher's handheld first and then, moves back to the director and grabs director's handheld… She is comparing two screens.)
46	D	She is the one like who will finalize this.

47	T	(after watching screens for a while, and she nods) Okay.
48	D	Not bad!

In this setting, the teacher was not provided with the "Look" network service; therefore, she was unable to retrieve students' views directly onto her screen. Instead, in order to check the students' activities, she was forced to walk among them and peer over their shoulders. This behavior could be problematic and lead to errors. For example, in turn 6, the director asked the teacher to check the matcher's answer because the matcher's reply in turn 4 was not clear. In turn 7, however, instead of approaching the matcher, the teacher approached the director in an attempt to first check the director's screen to determine what students were talking about. By deciding to view the director's screen, the teacher missed the precise moment when her attention was vital: in the time it took for her to walk to the director, students moved forward to the next step (turns 8 and 9). In this instance, if the "Look" network service had been available to the teacher, she could have caught the right moment and given advice on the spot.

This episode also indicates that gazing into the small screen of a handheld over someone's shoulder is a tricky task at best. In turns 10 to 17, the teacher misread the information on the screen and thus provided incorrect feedback. The student was surprised by the teacher's comment and reacted immediately (turn 13). The teacher corrected her error and excused her mistake: "There's like a glare. So, I couldn't see it" (turn 16).

In handheld-mediated classroom activities, a teacher must be able to check students' work for various reasons (e.g., grading, checking whether they are following correctly or paying attention) and at various phases of the activity. During this particular phase of the experiment, in order to check students' screens, the teacher walked back and forth in the classroom and occasionally resorted to the most straightforward way of checking their work: After each activity, she picked up each student's handheld and went through it in order to make sure the work was complete (turn 45). Clearly, reviewing each handheld in this manner presents considerable drawbacks to efficient and timely formative evaluation. Unlike the summative evaluation, which assesses the final result only, the formative evaluation requires frequent assessments to determine student progress. Physical reviewing of each handheld is not optimal for formative evaluation because the process must constantly disrupt students' work. On the other hand, the "Look" network service can provide fine-grained formative assessment: Using this service, the teacher can assess student work at any time simply by beaming to student's handheld.

Discussion

The experiment reported here investigated the adequacy of a particular implementation of “Look” to help with the problem of *side-assistant sufficiency*: the problem of allowing a side-assistant to gain adequate understanding of a shared visual workspace to enable meaningful monitoring of ongoing conversation about that workspace or even entry into the conversation. The experiment highlights a situation involving difficult shared reference. While the experiment did not show that side-assistants with “Look” had greater recognition of the referred to objects than those without “Look,” it did provide preliminary evidence that the side-assistant did a better job of associating the names of those objects with the objects. Also, there were indications from transcripts that side-assistants with “Look” could enter into the conversation without topic changes, while those without “Look” experienced more difficulty. Moreover, participants in groups with “Look” reported more positive comments about the experience compared to those without. Two specific hypotheses were tested in this experiment:

H1: “Look” functionality, compared to its absence, will help early side-assistants learn Korean characters, as evidenced by naming and recognition of Korean characters. As predicted, early side-assistants who had access to “Look” had significantly fewer number of errors in naming Korean characters when compared to those who had no access. With “Look,” they made fewer than half the number of errors. The director and matcher of the group whose side-assistants were equipped with “Look” had also fewer errors. That is, “Look” may improve the instructional judgment of side-assistants. However, unexpectedly, the difference in correctly identifying Korean characters between early side-assistants with “Look” and those without “Look” was not significant. All participants with “Look” recorded slightly fewer errors than those without “Look.” This might be because of the small number of participants in the experiment. It also might have to do with the different task demands experienced by the side-assistant with and without “Look.” Without “Look,” side-assistants may spend more time looking at the shape of the characters on their screen. That is, their process is less efficient than with “Look” and more isolated from a knowledge network that includes names, but sheer time on task provides some compensation.

H2: The nature of early side-assistants' experiences—whether positive or negative—will be more favorable if "Look" is available to early side-assistants. As predicted, early side-assistants with "Look" said that they had more positive experiences; those without "Look" said that they had more negative experiences. Side-assistants working under the "no-Look" condition pointed out the limitation of their interaction with central participants.

The experiment here is abstracted away from a situation found in the classroom use of handhelds to aid learning. Compared to normal classroom practice, it increased the need for deictic resolution, and therefore the potential for errors. If "Look" reduces errors in a stressful situation, it is highly likely to do so in a daily classroom usage.

The investigation has implications beyond the use of handhelds in the classroom. In particular, it highlights a gap in predictive theory about the nature of joint action. Current theory does not accommodate the range of situations that we find in ubiquitous and pervasive computing. Although Kraut, Gergle and Fussell (2002) have examined the cost of delay in sharing visual workspaces, they have not examined punctuated sharing, such as the kind obtained here. While other prior work has examined the information available to the overhearer, it has not examined side participation.

Additionally, this study is focused on a particular implementation with special, even idiosyncratic, features. Three factors require further exploration. First, a feature is that the infrared-based system requires little of the side-assistant defining the target of a "Look" action. That is, no private or previous work is required to name or locate a machine or a user. The side-assistant just points her/his machine at the partner machine and beams. In (for example) a radio-frequency implementation, the side-assistant would have to use her/his screen to somehow specify the IP address of the machine that s/he wanted to look at. Second, this implementation supports only overt monitoring by the side-assistant, enforced by the need to align the machines physically during pointing and by the repeated notification messages. That is, the monitored person has to know who is monitoring and when. While the act of looking covertly would interrupt less, it also might make entry into the conversation more difficult for the side-assistant than it is currently. In this experiment, the side-assistant takes a physical action similar to the adjusting of body position as one enters a hallway conversation. As the side-assistant's access to information becomes more covert, the matcher and director gain less information about the side-assistant's range of intentions. Third, this system provides only punctuated (rather than continuous) "looking" incidents. One way of thinking about this situation is that the side-assistant has less information about what is happening than if s/he had continuous monitoring. However, another point of view is that the side-assistant has an amount and kind of information that is controlled by him- or herself. The side-assistant's control over viewing may arguably prove more important to understanding than continuous visual information.

Three kinds of future work follow from this experiment. First, the study as conducted was lower power. Replication with more participants is desirable. Second, the various design options of proper wireless local area network (WLAN) architecture should be directly compared to investigate how different forms of implementing the shared visual workspace affect how well the side-assistant can use shared visual workspaces. Third, following from my analysis of different kinds of peripheral participants, I plan to create experimental situations that more closely resemble the "formative assessment" and "peer sufficiency" problems I started with. In particular, the teacher or peer typically is also a *latecomer* to the on-going interaction, and does not witness, as the early side-assistant here did, the creation of common ground between matcher and director.

Chapter 6: Experiment 2 - the Effect of "Look" on the Late Overhearer

In experiment 2, two kinds of investigations are conducted. The first one investigates the advantages of "Look" for late overhearers with regard to its ability to help them understand the context of the activity and create common ground. The second one examines how "Look" increases an overhearer's efficiency in learning while using handhelds. For the results of both investigations, the "no-Look" condition is included to serve as a baseline for evaluating the success with which participants use the "Look" network service for understanding conversation and creating common ground.

The decision to investigate how "Look" affects the overhearer derives from conclusions introduced in Schober and Clark's paper (1992) "Understanding by Addresses and Overhearers." Their experiment had one participant serve as a "director" who had a set of cards showing abstract figures that were difficult to describe, and another participant as a "matcher" who had to arrange the same set of cards by listening to the director's explanation. The other participant was put in the position of a "late overhearer" who could join the game later and also arrange cards. This work indicated that in collaborative activities, a late overhearer who had not been given the opportunity to witness the buildup of common ground between conversational participants performed much more poorly than his fellow participants. Late overhearers were 55% correct, compared with the matcher's 98%: The test responses of a late overhearer were much less accurate than those of a matcher (i.e., discourse participant).

The goal of Experiment 2 is to indicate how in collaborative activities, the "Look" network service can increase the accuracy of a late overhearer's understanding of conversation between central participants. By using "Look" to capture visual/indicatory context, a late overhearer will be able to understand more quickly the import of a conversation and thus will be able to reach common ground quickly and efficiently. Also, by virtue of the correct comprehension of the conversation, the late overhearer's successful learning about Korean characters will occur. I examine two main research hypotheses from this experiment.

- **H3**: “Look” functionality, compared to its absence, will help late overhearers gain common ground, as evidenced by accurate placement of the icons.

- **H4**: “Look” functionality, compared to its absence, will help late overhearers learn the Korean characters, as evidenced by naming and recognition of the Korean characters.

Participants

Via announcement on the Psychology department experiment management system, 141 students were recruited to participate in the experiment in 47 groups. Students were given extra credit for participating in the experiment. Participants' ethnic backgrounds were multi-cultural: African-American, Latin-American, Mexican-American, Asian-American, Austrian, Brazilian, Chinese, Filipino, Indian, Panamanian, Polish, Scandinavian, Spanish, Thai, Vietnamese, and Caucasian. None of the participants had prior knowledge of how to read Korean characters, were familiar with Korean culture, or had traveled to Korea. Participants' ages ranged from 18 to 28, with a mean age of 19 (SD: 1.42). Fifty-five percent of the group were female. All participants were undergraduates, with roughly half of them freshmen (52%). Psychology majors provided the largest group (21%) but other majors also took part, including students from communications, sociology, accounting, finance, marketing, animal science, human development, industrial system engineering, mining and minerals engineering, politics, music education, French, chemistry, hotel management, and computer science.

Apparatus

Among the large variety of networking options, currently the most widely deployed standards for short-range wireless technologies are infrared (IR) communication and wireless LAN networks, such as Bluetooth or IEEE 802.11 (Wi-Fi).

For years, TV remote controls have made extensive use of infrared technologies. Such devices communicate by using infrared beams of light to send and receive data. For Experiment 1, the network infrastructure for “Look” used IR communication. Applications for which IR is well suited include those that require faster communication or security: Because IR uses a direct point-to-point communication, with the beam of light being more focused than wider-ranging radio signals, the “seeking” or “controlling” device can clearly identify the target devices merely by pointing toward them.

However, every case does not work effectively with IR. For example, a situation that involves multiple people simultaneously using devices in the same room does not work effectively, because at any given time data can be transferred between two devices without disrupting the line-of-sight connection. Such a connection must remain relatively stationary for the duration of the data transmission session. Also, notification windows appear on the screen informing the user of the operation. This means that such low-level built-in “notification” conventions prevent totally covert monitoring, and any usual monitoring of what is happening on the handhelds is overt. As a result, in this study, the radio-frequency (RF) based option such as Bluetooth was investigated for its ability to provide better communication infrastructures for experiment 2 and 3.

With its omni-directional signaling, longer distance communications, and capacity to covert transmission, RF technology complements infrared’s narrow angle of sight (30 degrees or less), short range (three feet or less) signal, and point-and-shoot overt use. Table 10 compares different communication technologies for handheld networks. The “Look” function was embedded and tested as a component of the Korean Character Tangram game (see Figure 10).

Table 10: Comparison of communication technologies for handheld networks.

	IR	Bluetooth	Wi-Fi
Data transfer rate	High	Low	Medium
Power duration	Long	Medium	Short
Communication range	Very short	Medium	Long
Direction of connection	Limited	Omni-direction	Omni-direction
Initial configuration load	Light	Heavy	Medium
New connection configuration load	Light	Medium	Heavy
Security setting load	No Extra Setup	Medium	Complicated
Provided privacy	High	Medium	Low
Broadcasting	No	Limited	Yes
Intrusion to user activity	High	Medium	Low
Simultaneity	Short Delayed	Nearly Synchronous	Almost Synchronous

Figure 10. Korean Character Tangram game: a user can choose an opponent from the discovered trusted peers and start the connection (a-c). By clicking the *Look Others* button, a user can capture a snapshot of an opponent's screen (d).

Procedure

The experiment consisted of two phases. During the first phase, a pair of students carried out a task in which one person assumed the role of *director*, while the other one played the role of *matcher*. In front of the director was placed a handheld screen that contained the same figures in the same order as those on the matcher's device. By clicking the *Shuffle* button, the director randomly rearranged the figures. Once the director determined the order of figures, he would begin reviewing the positions and figures sequentially; starting from the top left figure and ending with the one at bottom right. The goal of the task was for the director to tell the matcher how to rearrange the twelve complex figures so that the matcher's order matched the director's and to teach the matcher the pronunciation of each character. Participants were not allowed to look at each other's screen. The director could describe the figures out loud, identifying which should go first, second, and so on. The matcher then used the stylus to move her figures around. The activity was finished when the matcher and director agreed that the figures were in the same order. They repeated this task for five trials.

During the second phase, from the third trial, a third person, the *late overhearer*, joined the activity. The late overhearer would assume the role of a particular kind of peripheral participant, an overhearer who has no right of taking part in the conversation. The late overhearer must join trials 3, 4, and 5 and then sort the figures using clues he was able to learn from the director and matcher's conversation. Only half of late overhearers were allowed to use the *Look Others* button to find out what was on a matcher's screen; by clicking the button, he could capture the screen view of the matcher's handheld, a capability made possible by Bluetooth communication technology. However, in the condition without "Look," late overhearers were not allowed to use the *Look Others* button. The results of each condition were analyzed to explore the effects of sharing visual context for collaborative activity and to compare the impact of "Look" on students' abilities to learn. The sessions were timed and videotaped. Furthermore, I collected quantitative evidence about correct placement of the right figure and errors on quizzes about naming it and identifying the Korean character. Each session took about 1.5 hours.

Results

The principal test of the benefits provided by “Look” was based on accuracy; the percentage of figures placed correctly. According to the hypotheses, late overhearers whose handhelds are equipped with the “Look” functionality should better understand the conversation and thus should more be able to rearrange the figures correctly. This was precisely what occurred. Through all three trials, late overhearers in the group that had access to “Look” experienced significantly fewer errors than did those who were not supported with it. During trial 3, in which the late overhearer entered the discourse the first time, experiment results indicated an average of over 90 percent correct (Standard Deviation (SD): 17.6) among those overhearers who used “Look,” compared to an average of about 69 percent correct (SD: 24.2) for overhearers without the “Look” functionality: $F(1, 41) = 11.15$, $p < .002$ (see Figure 12). As late overhearers repeated tasks through trials 3 to 5, the task correctness of late overhearers increased in both groups with “Look” and without “Look” (see Figure 11). However, the statistically significant difference remained through trial 5 between groups with and without “Look” ($F(1, 43) = 9.97$, $p < .003$ in trial 4; $F(1, 40) = 9.87$, $p < .004$ in trial 5). These differences suggest that the “Look” handheld network service, which provides a visual context for focal artifacts, greatly influences late overhearers’ understanding of the conversation.

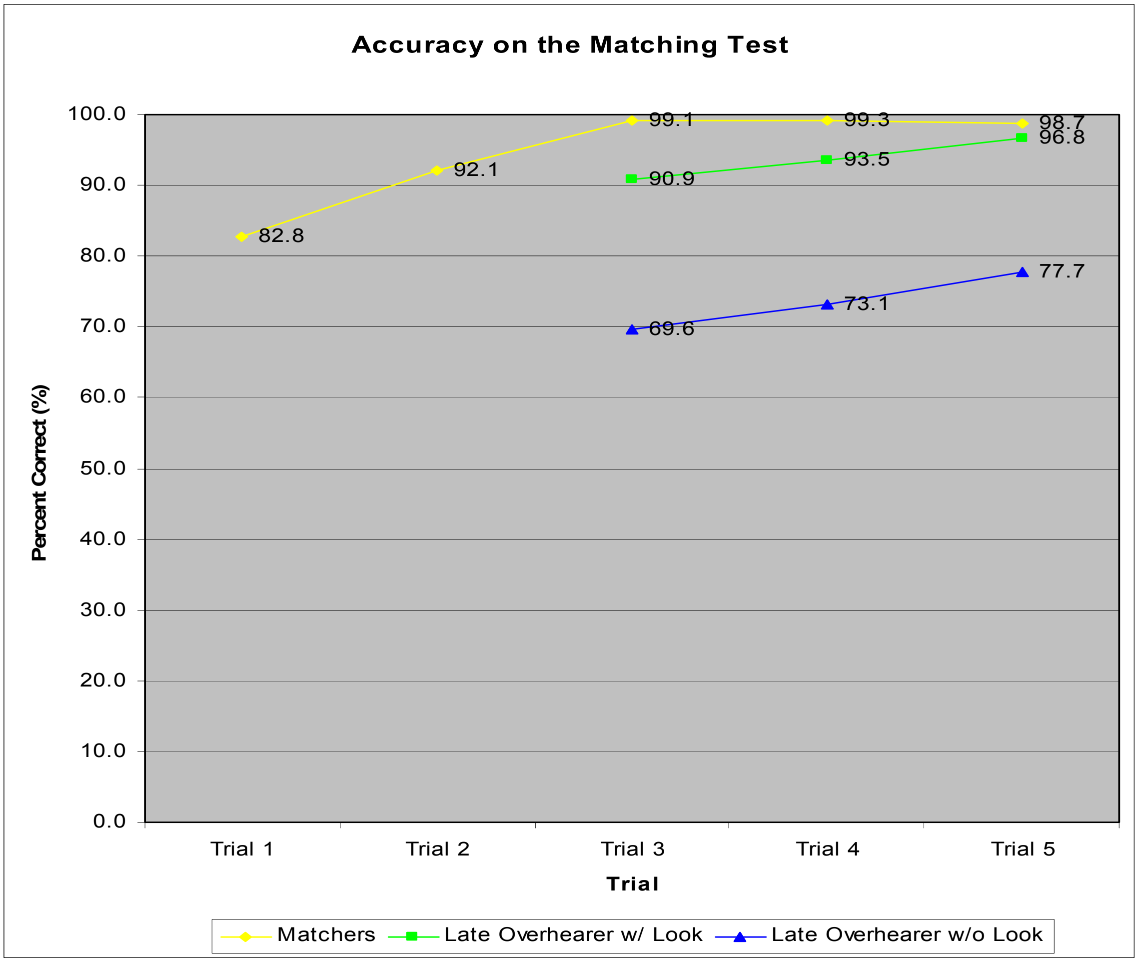


Figure 11. Percentage correct in each condition (matcher, late overhearer with "Look" and without "Look") in each trial on rearranging icons. Late overhearers in the group that had access to "Look" (i.e., green line) were significantly more correct than those without "Look" (i.e., blue line) ($F(1, 41) = 11.15$, $p < .002$ in trial 3: $F(1, 43) = 9.97$, $p < .003$ in trial 4; $F(1, 40) = 9.87$, $p < .004$ in trial 5)

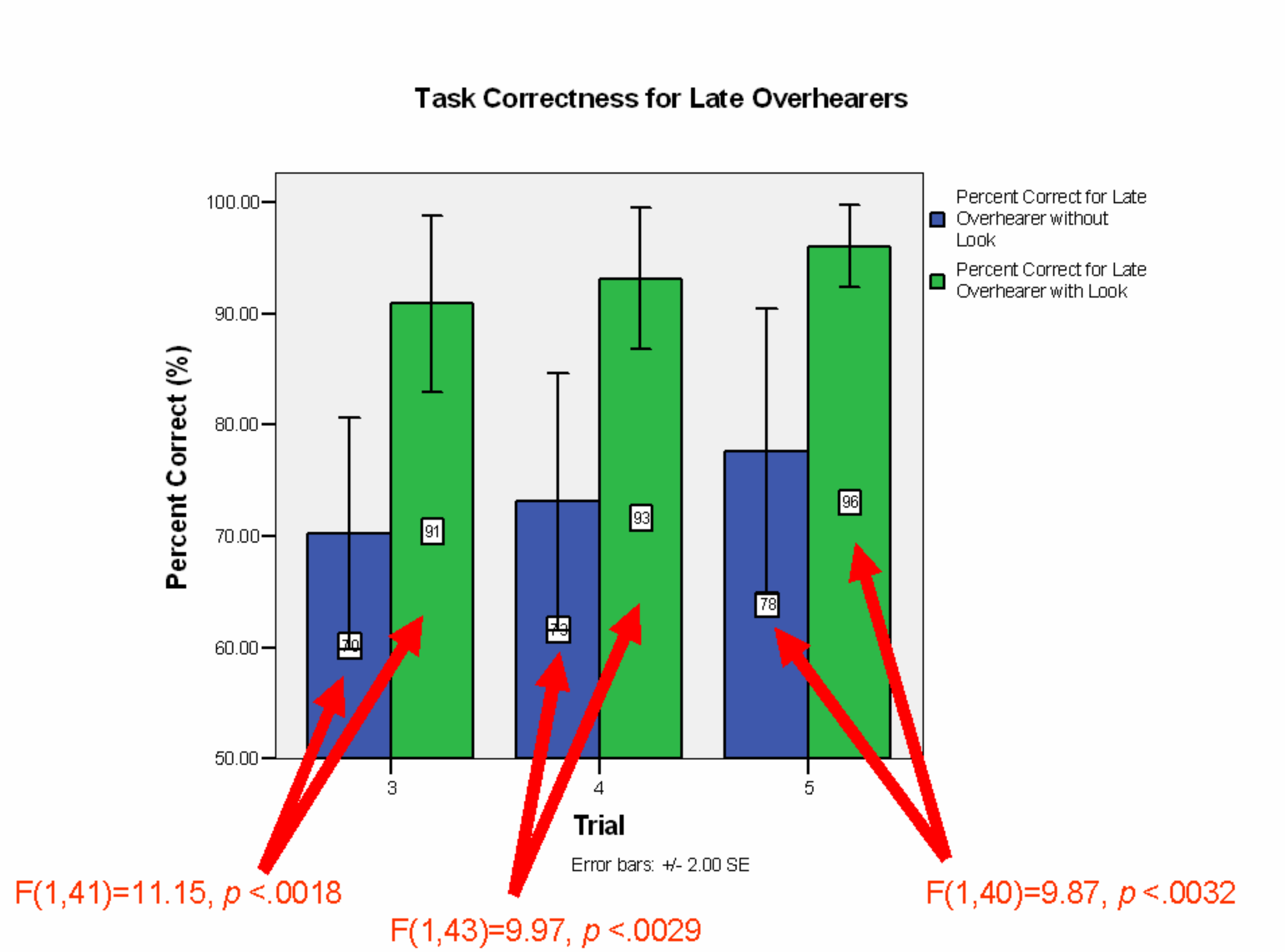


Figure 12. Correct placement of figures of Korean character by late overhearers with and without "Look."

The second test used for learning involved a naming and recognizing quiz, administered after each trial, which asked participants to correctly recognize and name each Korean character. This test was designed to measure whether during the task participants had indeed learned the characters' correct names. Over all three trials, the percentage of correctness by each late overhearer in the naming of Korean characters was higher for the groups that had access to "Look" (see Figure 13). Specifically, in trial 4, an analysis of variance yielded a significant advantage, with F (1, 44) = 4.15, $p < .048$ (see Figure 14). The graph shows also marginal improvements in trials 3 and 5. (F (1, 44) = 3.22, $p < .079$ in trial 3; F (1, 43) = 2.44, $p < .125$ in trial 5.)

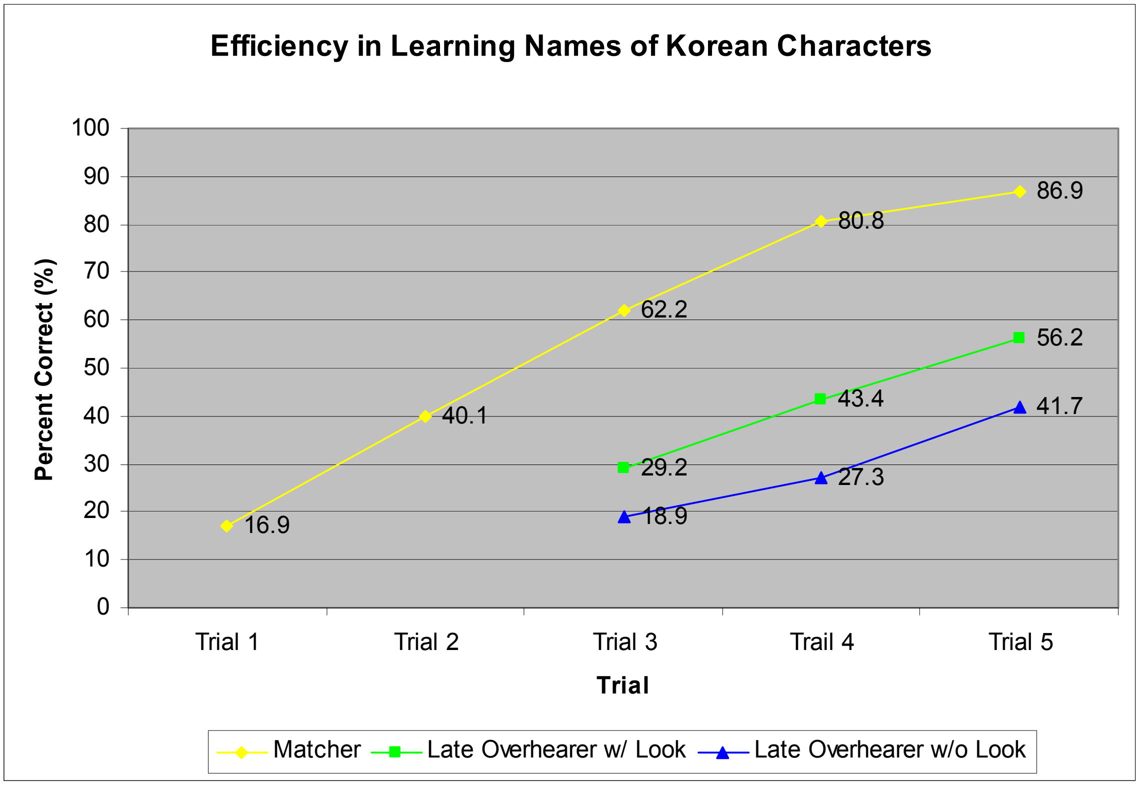


Figure 13. Percentage correct in each condition (matcher, late overhearer with "Look" and without "Look") on quizzes on naming Korean characters. Late overhearers in the group that had access to "Look" (i.e., green line) were significantly more correct than those without "Look" (i.e., blue line) in trial 4 ($F(1, 44) = 4.15$, $p < .048$) and marginally more correct in trials 3 and 5 ($F(1, 44) = 3.22$, $p < .079$ in trial 3; $F(1, 43) = 2.44$, $p < .125$ in trial 5).

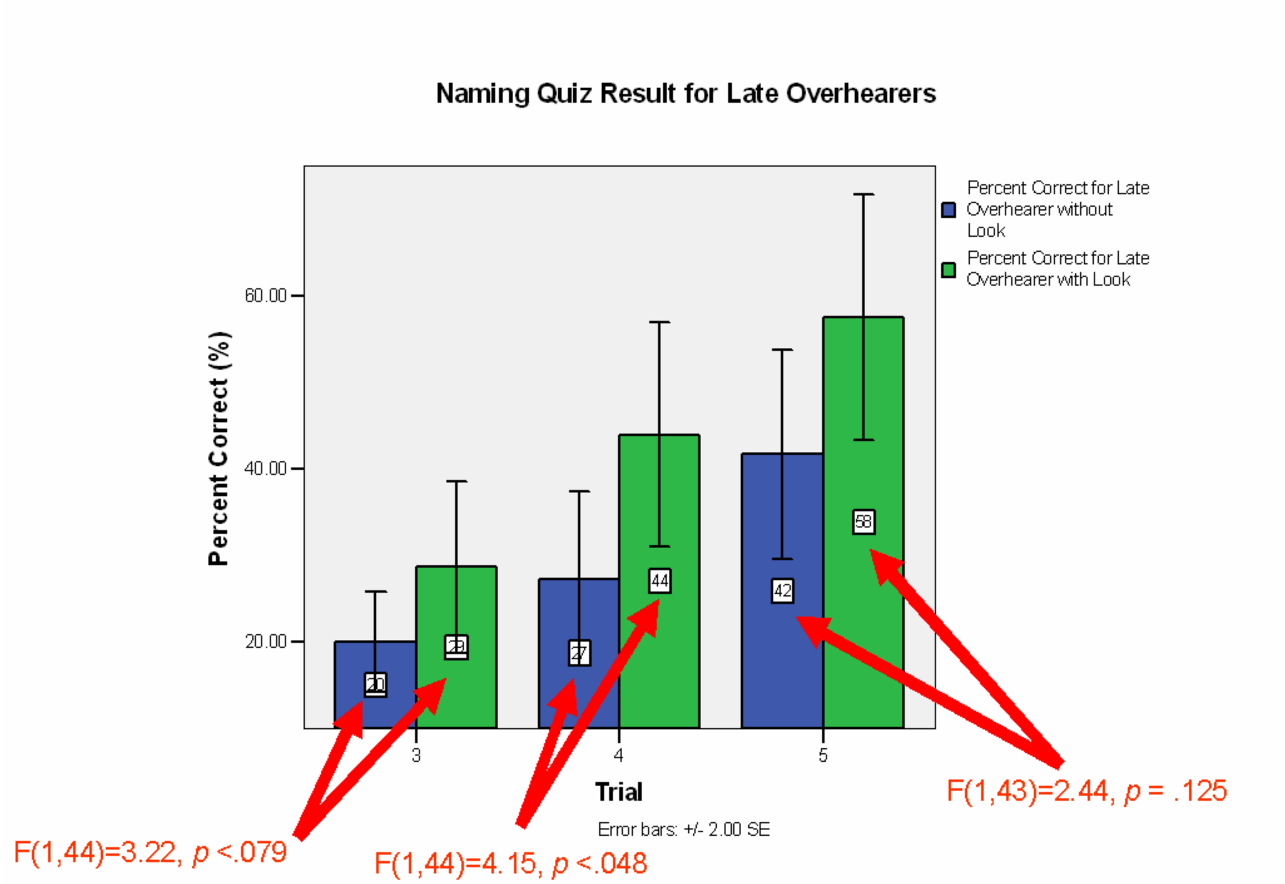


Figure 14. Correct naming of Korean characters by late overhearers with and without "Look" in each trial.

The other test used for learning by the late overhearer involved a recognition quiz, administered after each trial, which asked participants to correctly identify twelve Korean characters viewed during the activity from a list of twenty-four characters. The difference between "Look" users and non-users was not significant. Surprisingly, the percent correct by each late overhearer in recognizing Korean characters was slightly higher for the groups that did not have access to "Look" (see Figure 15). Specifically, in trial 4, an analysis of variance yielded a marginal difference, with F (1, 45) = 2.41, p < .13 (see Figure 16). Figure 16 shows the mean of correct percentage in the recognizing quiz in each trial for late overhearers. Table 11 summarizes naming and recognition quizzes' results for each trial.

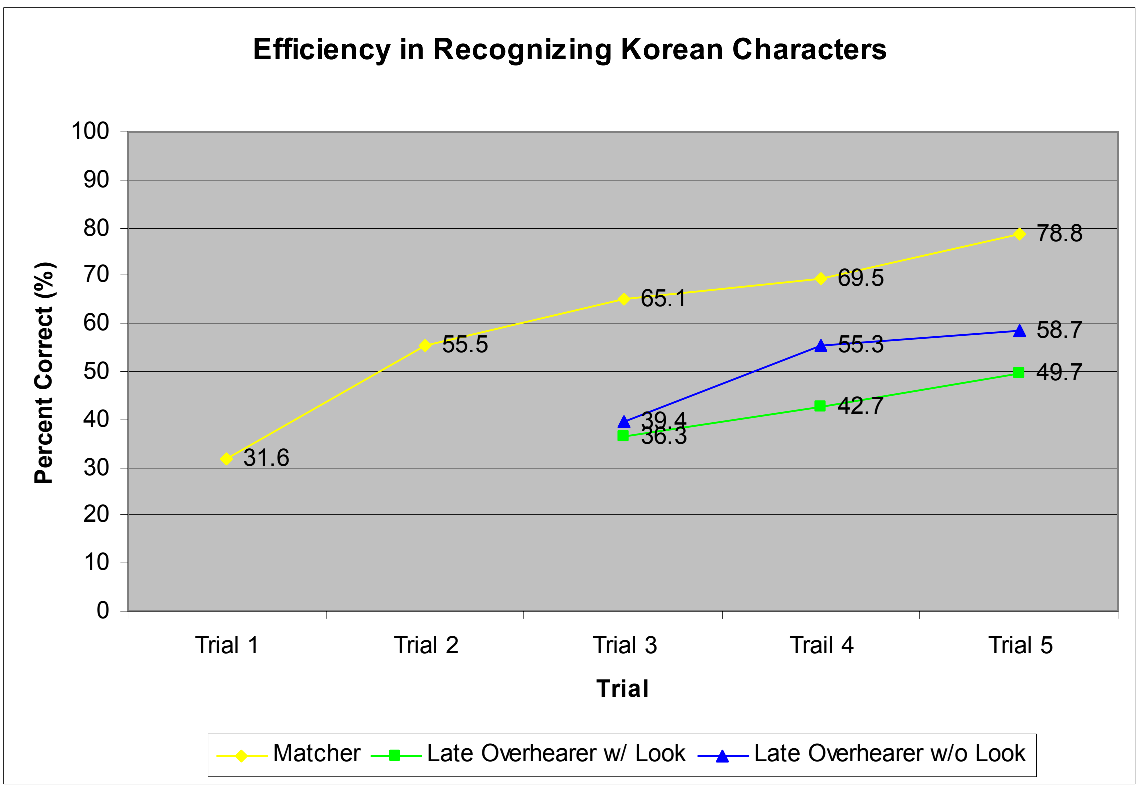


Figure 15. Percent correct in each condition (matcher, late overhearer with "Look" and without "Look") during quizzes on recognition of Korean characters. Late overhearers in the group that had access to "Look" (i.e., green line) were slightly less correct than those without "Look" (i.e., blue line). There is no significant difference in performance in all trials.

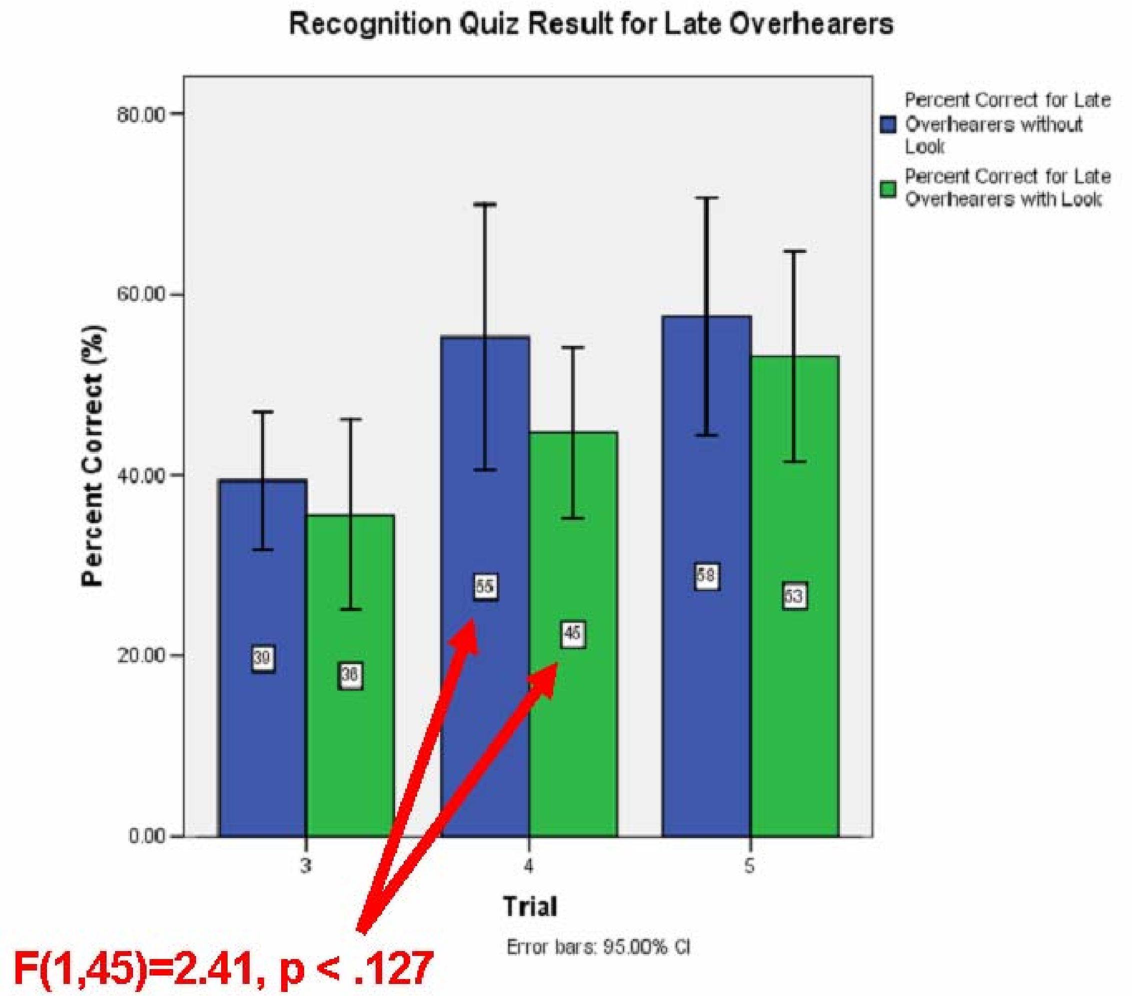


Figure 16. Percent correct in recognition of Korean characters by late overhearers with and without “Look” during each trial.

Table 11: Percent correct in naming and recognition quiz by late overhearers.

The numbers in each cell represent mean of percent correct and (*standard deviation*).

With Look / Without Look	**Trial 3**	**Trial 4**	**Trial 5**
Naming Quiz	29.2(*23.4*)* / 18.9(*13.4*)*	43.4(*29.4*)** / 27.3(*23.7*)**	56.2(*33.4*)*** / 41.7(*28.5*)***
Recognizing Quiz	36.3(*23.9*) / 39.4(*17.3*)	42.7 (*22.4*) † / 55.3 (*32.9*) †	49.7(*25.8*) / 58.7(*28.8*)

* $F(1,44) = 3.22$, $p < .079$; ** $F(1,44) = 4.15$, $p < .048$; *** $F(1,43) = 2.44$, $p < .125$; † $F(1,45)=2.41$, $p < .127$

Discussion

Active participation in conversation is not the only means by which learning can occur. Because learning is fundamentally a social process that dwells in contextualized settings, it also takes place through the observation of others (Stenning, McKendree et al. 1999). Successful self-assessment of understanding using handhelds depends upon such issues as how to design devices that involve minimal disruption and incorporate contextual data from learning situations. To draw attention to these concerns, this experiment created a situation for the late overhearer that highlighted the effort involved in attaining sufficient common ground. The experiment reported here investigated the adequacy of "Look" to promote late overhearers' understanding of an overheard task. The overhearer engaged in continuous monitoring of an activity either aided by periodic information from the handheld, or without that information. Using "Look," late overhearers were better able to place icons correctly than without "Look." In addition to the correct comprehension of the conversation, there is equivocal evidence that the late overhearers were able to learn more names of Korean characters with "Look" than without.

Two specific hypotheses were tested in this experiment:

H3: "Look" functionality, compared to its absence, will help late overhearers gain common ground, as evidenced by accurate placement of the icons. As predicted, late overhearers whose handhelds were equipped with the "Look" functionality were more able to rearrange the icons correctly than did those who were not supported with it. Through all three trials, late overhearers in the group that had access to "Look" experienced significantly fewer errors than did those who were not supported with it.

H4: "Look" functionality, compared to its absence, will help late overhearers learn the Korean characters, as evidenced by naming and recognition of the Korean characters. There was some evidence that late overhearers performed better in naming Korean characters when they had access to "Look" than did those without "Look." Specifically, in trial 4, an analysis of variance yielded a significant advantage. However, results were only marginally different for trials 3 and 5. Additionally, the difference in correctly recognizing Korea characters between late overhearers with "Look" and those without "Look" was not significant. Along with similar results from Experiment 1, these mixed results suggest a complex picture of task demands. Late overhearers may get the most benefit from "Look" once they get accustomed to how to use the system (compared to trial 3) or before they accumulate enough common ground by repeating trials (compared to trial 5). Furthermore, they may be allocating attention differently without "Look," perhaps even in a way more conducive to remembering than with "Look."

Two kinds of future work follow from this experiment. First, I showed an advantage for accuracy of placing icons but not for recognizing icons after the experiment. This result suggests that "Look"ing at others' screens may cause peripheral participants to focus on the momentary resolution of deixis rather than the long-term. The effect of "Look" on student's attention to the task needs further investigation. Second, Schober and Clark's experiment (1989) shows that the overhearers' performance did not improve even after the sixth trial. However, in my experiment, the late overhearer could quickly catch up with "Look" and compensate coming in late in trial 5 (i.e., task performance difference among matchers and overhearers was not significant, $p > .23$). In general, this raises the question, "does sharing a visual context compensate for the disadvantage of not speaking?"

Chapter 7: Experiment 3 - the Effect of "Look" on the Late Side-Participant

Experiment 3 focused on the effect of sharing visual context on side-participant in handheld-based collaboration. The role of the side-participant was slightly different with the one of a side-assistant or of an overhearer. Unlike the side-assistant (whose main job was to interact dynamically with central-participants to help them), side-participant's main job was to do a task without interrupting the central participants, such as a student trying to enter the group. Also, unlike the overhearer (who could not talk), the side-participant could ask the director or the matcher to clarify if s/he didn't understand something. Experiment 3 was built on (1) Clark's previous study (Clark and Krych, 2004) for shared visual workspaces and (2) Monk's previous work for peripheral participation in video-mediated communication (Monk and Watts, 2000). In his previous study, Clark indicated that pairs of participants performed much more quickly when directors could see their partner's workspace, and that two partners together used fewer words to describe their activity when the workspace was visible rather than hidden, although monitoring partner's face did not lead to measurably greater efficiency. In addition, Monk showed that grounding mechanism might be difficult for peripheral participants. The mutual obligations between a speaker and a peripheral participant were very weak. Although the speaker might adjust his or her utterance with the knowledge of the presence of the peripheral participant, speaker's discourse contributions were often completed without waiting for acknowledgement or validation from the peripheral participant, and neither did the peripheral participant have the obligation to signal the evidence of her/his understanding to the speaker.

If given an opportunity to provide a visual context of workspace, peripheral participants will be able to perform more effectively and more quickly: Using the "Look" network service, the peripheral participant makes displays and exemplifications of her/his understanding practicable for the purpose of validation and correction of construal. The speaker is also able to keep monitoring peripheral participant's understanding with visual evidence of the shared workspace and so, able to move on next presentation without waiting verbal-acceptance from the peripheral participant. To test this prediction, I conducted an experiment similar to the one designed by Clark and Krych (2004). The design of experiment 3 is identical to that of experiment 2 (i.e., the effects of "Look" on the late overhearer) except for one thing: During the experiment, the latecomer can talk with the director or the matcher to get additional descriptions, ask questions, and clarify points. Therefore, I use the term "late side-participant" instead of the term "late overhearer" to describe this role. I examined two main research hypotheses from this experiment:

- **H5**: "Look" functionality, compared to its absence, will help late side-participants gain common ground, as evidenced by accurate placement of the icons and the use of less time to complete the task.

- **H6**: "Look" functionality, compared to its absence, will help late side-participants communicate efficiently, as evidenced by fewer turn-takings and overlappings in conversation.

Experiment 3 consists of two parts, Experiment 3a and 3b. It attempted to replicate the findings from Experiment 3a and 3b while exploring the possibility that the weak findings from Experiment 3a were due to task-complexity issues. Experiment 3b differed from Experiment 3a in three respects. One is that the number of icons to be arranged was increased from twelve to twenty-five. The second is that the size of the icon was smaller in Experiment 3b. The third is that participants did four trials instead of five trials in Experiment 3b.

The following section describes the experiments in detail. I focus mainly on the discussion about the results of Experiment 3b but discuss briefly the findings from Experiment 3a, too.

Experiment 3a

Participants

Via announcement on mailing lists and on the Psychology department experiment management system, 114 students were recruited to participate in the experiment in 38 groups. Some of students received *Professionalism in Computing* course extra credit or some of them were given extra credit for introductory psychology course for participating in the experiment. Participants' ethnic backgrounds were multi-cultural: Vietnamese, Palestinian, Middle Eastern, Irish, Indian, Hispanic, Greek, German, Eritrean, Cambodian, Chinese, African-American, Filipino-American, and Caucasian. None of the participants had prior knowledge of how to read Korean characters, were familiar with Korean culture, or had traveled to Korea. Participants' ages ranged from 18 to 34, with a mean age of 20 (SD: 2.07). Fifty-one percent of the group were female. All participants were undergraduates, with roughly half of them freshmen (41%). Psychology majors provided the largest group (18%) but other majors also took part, including students from Sociology, Public Affairs, Music, Mining Engineering, Mechanical Engineering, Marketing, Human Development, Hospitality and Hotel Management, Human Nutrition and Food Engineering, Geology, Geography, Finance, Computer Science, Computer Engineering, Communication, Chemistry, Chemical Engineering, Business, Biology, Biochemistry, Architecture and Animal Science.

Apparatus

Use the same device as the one in experiment 2 (see Figure 10).

Procedure

During an hour or so, participants were asked to play a game called Korean Character Tangram in which one person was the "director," another person was the "matcher," and the other person was the "late side-participant." The role was randomly chosen by picking up three slips of paper from a bag. In the game, everybody had a handheld device with twelve Korean characters on it. They played five rounds of the game. At the beginning of every round, the director hit the shuffle button to put his characters in a specific order. The game was for the matcher and director to put the matcher's characters into the same order as the director's without one person ever looking at the other one's screen. The matcher used the stylus to drag and drop characters on her screen to rearrange them. The director could use words to describe the characters, but he also had the characters' names, and was encouraged to use the name of each character at least once in every round, maybe before he moved to the next character. The round ended when the director and matcher agreed that the characters were in the same order. At the end of each round, their answers were compared to each other. All participants also individually answered quizzes about naming and identifying the Korean characters.

The director and matcher played five rounds of the game. During the first two rounds, the late side-participant was out of the room. Then, the late side-participant was brought back into the room. The late side-participant's job was the same as the matcher's, to put his characters into the same order that the director had, but his handheld had an added feature: a "Look Others" button. By clicking this button, the late side-participant could capture a screenshot of the matcher's handheld. Only half of late side-participants were allowed to use this *Look Others* button to find out what was on a matcher's screen (i.e., the "Look" condition). In the "no-Look" condition, the *Look Others* button was not available to the late side-participant. The late side-participant could use this screen capture in any way that helped him.

The job of the late side-participant was to "catch on without being too much of a burden." All participants could talk with one another, but the matcher's and the director's main job was to work with each other. Their job was not to tutor the late side-participant. The late side-participant did three rounds altogether. Then, all of them were asked some more questions regarding their experience.

Results

To measure participants' understandings of what was said in the conversation, I examined the result of a Korean Character Tangram game. This game has been widely used to explore the creation and maintenance of common ground in psycholinguistic literature (Clark, 1996). Participants' understanding is reflected by the result of matching Tangram figures in the task. In general, this matching measurement should show more correct performance for the central participants and less correct performance for the peripheral participants because the peripheral participants are less directly interweaved with the conversation compared to central participants, and so the peripheral participants are at a considerable disadvantage in creating common ground in the task.

Figure 17 shows the matching result by the matcher (i.e., central participant) and the late side-participant (i.e., peripheral participant) both with "Look" and without "Look." The difference in the performances of the matcher and of the late side-participant was not significant in trial 4 and trial 5. This lack of difference in matching Tangrams was unexpected: The effect of the shared visual context was puzzling. In trial 3, there was perhaps the issue of negative skew (i.e., ceiling effect) of the distribution of results. To coax the ceiling effect, Fisher's exact test was used to analyze the results in trial 3. Statistical analysis (one-sided Fisher's exact test) confirmed that the late side-participant without "Look" was significantly more likely to conduct the task less accurately ($p < .005$, Fisher's exact test) than did the matcher or the late side-participant with "Look."

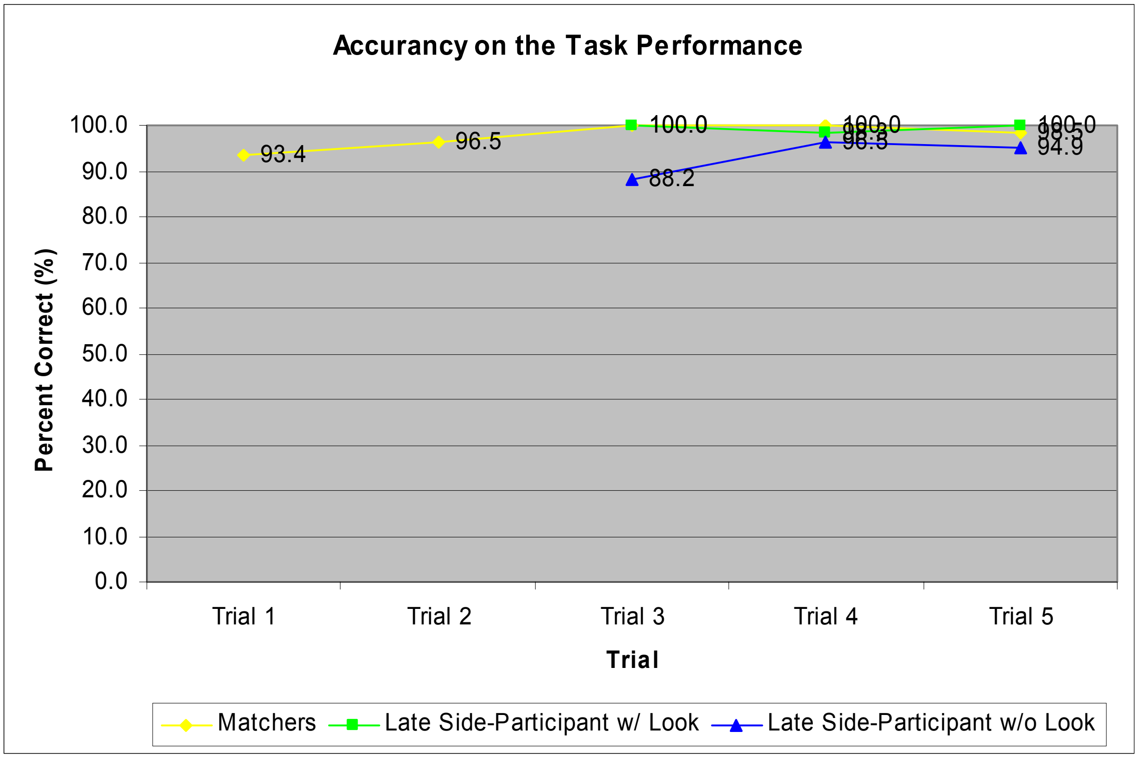


Figure 17. Accuracy on the task performance by different participatory roles. In trial 3, late side-participants with "Look" were significantly more likely to put icons in the right position than those without "Look" ($p < .005$, Fisher's exact test).

The second test used for learning involved the naming and recognizing quiz, administered after each trial, which asked participants to correctly recognize and name each Korean character. This test was designed to measure whether during the task participants had indeed learned the characters' correct names. The difference between "Look" users and non-users was not significant. Figure 18 shows the mean of correct percentage in the naming quiz in each trial by late side-participants.

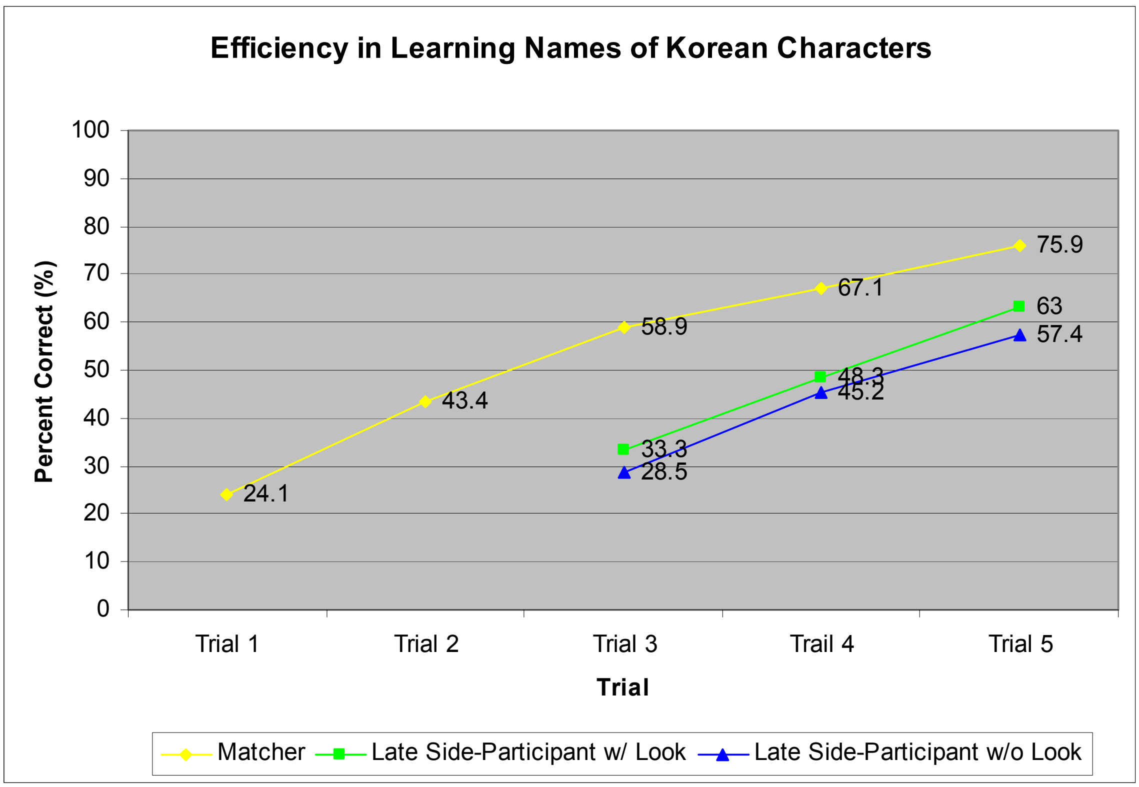


Figure 18. Percentage correct in each condition (matcher, late side-participant with "Look" and without "Look") during quizzes involving the naming of Korean characters. There is no significant difference in performance in all three trials between late side-participants with "Look" and those without "Look."

The other test used for learning by the late side-participant involved a recognition quiz, administered after each trial, which asked participants to correctly identify twelve Korean characters viewed during the activity from a list of twenty-four characters. The difference between "Look" users and non-users was not significant. Unexpectedly, the percent correct by each late side-participant in the recognition of Korean characters was slightly higher for the groups that did not have access to "Look" (see Figure 19). Specifically, in trial 5, an analysis of variance yielded a marginal difference, with F (1, 32) = 2.95, $p < .096$ (see Figure 20). Figure 20 shows the mean of correct percentage in the recognizing quiz in each trial by late side-participants. Table 12 summarizes naming and recognizing quiz' results for each trial.

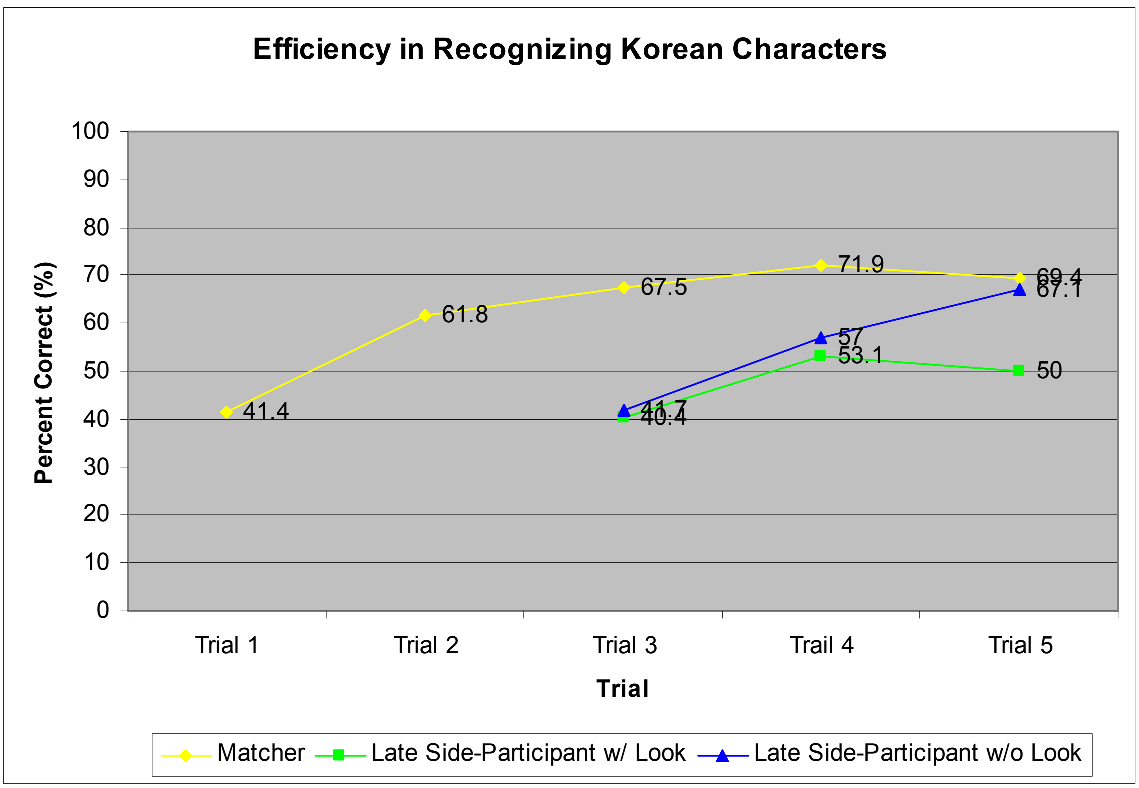


Figure 19. Percent correct in each condition (matcher, late side-participant with "Look" and without "Look") during quizzes on recognition of Korean characters. Late side-participants in the group that had access to "Look" (i.e., green line) were marginally less correct than those without "Look" (i.e., blue line) in trial 5 (F (1, 32) = 2.95, p < .096).

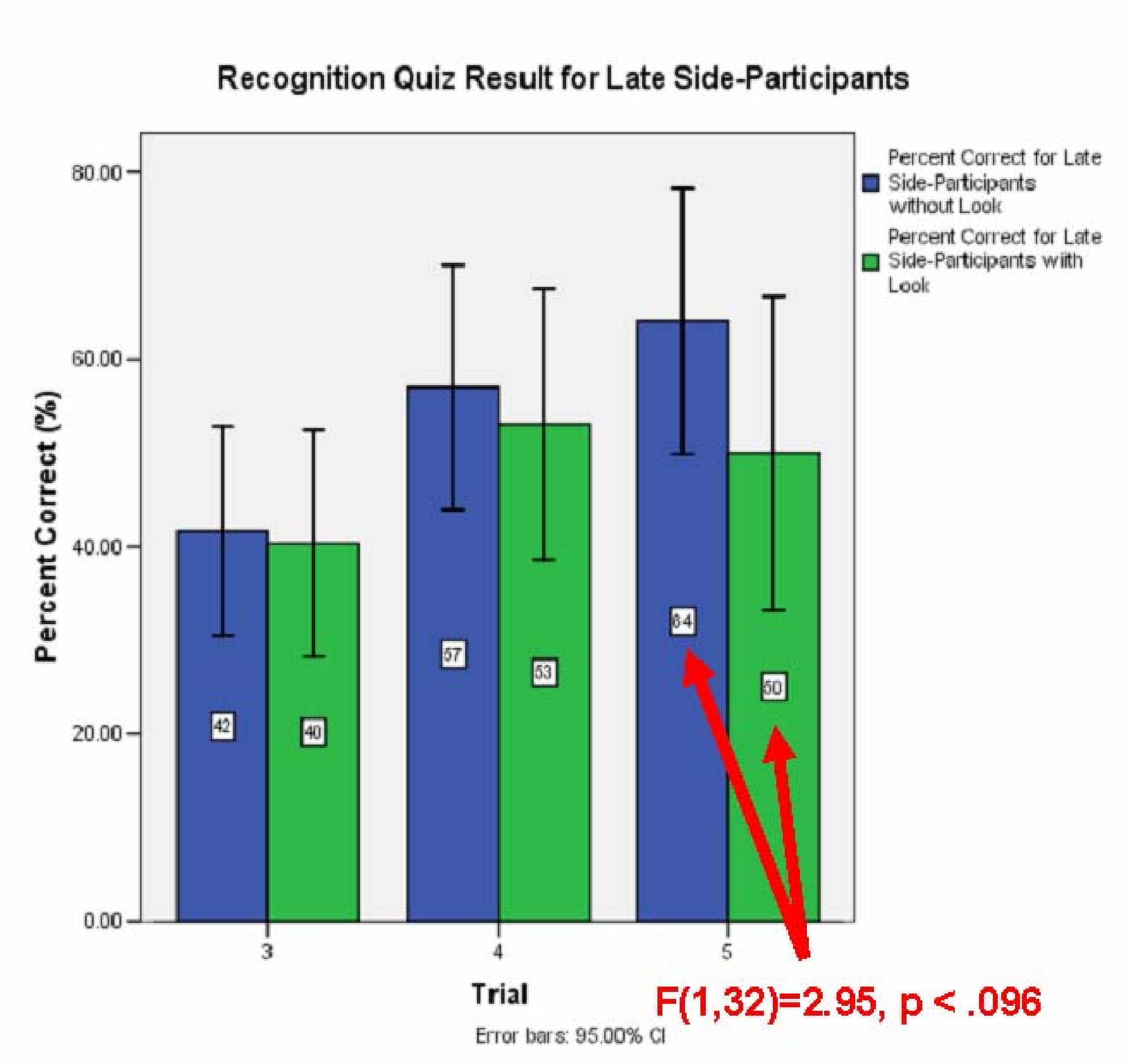


Figure 20. Percent correct of recognition of Korean characters by late side-participants with and without "Look" during each trial.

Table 12: Percent correct during naming and recognizing quiz by late side-participants. The numbers in each cell represent mean of percent correct and (*standard deviation*).

With Look / Without Look	**Trial 3**	**Trial 4**	**Trial 5**
Naming Quiz	33.3(*27.9*) / 28.5(*28.9*)	48.2(*31.5*) / 45.2(*30.8*)	63.0(*29.8*) / 57.4(*32.9*)
Recognizing Quiz	40.4(*25.0*) / 41.7(*23.1*)	53.1(*29.9*) / 57.0 (*27.1*)	50.0(*31.5*)† / 67.1(*26.7*)†

$^{\dagger}F(1,32)=2.95$, $p < .096$

In Experiment 3a, I also investigated whether the behaviors of the participants in the task would successfully assume different participatory roles (i.e., speaker, addressee and late side-participant). The criterion for the success of different participatory status is that two central participants (i.e., the director and the matcher) should be highly aware of each other and much less aware of, though still sensitive to, a peripheral participant (i.e., the late side-participant). On the other hand, the peripheral participant should be aware of the central participants and the discussion that they are having, to some extent. If this condition can be demonstrated, then we can go on to see if it is possible to affect the degree of common ground of the peripheral participant by making changes to the configuration of the shared visual context with the handheld network service "Look."

To obtain proof that it was possible to create the experiment task, which simulated different participatory roles, I examined ratings of interpersonal awareness by central and peripheral participants. Interpersonal awareness was measured by several post-experiment questionnaires, which used a 10-point rating scale. A rating close to 1-2 is viewed as a negative experience/judgment and 9-10 as a positive experience/judgment. The first several questions assess asymmetries in the communication roles taken in the experiment: "How well did you work with (the director/the matcher/the late side-participant)?", "How much did you interact with …?", and "How much did you cooperate with ….?" Later questions are relevant to the ability of the peripheral participant to perform the task: "How responsive was (the director/the matcher) toward you?", "How intrusive was the late side-participant to your main task?" (asked of the director and the matcher) and "How intrusive did you feel you were being to the matcher and director?" (asked of the late side-participant). The expectation was that two central participants would be highly aware of each other but much less aware of the peripheral participant. Consequently, the peripheral participant would feel that she was less known to the central participants.

Tables 13 ~ 15 show the mean rating scores for different discourse participants. The ratings of each other made by central participants (i.e., director and matcher) were high, whereas their ratings of the peripheral participant (i.e., late side-participant) were low. There are significant effects by the role in rating interpersonal awareness. Director and matcher felt that they worked well with each other as contrasted with the late side-participant in both "Look" and "no-Look" conditions (director as rater: $F(1, 74) = 9.68$, p

$< .003$; matcher as rater: $F(1, 74) = 19.06$, $p < .000$). Likewise, regarding interaction and cooperation, director and matcher rated each other higher as opposed to the late side-participant (director as rater: $F(1, 74)=28.4$, $p < .000$ for interaction, $F(1, 74)=8.83$, $p < .004$ for cooperation; matcher as rater: $F(1,74)=106.02$, $p < .000$ for interaction, $F(1,74)=26.83$, $p < .000$ for cooperation). The ratings of awareness of central participants made by the peripheral participant were low and quite comparable with the ratings of awareness of a peripheral participant made by the central participants.

These rating data show that the two central participants were far more aware of each other than of the peripheral participant. Therefore, it seemed that the experiment tasks succeeded in creating situations that satisfied the concept of central and peripheral participatory status.

Table 13: Mean interpersonal awareness rating (and standard deviation) for collaboration.

Rater	Rated	"How well work with"		Mean "How well work with"
		without "Look"	with "Look"	
Director	Matcher	8.7(1.0)	8.8(1.4)	8.79(1.21)*
	Latecomer	7.9(2.3)	7.0(2.4)	7.45(2.37)*
Matcher	Director	8.8(1.7)	9.0(1.2)	8.89(1.43)**
	Latecomer	6.7(2.7)	6.5(3.1)	6.61(2.90)**
Late Side-Participant	Director	8.4(1.9)	7.5(2.5)	7.92(2.22)
	Matcher	6.2(3.1)	7.4(2.5)	6.79(2.86)

* $F(1, 74) = 9.68$, $p < .003$, ** $F(1, 74) = 19.06$, $p < .000$

Table 14: Mean interpersonal awareness rating (and standard deviation) for interaction.

Rater	Rated	"How much interact with"		Mean "How much interact with"
		without "Look"	With "Look"	
Director	Matcher	8.3(1.5)	8.2(1.8)	8.24(1.65)*
	Latecomer	6.0(2.9)	4.8(2.8)	5.39(2.84)*
Matcher	Director	7.1(2.0)	8.1(1.6)	7.61(1.85)**
	Latecomer	3.1(1.8)	3.0(2.2)	3.03(2.02)**
Late Side-Participant	Director	5.0(2.5)	4.1(2.5)	4.55(2.53)
	Matcher	3.7(3.1)	3.9(2.6)	3.82(2.82)

* $F(1, 74)=28.4$, $p < .000$, ** $F(1,74)=106.02$, $p < .000$

Table 15: Mean interpersonal awareness rating (and standard deviation) for cooperation.

Rater	Rated	"How much cooperate with"		Mean "How much cooperate with"
		without "Look"	With "Look"	
Director	Matcher	9.2(1.2)	9.1(1.3)	9.13(1.23)*
	Latecomer	8.1(2.4)	7.4(2.9)	7.74(2.62)*
Matcher	Director	9.0(1.3)	8.9(1.2)	8.92(1.22)**
	Latecomer	6.8(2.8)	5.6(3.2)	6.18(3.02)**
Late Side-Participant	Director	7.6(2.6)	7.3(2.9)	7.45(2.72)
	Matcher	6.1(3.5)	6.7(3.2)	6.39(3.31)

* $F(1, 74)=8.83$, $p < .004$, ** $F(1,74)=26.83$, $p < .000$

Discussion

Overall, Experiment 3a was successful in demonstrating that the distinction between central- and peripheral-participation can be managed in the experiment. I also examined the main question, the effect of the shared visual context. However, the result of matching icons was not highly obvious in our task. This may be due to a ceiling effect in the task performance of participants. Because the conducted task itself was not complex enough, there might be no scope for the advantage of sharing visual context. Shared visual context would have produced greater benefits when tasks had been visually complex or when there had been no simple vocabulary for describing the task state (Kraut, Fussell et al. 2003; Fussell, Kraut et al. 2000; Kraut, Fussell et al. 2002; Monk and Gale 2002; Clark and Krych 2004). Otherwise, if tasks are simple enough or discourse participants have well-practiced vocabulary to describe the state of tasks, visual context will not provide any new information. Considering this fact, I redesigned the task of Experiment 3b to be sufficiently complicated so as to make a difference in the participant's performance: First, the number of icons to be arranged was increased from twelve to twenty-five. Second, the size of icons was smaller than the ones in Experiment 3a. Third, participants did four trials instead of five trials in Experiment 3b because each trial took much longer to solve than the trial in Experiment 3a. The following sections describe in detail newly-devised Experiment 3b based on the findings from Experiment 3a. It includes discussions of choice of participants, the experiment apparatus, and procedures. It concludes with a discussion of results.

Experiment 3b

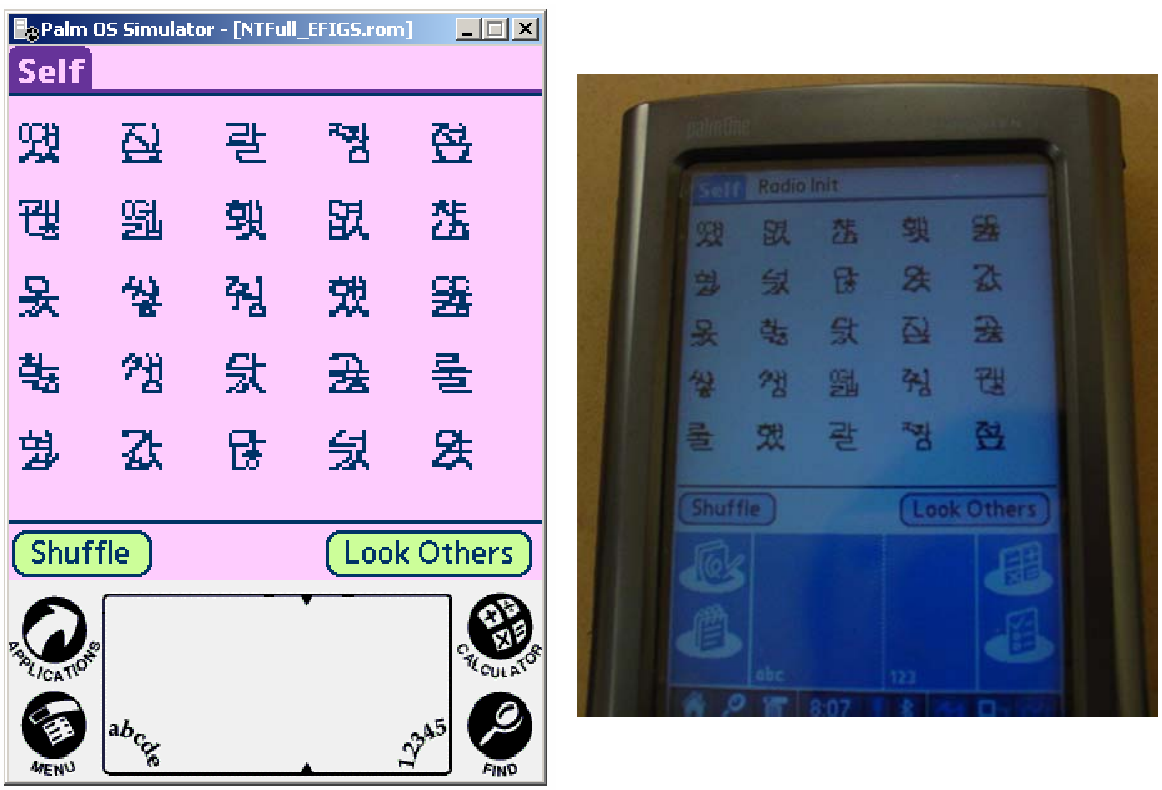
Participants

Through the Psychology department experiment management system, 96 students were recruited to participate in the experiment. 32 groups of three people were randomly assigned to one of two conditions, with "Look" and without "Look" condition, 16 per condition. Students were given extra credit for participating in the experiment. Participants' ethnic backgrounds were multi-cultural: African-American, Mexican-American, Asian-American, Chinese, Indian, Japanese-Brazilian, Jewish, Puerto Rican, and Caucasian (84.4%). None of them had prior knowledge of how to read Korean characters, were familiar with Korean culture, or had traveled to Korea. Participants' ages ranged from 18 to 22, with a mean age of 19 (SD: 1.1). Fifty-one percent of the group were female. All participants were undergraduates, with half of them freshmen (50%). Psychology majors provided the largest group (15.6%) but other majors also took part, including students from accounting, animal science, architecture, bio-chemistry, biology, building construction, business, chemistry, communication, computer science, electrical engineering, English, finance, history, human development, hospitality and tourism management, marketing, mathematics education, mechanical engineering, and political science.

Apparatus

The game implemented for Experiment 3b attempted to replicate the game used for experiment 2, the late overhearer experiment, while exploring the possibility that making the task more complicated might reveal the advantage of the shared visual context more clearly. The implementation differed from experiment 2 in two respects. One is that the number of Korean character Tangrams on handheld devices was increased from twelve to twenty-five. The second difference is that the figures of Korean characters were smaller and more complex to describe verbally than the figures in experiment 2.

As before, to investigate the effects of shared visual contexts on a late side-participant's understanding in a handheld-based activity, I embedded and tested the "Look" function as a component of the Tangram game. Figure 21 shows user interface of Korean Character Tangram game on Palm OS simulator and on the real device, Tungsten T5 handheld.



(a) Screen capture on Palm OS Simulator (b) KCT game on the real device

Figure 21. Korean Character Tangram (KCT) game.

Procedure

During a roughly two-hour period, participants were asked to play a game called Korean Character Tangram (KCT), in which one person was the "director," another person was the "matcher," and the other person was the "late side-participant." In this game, everybody would have a handheld device with twenty-five Korean characters on it. They were going to play four rounds of the game. At the beginning of every round, the director would hit the *Shuffle* button to put his characters in a specific order. The game asked the matcher and director to put the matcher's characters into the same order as the director's without one person ever looking at the other one's screen. The matcher used the stylus to drag and drop characters on her screen to rearrange them. The director could use words to describe the characters, but he also had their names and was encouraged to use the name of each character at least once in every round, maybe before he moved to the next character. The round ended when the director and matcher agreed that the characters were in the same order. At the end of each round, their answers were compared to each other.

The director and matcher would play four rounds of the game. During the first two rounds, the late side-participant was out of the room. Then, the late side-participant was brought back into the room. The late side-participant's job was the same as the matcher's: to put her own characters into the same order that the director had, but only half of late side-participants were allowed to use the *Look Others* button. By clicking the *Look Others* button, the late side-participant could capture a screenshot of the matcher's handheld. The late side-participant could use this screen capture in any way that helped herself. In the "no-Look" condition, the *Look Others* button option was not available to the late side-participant and she could not capture a screenshot of the matcher's handheld.

The job of the late side-participant was to "catch on without being too much of a burden." Participants could talk with one another, but the director's and matcher's main job was to work with each other. Their job was not to tutor the late side-participant. The late side-participant would do two rounds altogether.

The results of each condition were analyzed to explore the effects of sharing visual context for collaborative activity and to compare the impact of "Look" on late side-participants' abilities to create a common ground. The sessions were timed and videotaped. Furthermore, I collected quantitative evidence about correct placement of the right figure.

Measures

I collected two sets of dependent measures: task outcome and communication efficiency.

Task outcome. Task performance was measured by the accuracy of execution and completion time. According to the hypotheses, late side-participants whose handhelds were equipped with the "Look" functionality should better understand the conversation and thus should be more able to rearrange the figures correctly and quickly.

Communication efficiency. To examine how "Look" changed coordination strategies, the experimenter reviewed all of the video recordings and noted all events of turn-taking and overlapping in the conversation. According to the hypotheses, sharing visual context by "Look" would contribute to decreasing efforts and problems in the coordination of group members' interactions. Without strong evidence of the shared visual context, participants should make more effort to reach a mutual agreement, especially more turn-taking and overlapping of utterances.

Results

First, I examine the effect of the handheld network service "Look" on the task outcome, and then I examine the relation between the shared visual context and communication efficiency. Finally, I present an analysis of dialogue content, which provides insight into the discourse characteristics in real time.

Task outcome

Task outcome was evaluated by comparing the order of Korean character figures arranged by the late side-participant with the target order described by the director. The number of matching figures between the late side-participant and the director was counted. These scores were then compared across two conditions, with "Look" and without "Look" conditions. Performance did differ significantly across the conditions (see Figure 23). During trial 3, in which the late side-participant entered the discourse the first time, experiment results indicated an average of over 88 percent correct (Standard Deviation (SD): 9.96) among those late side-participants who used "Look," compared to an average of about 73 percent correct (SD: 26.94) for late side-participants without the "Look" functionality: $F(1, 30) = 4.66$, $p < .039$. Note that the standard deviation was also smaller for the groups with "Look" than for those without "Look."

As the late side-participants repeated tasks through trials, the average accuracy per trial increased in both groups: with "Look" and without "Look" (see Figure 22). In trial 4, the statistically marginal difference remained between groups with "Look" (95% (SD: 7.83)) and without "Look" (86% (19.31)): $F(1, 30) = 3.15$, $p < .086$. The decrease of difference in trail 4 is possibly due to the effect of the accumulated common ground by repeated trial.

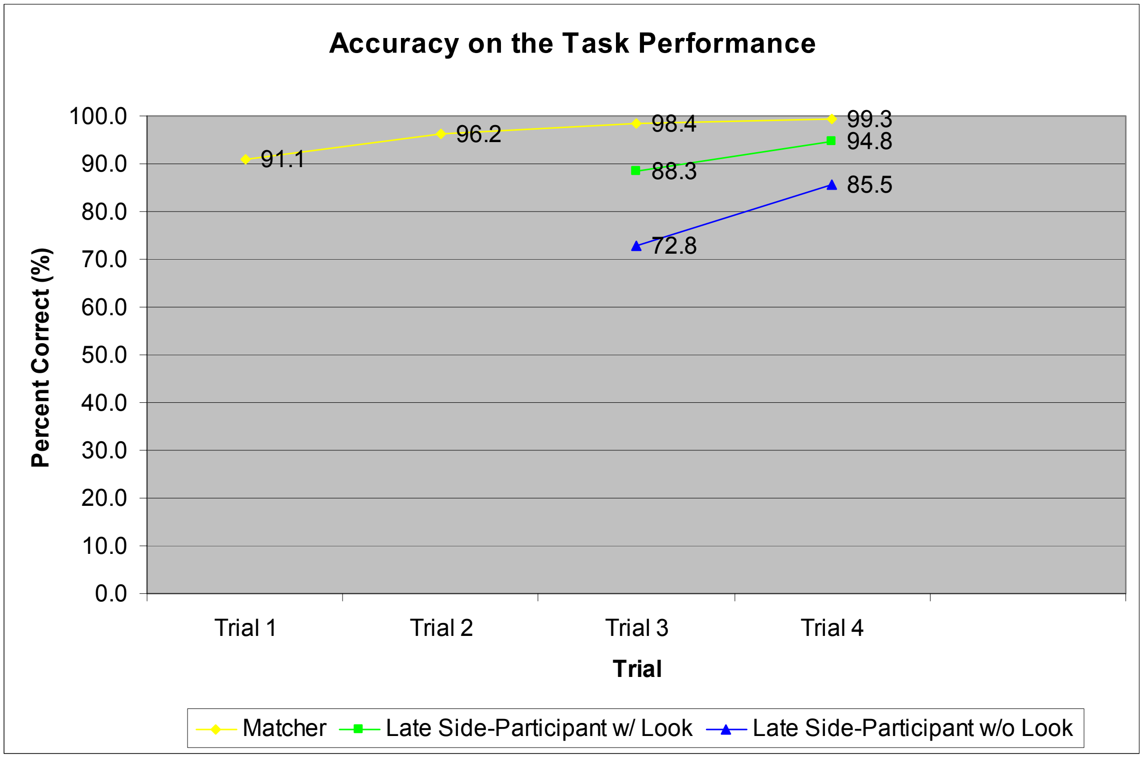


Figure 22. Percentage correct of matching Korean character Tangrams on each trial by the matcher, late side-participants with "Look" and without "Look." Late side-participants in the group that had access to "Look" (i.e., green line) were significantly more correct than those without "Look" (i.e., blue line) in trial 3 ($F(1, 30) = 4.66$, $p < .039$) and marginally more correct in trial 4 ($F(1, 30) = 3.15$, $p < .086$).

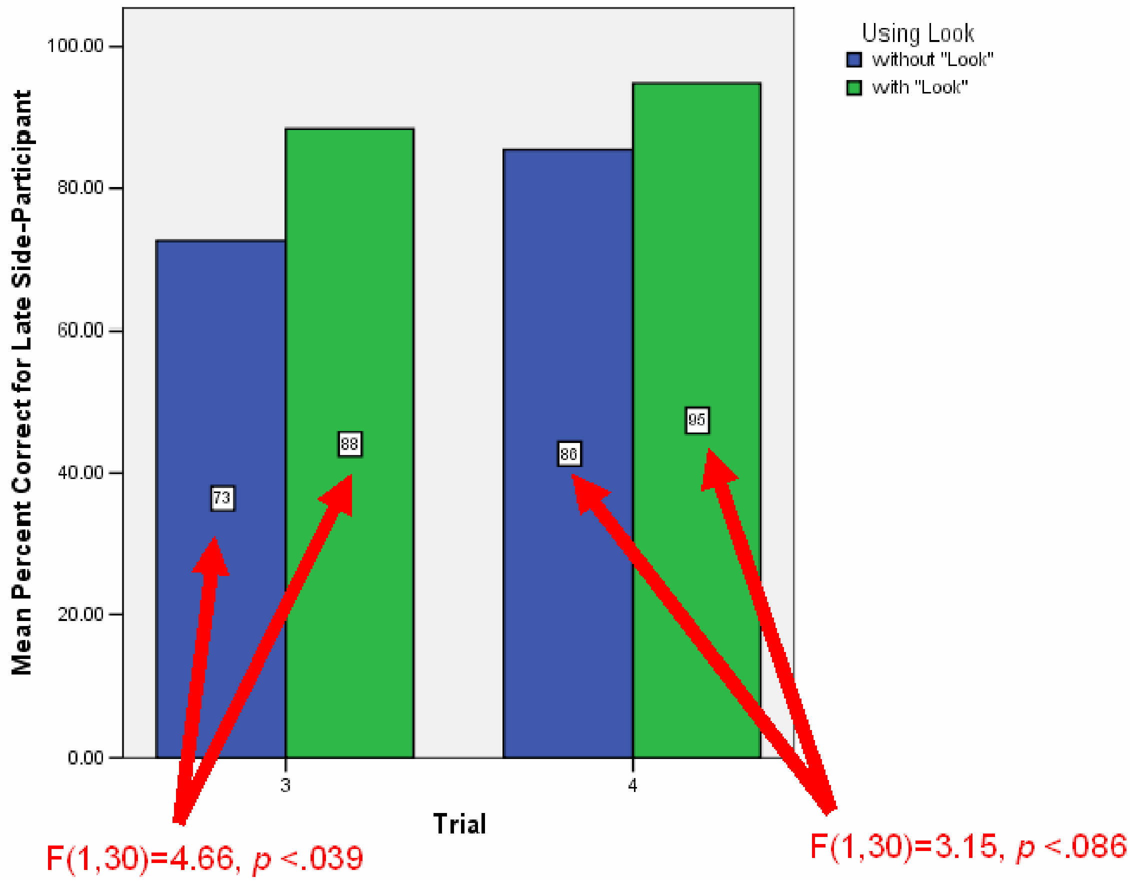


Figure 23. Mean percent correct placement of figures of Korean characters by late side-participants with and without “Look.”

According to Clark's conversation grounding theory, participants accumulate their common ground by repeating trials and can complete the task quickly as they do more trials. This was what occurred in this experiment. As Figure 24 shows, the average time per trial dropped dramatically from 27m 57s (trial 1) to 8m 47s (trial 4). In the first two trials without the late side-participant, there were no reliable differences among groups under "Look" and "no-Look" conditions: The average times the director and matcher spent on trial 1 and 2 were 29m 18s ("Look" group), 26m 36s ("no-Look" group) in trial 1 and 14m 9s ("Look" group), 14m 57s ("no-Look" group) in trial 2, respectively. These times are not significantly different ($F(1,30) = .529$, $p > .48$ in trial 1, and $F(1,30) = .269$, $p > .60$ in trial 2). So, two sets of directors and matchers for different "Look" conditions were equal in efficiency up to the point at which the late side-participant entered in trial 3.

On the contrary, the efficiency in the late side-participant's trials should vary with the shared visual context by "Look," and it did. In trials 3 and 4, the average time for the "Look" condition and the one for the "no-Look" condition were significantly different (see Figure 25). The task completion time in trial 3 was faster when the late side-participant was equipped with "Look" (10m 52s) than when he was not (18m 43s) ($F(1,30) = 8.73$, $p < .006$). The pattern is the same in trial 4. The average time with the "Look" condition (6m 53s) was faster than the one without the "Look" condition (10m 42s) ($F(1,30) = 20.34$, $p < .000$).

More interesting findings turn up when we look at the difference in the average time between the final trial of a two-person conversation and the first trial of a three-person conversation, which is the defining difference between trials 2 and 3. Generally, when more than two persons are involved in a conversation, we expect that achieving common ground may become more difficult. This was the case for the "no-Look" situation (from trial 2 to trial 3, the average completion time was increased by 3m 45s). However, with "Look," because visible evidence of understanding was available to the late side-participant, the task completion time did not increase from trial 2 to trial 3 (actually, the time was decreased by 3m 18s). This is due to when the visual context was available, checking process time for the correctness of discourse participants' mutual understanding was shorter.

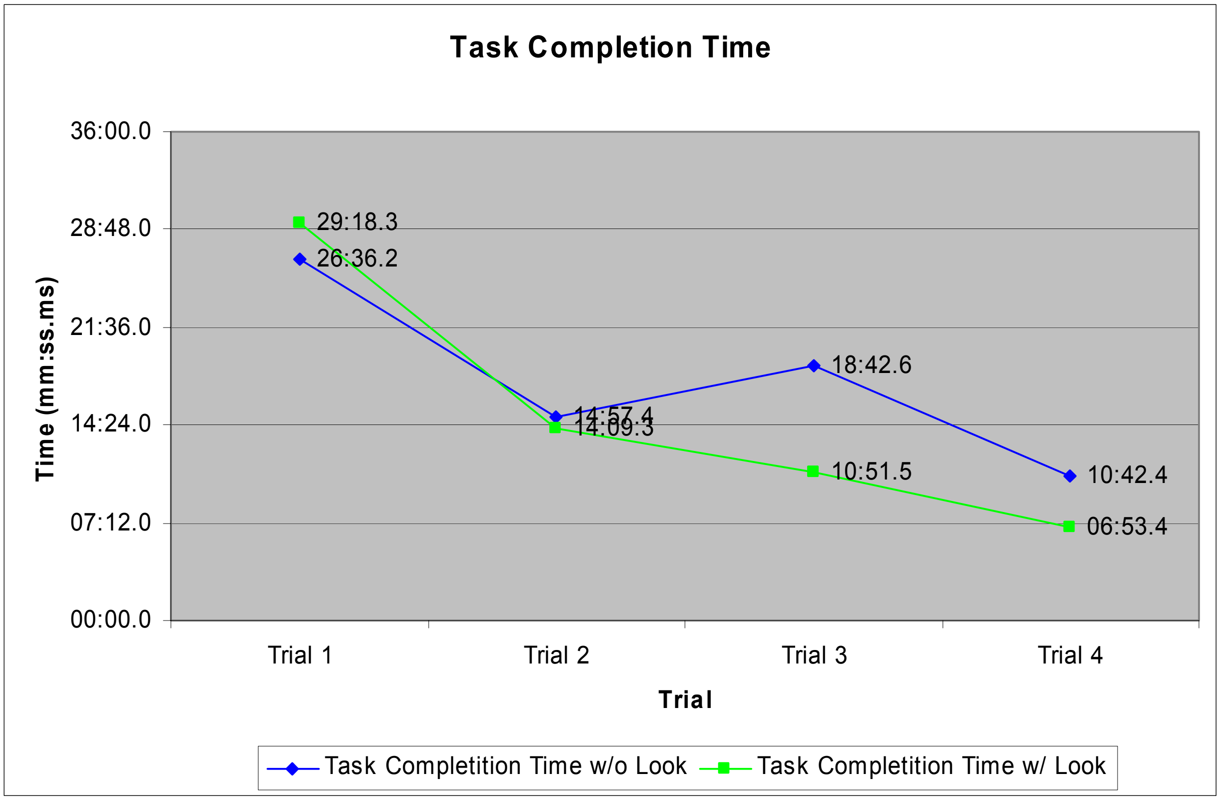


Figure 24. Task completion time in each trial under "Look" and "no-Look" conditions.

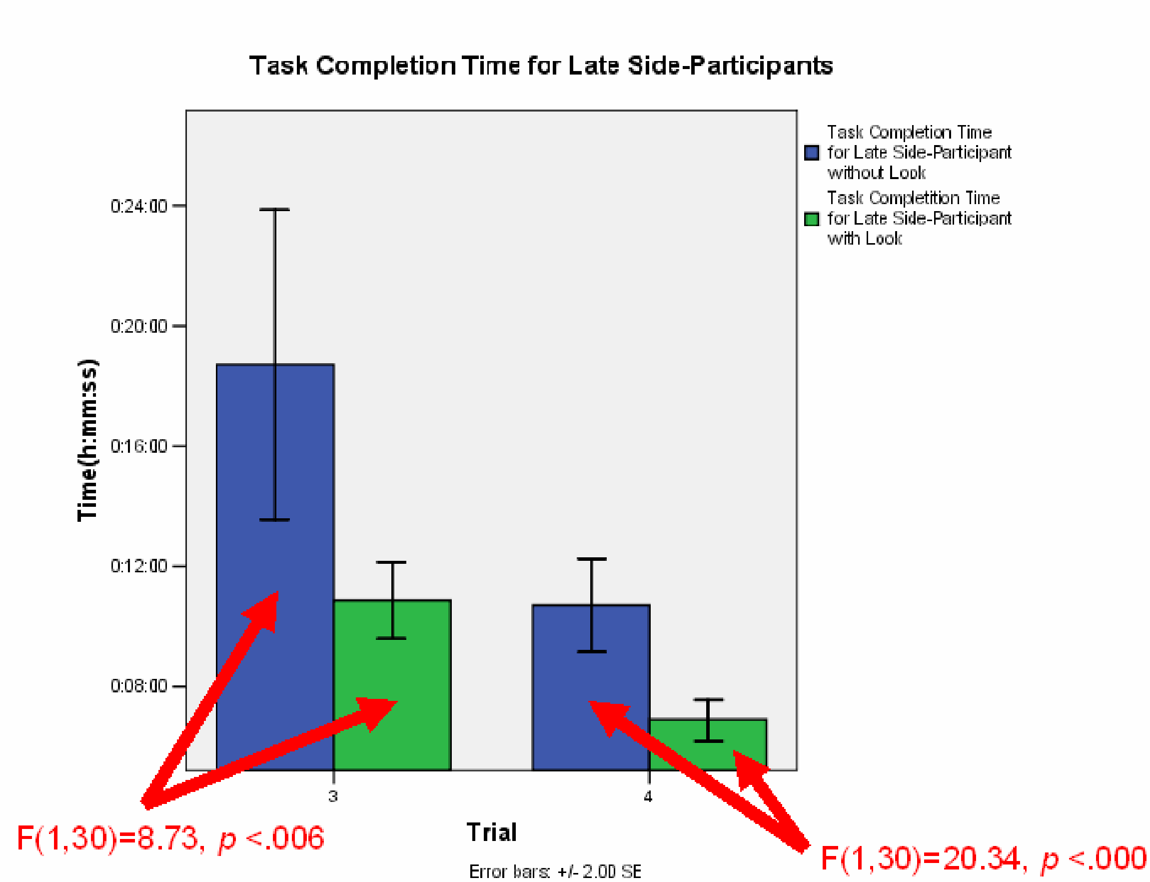


Figure 25. Average task completion time for late side-participants under "Look" and "no-Look" conditions.

Table 16 summarizes task outcome, the mean of percent correct in matching Korean character Tangrams, and the task completion time. As seen in the table, overall, late side-participants could perform tasks substantially better with the handheld network service "Look" than without it.

Table 16: Means and standard deviations for percent correct and the time to complete the tasks by late side-participants with and without "Look."

	Trial 3		Trial 4	
	Mean	Standard deviation	Mean	Standard deviation
Percent correct				
With Look	88.25*	9.96	94.75**	7.83
Without Look	72.75*	26.94	85.50**	19.31
Time to complete (mm:ss)				
With Look	10:52†	2:33	6:53‡	1:23
Without Look	18:43†	10:19	10:42‡	3:05

* $p < .039$, ** $p < .086$, † $p < .006$, ‡ $p < .000$

Communication efficiency

During the experiment, all sections were recorded on digital video- and audiotapes. In the video analysis, we focused on two factors: the mean number of turn-takings and the mean number of overlappings in the conversation. A turn was defined as a stretch of talk contributed by a single speaker and an overlapping was defined as the situation when two persons spoke at a time.

Previous literature shows that the effort of achieving common ground is indicated by more turns of talk (Anderson 2006; Clark and Krych 2004). The act of grounding between participants in a conversation requires that *A* presents an action and/or a signal for *B* to understand, and *B* in turn eventually validates that action and/or that signal as having been recognized or understood. When these two phases are accomplished properly, they constitute the shared basis for the mutual belief that *B* understands what *A* means by signal *s* (Clark 1996).

Displaying understanding gives partners the opportunity for such validation or correction. Using the "Look" network service, participants make displays and exemplifications of understanding practicable for the purpose of validation. Although speakers tend to avoid verbal overlap in primary talk, utterances with visual presentation of understanding are usual enough in everyday settings (Sacks, Schegloff et al. 1974). Therefore, "Look" can be used to allow that the late side-participant's presentations overlap the central participants' verbal descriptions, and thus they continue the conversation without separate turns: When the workspace is made visible by "Look," the late side-participant will be able to continuously reformulate his/her tryouts without forming turn-taking. However, without "Look," the workspace is not visible, so the late side-participant will seek validation from central participants, which requires both parties to take more turns.

This difference was reflected in the mean number of turns by the late side-participant, as shown in Figure 26. In trial 3, the late side-participant without "Look" took over five times as many turns as the late side-participant with "Look" (67 turns vs. 13 turns, $F(1, 30) = 13.66$, $p < .001$). A similar pattern of result was shown in trial 4. Without "Look," there was an average of 37 turns but with "Look," an average of 10 turns occurred ($F(1,30)=12.35$, $p < .001$).

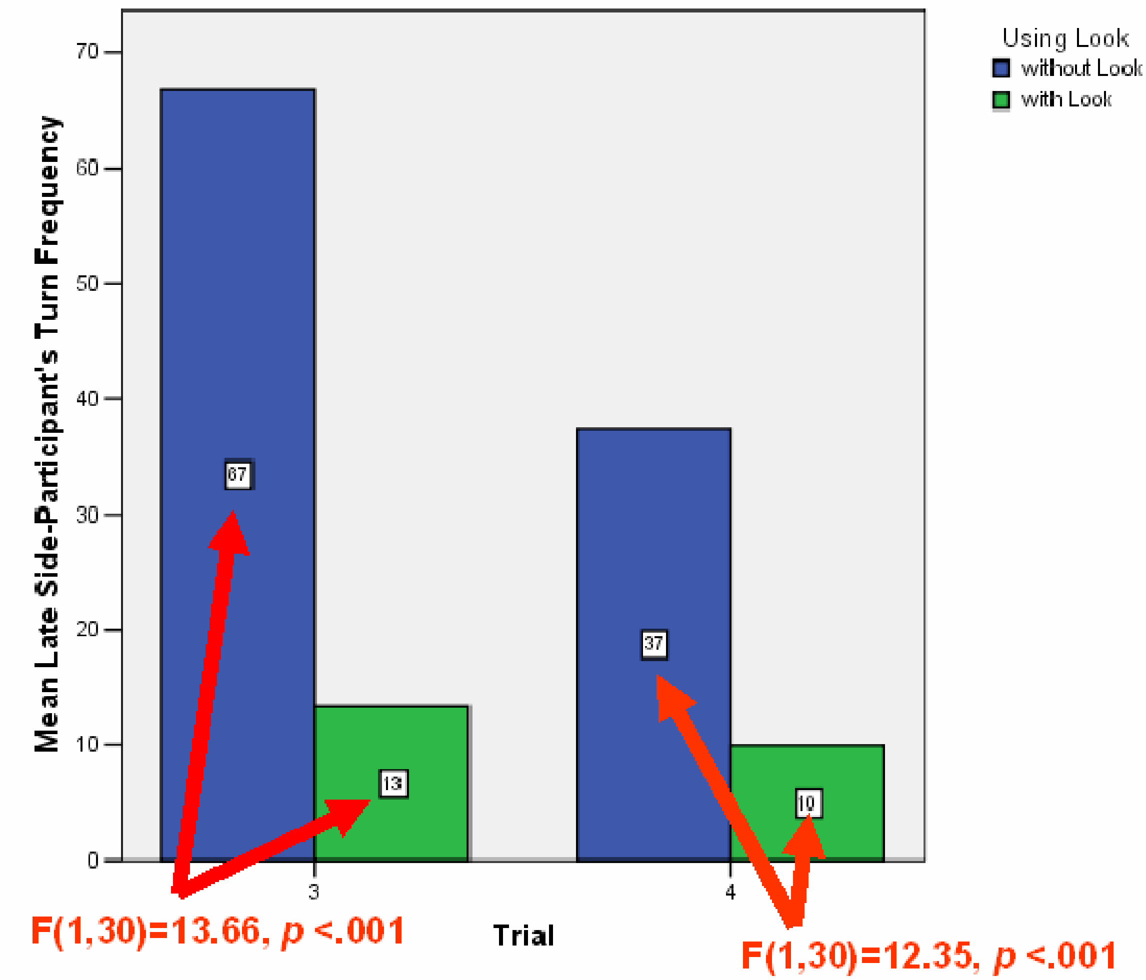


Figure 26. Mean number of turn-takings by late side-participants under “Look” and “no-Look” conditions.

The second test used for communication efficiency involved the overlapping of utterances, which is simultaneous speech by participants. Previous findings for audio-only and video-mediated conversation show more interruptions when visual cues are reduced (Argyle et al. 1968). Simultaneous speech may be taken to indicate a problem in floor control of a conversation (Sellen 1992). Participants may miss the timing for floor control, or may bid for the floor and fail. Studies which label simultaneous speech as "interruptions" make this tacit assumption. Overlapping speech should be tolerated only if both participants can be attended to well enough for current purposes (Clark 1996).

The mean number of overlappings by late side-participants under two different "Look" conditions is shown in Figure 27. As predicted, the occurrence of overlapping by the late side-participant in the "no-Look" condition was larger than the occurrence in the group which had access to "Look." In trial 3, an analysis of variance yields a significant difference: 16.4 occurrences vs. 2.4 occurrences, $F(1, 30) = 22.47$, $p < .000$. In trial 4, the graph shows also a significant difference, 12.8 vs. 2.2, $F(1, 30) = 13.45$, $p < .001$.

Taken together with the measure of the task outcome, these results indicate the certain effect of sharing visual context for collaborative activity and show the impact of "Look" on late side-participants' abilities to create a common ground more easily and efficiently.

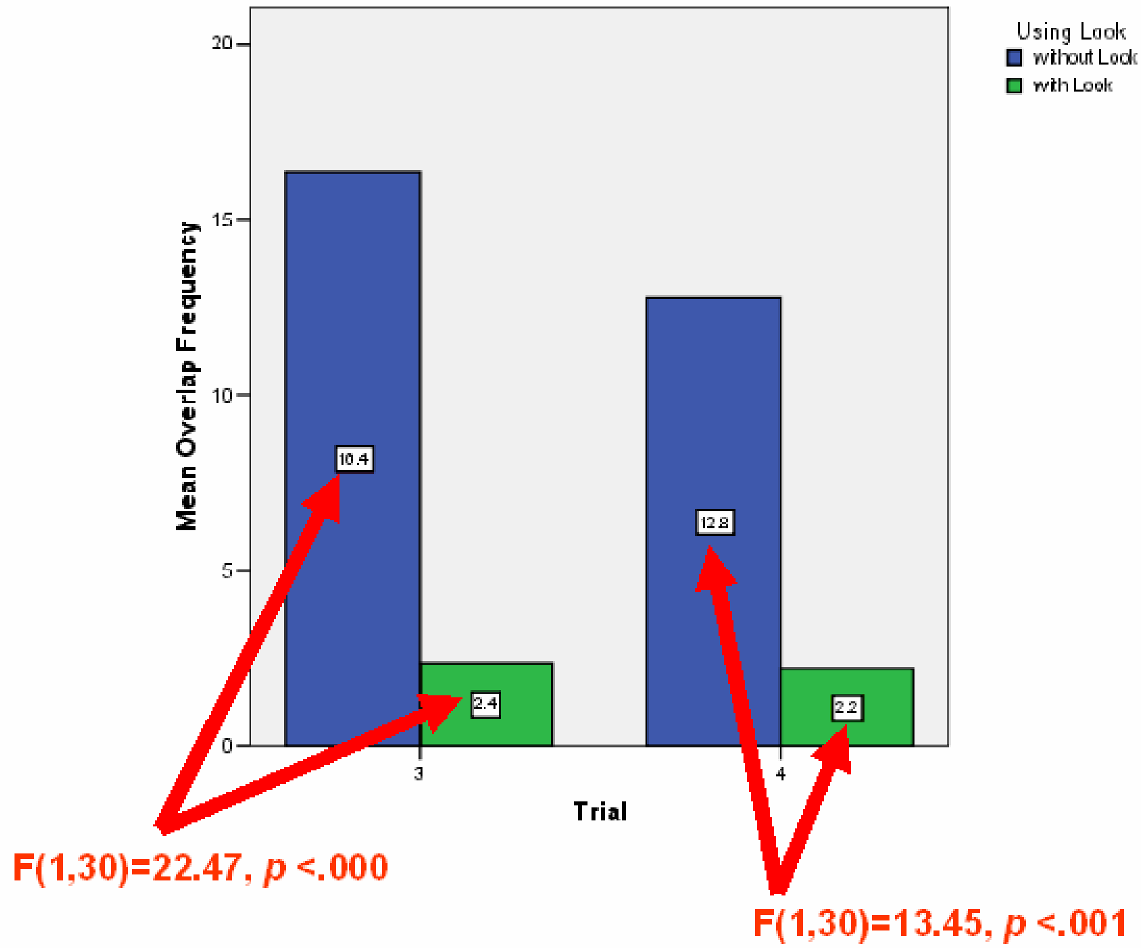


Figure 27. Mean number of overlappings by late side-participants under “Look” and “no-Look” conditions.

Analysis of Dialogue Content

One independent coder transcribed “Look” and “no-Look” groups’ communication behaviors. These transcripts were verified against the video recordings and corrected where necessary by the experimenter. The key comparison I tried to explore here was whether the process of establishing common ground was much easier for late side-participants with the “Look” network service than for ones without “Look.” I investigated whether this aspect of sharing visual contexts led to fewer turn-takings and overlappings in conversation and therefore, whether it took less time to complete the given task. Two representative excerpts from the dialogues are examined here for identifying the effects of the shared visual context.

Extract 1: Example of how the participants establish common ground without “Look”

One way to reach common ground is by displaying an understanding of what is taking place so that others can accept or correct it. With “Look,” joint construal can be achieved more efficiently and certainly with visual displays of understanding. In social interactions, participants must be consistent with regard to what is occurring to give partners the opportunity to validate and correct them. In my experiment, I set up this situation by making three participants work together but in different social roles. Through a sharing of screen captures, “Look” makes displays of understanding feasible for the purpose of validation. However, without “Look,” participants need make more effort to reach a mutual agreement and it takes a longer discussion to complete the task. These properties can be seen in the interactions captured by the excerpt introduced in Table 17.

Table 17: Transcript of an episode without "Look."

(With pairs of asterisks, overlapping speech is marked. Gesture acts are enclosed in parentheses.)

1. Director (D): The third one is the OCH one. It's got two V's.
2. D: The fourth one is a really hard one. It's got a V. It's got two lines over it. It's got the curve over it. (hand gesture)
3. Matcher (M): (looking at the director).
4. D: I don't know *what we called it.*
5. M: *Oh yeah, okay.*

6. D: It got underneath it, it's got a line. (hand gesture)
7. M: Okay
8. Late Side-Participant (SP): Okay so there's like two lines that are connected on the left side by like *but…*
9. M: *It's a triangle.*
10. D: Yeah, but they split out (gesture with looking at the late side-participant).
11. SP: Yeah… and then there's like that little like…(hand gesture)
12. D: *Curvy thing on top. (hand gesture)*
13. SP: *Curvy thing on top.* Okay.

14. D: Okay, the next one is, is, it's got a V and a line coming up and it's got two parallel to that, but it's got a circle on the left hand side.
15. M: In the top left hand corner?
16. D: Yeah. (whispering)

17. SP It's like a…(hand gesture)
18. D: It is, looks like a broom kind of with two things going through it (hand gesture).
19. SP: On the right?
20. D: *Yeah.*
21. SP: *And* then there's *like a… (gesture and watching a director)*
22. D: Circle with *a line through it.* (gesture and watching the side-participant)
23. SP: *Another settling vest kind of thing on the side and another circle.*
24. D: Okay, it has a V and a line with two things going through it and it's got the circle and it's got like this (hand gesture with looking at the late side-participant).
25. SP: Yeah
26. D: Yeah, okay

27. D: The fourth row is, it's got a semicircle at the bottom right with a line coming up from it and some weird, you can't really tell what it is.
28. SP: A semi-?
29. D: A semi-circle.

30. SP: Is there like a flat line on the very top (gesture)? Like a horizontal line on the *very top?*
31. M: *Hmm, hmm.*
32. D: It's got a *semi circle… (gesture)*
33. SP: *Oh, on the bottom* it kind of looks *like a bowl. (gesture)*
34. D: *Yeah, it goes like….*
35. SP: (Laughing) Never mind… (flustering)
36. D: *Um, it kind of looks like…(whispering)*
37. SP: *I don't know what I'm asking…*
38. D: The next one is the C7 but it looks connected. (watching the late side-participant)

39. SP: And that's the second one *on the…?*
40. D: *Yeap, that's the second one*
41. D: The next one is the zigzag, but it's the thin one.
42. D: The next one is the curvy 7 looking one. (watching the matcher)
43. M: Like the 7 at the top *and…?*
44. D: *The 7 at the top and* it's got the line down to a V. (hand gesture)
45. M: Yeah okay.
46. SP: The what…?(whispering)

47. D: The last one is, um, on that row is a V with a line over it and a circle at the top. It's the center circle, it's the only *one with the center circle.* (gesture with watching the late side-participant)
48. SP: *The one that looks like a person one!*
49. D: *Yeah…*
50. D: Fifth row is the CC one. (watching the late side-participant to check)
51. D: It's got two C's. The second one over, it's got, um it's the big box little box with the line coming up. (watching the matcher)
52. M: Oh, okay. (watching the director)
53. SP: A big box and little box at the top? (hand gesture)
54. D: Yeah. The third one over is the one with the plus signs.

55. D: The fourth one over is the one with the semi-circle that's pointing upwards. The big semi-circle. Looks like a bathtub kind of.
56. SP: That's the one I was trying to talk about the cereal bowl? (laughing)
57. D: *Oh* (watching the side-participant)
58. M: *Oh*
59. SP: (Laughing) Okay

60. D: And the last one's the PH.

This interaction shows an example of how the late side-participant tried to resolve her confusion with the director and the matcher, which originated from the fact that they had slightly different views of the same object. As indicated in turns 33 and 56, the late side-participant had her own slightly different interpretation of the shape of the character  than either the director or the matcher had. This confusion began in the conversation that occurred between turns 27 and 37. If she had used the evidence of shared visual clues, her confusion could have been resolved much earlier than turn 56. Turns between 27 and 37, and turns between 55 and 59, show those extra interactive cycles of conversational turn-taking between the late side-participant and the central participants. If "Look" had been available to the late side-participant, the convergence of meaning would have been achieved quickly without those extra turn-takings.

Between turns 17 and 26, we found another example of how, without sharing visual contexts, more turn-takings and overlappings of utterances occurred to create common ground among participants. The late side-participant checked on her understanding several times before the director moved on: Turns 21, 23 and 25 showed that the late side-participant was abruptly interrupting the director to clarify her confusion. Because concrete visual evidence was not available to the late side-participant, she had difficulty in creating common ground with the director and needed more turns to understand the director's explanation.

In the following episode, I demonstrate how the shared visual context with "Look" can decrease turn-takings for acknowledgement and abrupt interruptions by the late side-participant.

Extract 2: Example of how the participants establish common ground with "Look"

According to Clark and Schaefer's contribution model (1989), a contribution to a conversation is achieved jointly by a presentation phase and an acceptance phase. In that case, how do discourse participants know when to stop seeking and providing evidences and conclude that they understand each other well enough? People apparently employ available techniques that use the least collaborative effort for the current purpose. The principle of least effort assumes speakers are supposed to create proper utterances which they believe will be readily and fully understood by their addressees (Grice 1975). Moreover, the acceptance phase would differ depending on the modality of the evidence available for grounding (Clark and Brennan 1991). In this respect, providing the extra modality of visual evidence should have its impact in a contribution.

Clark and Schaefer (1989) mentioned that contributions come in many sizes. Some are initiated by single words or phrases, others by clauses, full sentences, or whole turns. By the principle of least collaborative effort, participants dynamically change the size and make-up of their contributions for the current purpose. If it is anticipated by central participants that a late side-participant will understand the discussion easily with the shared visual context thanks to help from "Look," the central participants can make their presentations minimally. Likewise, the acceptance process by the late side-participant will be minimal also. These minimal presentation and acceptance patterns for contributions to the conversation can be found in the interactions captured by the extract introduced in Table 18.

Table 18: Transcript of an episode with "Look."

(With pairs of asterisks, overlapping speech is marked. Gesture acts are enclosed in parentheses.)

1. Director (D): Alright, the first one is, umm, TTAES.
2. Matcher (M): TTAES?
3. D:Yeah, it's the OC, the one over two.
4. Late Side-Participant (SP): (Nodding)
5. D: (Watching the matcher and the late side-participant)
6. M: Mmm, with the Z?
7. D: No, it's like an OCH with the two V's below it.
8. M: Oh, yeah, yeah.
9. D: (Watching the late side-participant)
10. M: *Oh. Wait.*
11. SP: *It's on your third row* in the middle between the fourth and the fifth column.
12. SP: (Glancing the matcher)
13. SP: Do you see it?
14. SP: (Glancing the matcher)
15. M: Oh, OCH?
16. SP: *Yeah*
17. D: *Mmm*
18. SP: (Glancing the matcher)
19. M: Okay, I got it.

:

20. D: Okay in the fourth column is JIP, which is the narrower bowl, the smaller bowl.
21. SP: Got it.
22. D: Okay and the fifth column, the third row is GOLH, which is like the D that goes over the little line.
23. SP: Got it.
24. D: Fourth row, first column is the anchor which is…
25. M: SSAH.
26. D: SSAH. Yeah
27. SP: Got it.
28. D: Second column is SSAENG, it's the one with the wavy H.
29. SP: Got it.

:

30. D: In the, uh, second column you've got HAESS, battery with the two V's as opposed to just one.
31. D: The third column is RAL. The thinner 2 divided by the thinner 2 with the line and the little thing popping out on the right.
32. SP: (Nodding)

33. D: Umm…
34. SP: Wait, wait,
35. D: Yeah?
36. SP: What was, umm, what was the third two? Did you say this was the fourth one?
37. D: We're going on the fourth one. I, we, just did the third one.
38. SP: And the third one is… which one again?
39. D: *RAL.*
40. SP: *Which is…*
41. D: Do you have it? (with looking at the Matcher)
42. M: RAL?
43. D: Yeah.
44. SP: *Wait,* there's the thin 2's on the third one.
45. M: *Here's the 2's. It's the thin 2's…*
46. D: *Yeah, it's the thin 2's.*
47. M: And the perpendicular lines.
48. D: Yes, the perpendicular lines. If he (matcher)'s got it then it's right.
49. M: (Nodding with smiling at the director)
50. SP: Okay.
51. D: Okay, cool.
52. D: Fourth one is, uh, JJANG. In the bottom right it's like the thicker block.
53. D: There's nothing in the bottom left.
54. D: And fifth column finally is, uh, JEOP. It's the thicker bowl.
55. M: Okay.
56. SP: JIP and JEOP. That's good.
57. D: Alright.

Overall, compared to the "no-Look" condition, the acceptance utterances by the late side-participant were succinct, as in turns 21, 23, 27 and 29. On turns 4, 32 and 49, acceptance phase was even achieved without the addressee saying a word. This was possible because, with the shared visual workspace, the director inferred that the matcher and the late side-participant could see each other by using the "Look" network service.

With "Look," overlapping of utterances also significantly decreased because the late side-participant could understand more easily the conversation between central participants; as a result, she did not need to make many interruptions. However, the late side-participant actively participated in the discussion when she thought that she could contribute to the central participants; for example, between turn 1 and turn 19, the late side-participant helped the matcher find out the right character by using deictic expression (i.e., turn 11). This was possible because by using "Look," the late side-participant and the matcher could establish together that the thing indexed was in their joint attention.

Providing "Look" to the participants not only changed the behaviors of the late side-participant (i.e., addressee) but also changed the attitude of the director (i.e., speaker). As you see in turns 31 to 51, the director asked the late side-participant to fix her confusion by "Look"-ing the matcher's workspace (i.e., turn 48). This specific episode demonstrates the true of the least collaborative effort theory. The speaker did not expend any more effort than he needed to get his addressee to understand him with as little effort as possible: With the "Look" network service, the directors suggested that the late side-participant used visual evidence, which required less effort and was more efficient, instead of providing longer but less accurate verbal descriptions of the objects (i.e., linguistic evidence).

Discussion

The experiment reported here investigated a proposed solution to the problem of latecomers' understanding for ongoing collaborative activity while protecting the privacy and control of individuals over small-scale devices. "Look" is intended to enable a late side-participant to see what is happening in an activity without interrupting that activity. My question was whether "Look" was sufficient to allow effective comprehension of the situation and efficient communication based on that comprehension. To evaluate the success of "Look" functionality, two specific hypotheses were tested in this experiment:

H5: "Look" functionality, compared to its absence, will help late side-participants gain common ground, as evidenced by accurate placement of the icons and the use of less time to complete the task. Overall, as predicted, late side-participants whose handhelds were equipped with "Look" functionality were more able to rearrange the icons correctly and quickly than did those who were not supported with it. In the two trials, late side-participants in the group that had access to "Look" completed tasks significantly faster than did those who were not supported with it ($F(1,30) = 8.73$, $p < .006$ in trial 3; $F(1,30) = 20.34$, $p < .000$ in trial 4). Also, late side-participants with "Look" were significantly more correct than those without "Look" in trial 3 ($F\ (1, 30) = 4.66$, $p < .039$) and marginally more correct in trial 4 ($F\ (1, 30) = 3.15$, $p < .086$).

H6: "Look" functionality, compared to its absence, will help late side-participants communicate efficiently, as evidenced by fewer turn-takings and overlappings in conversation. As predicted, late side-participants whose handhelds were equipped with "Look" functionality communicated with central participants with fewer turn-takings and overlappings of utterances than did those who were not supported with it. The late side-participant without "Look" took over five times more turns than the late side-participant with "Look" in trial 3 ($F(1, 30) = 13.66$, $p < .001$) and over three times more turns in trial 4 ($F(1,30)=12.35$, $p < .001$). A similar pattern of results was shown in the overlapping of utterances. Without "Look," there was over seven times more overlaps than that of the late side-participant with "Look" in trial 3 ($F\ (1, 30) = 22.47$, $p < .000$) and over five times more in trial 4 ($F\ (1, 30) = 13.45$, $p < .001$).

Four factors differentiate this study from other related work on shared visual spaces and overhearers. First, I manipulated at least two layers of difficulty in creating common ground of a participant (i.e., to become a latecomer and a side-participant). This setting emphasizes the peripheral participant's role in the classroom (e.g., teacher or peer commentator), and the creation of common ground is sufficiently complex to have produced a wide range of errors during the task. Second, for technical reasons, "Look" involves a kind of sharing that is punctuated rather than smooth. The most obvious shared visual space can be continuous real-time video monitoring. However, the handheld's limited computational performance and its restricted flexibility, such as configuring a setting for cameras, make the continuous video-monitoring in handheld-mediated communication unpractical. This study investigated whether implementing a *minimal* shared visual workspace for peripheral participants using wirelessly connected handheld was worthwhile. Third, a subtle social role of the side-participant in an interaction was successfully managed in this study. When participants are allowed to speak to each other, the exact status of side-participants is hard to manage; people are polite to and cannot ignore each other. In previous work on overhearers, the absolute separation between an overhearer and discourse participants was enforced by physical separation between rooms. Indeed, sometimes the overhearer was a witness only to a videotaped interaction (c.f. Schober and Clark 1989). In my case, controlled interaction was made inevitable by the constraints of the device. Last, I was interested not only in how the interaction proceeded, but also in the consequences for learning as an outcome of engagement in the interaction. To this end, I chose a task that presented a considerable visual learning challenge: global naming and recognition of foreign characters.

One limitation of this work was that the learning task was confined to one factual task rather than a richer array of tasks including more complex, inquiry-based learning. Another limitation is that the side-participant was not motivated by the rich set of priorities and considerations that motivate a real "student" or "teacher" to intervene or not. The movement from an overhearer role to that of a side or even full participant was not fully situated in the present work.

Although these demonstrations are limited, I feel that there is enough evidence to go through the effort to incorporate the "Look" functionality in a more contextualized learning environment.

Chapter 8: General Discussion

Three factors were considered in this study to investigate the effects of sharing visual context on peripheral participation in handheld-based collaboration; (1) different kinds of peripheral participation, (2) timing of joining the conversation and (3) different implementation of the shared visual space. Each experiment targeted a different constellation of affordances: The first experiment focused on early side-assistants and implemented visual sharing in an overt way. The second experiment focused on late overhearers and implemented visual sharing in a convert way. Lastly, the third experiment focused on late side-participants and implemented visual sharing in a covert way. Each of three experiments highlighted advantages to the peripheral participants conveyed by "Look."

The comparative study of with "Look" situation and without "Look" situation worked well to answer whether the "Look" was useful or not, although this approach had limitations to answer what situation was the best one for "Look" or which situation could get better help from "Look." As shown in previous chapters, participants got the benefit from "Look," comparing to "no-Look" for some specific case. In this chapter, I discuss the result of those case and other possible design options. I start by explaining the possible experimental design space and the specific design choice for this study. It compares the data presented in Chapters 5, 6 and 7, and then summarizes the test of hypotheses presented earlier.

Different kinds of conversation roles were defined, based on the degree of participation (Clark 1996): speaker (the person who utters the words), addressee (the person to whom the speaker directs a given utterance), side-participant (the person who takes part in the conversation but is not currently being addressed), overhearer (the listener who does not have rights or responsibilities in conversation), bystander (the person who is openly present but not part of the conversation), and eavesdropper (the person who listens in without the speaker's awareness). These conversation roles can influence how utterances are designed and how troubles are repaired in order to achieve shared understanding. Among various conversation roles, I examined three different conversation roles in three experiments: a side-assistant, an overhearer, and a side-participant.

In addition, peripheral participants differed by virtue of when they join a conversation. In experiment 1, peripheral participants joined the conversation from the beginning and in experiments 2 and 3, they became latecomers. In all three experiments, speakers and addressees were presented as a basic task paradigm.

The other alternative of the conducted experiments was different network technology for the "Look" system. Two different technologies were adopted for the experiments; (1) infrared (IR) communication based on IrDA networking protocols and (2) Bluetooth communication based on wireless radio-frequency (RF) local-area network (LAN). IR communication's point-to-point beaming allowed each participant to aim her or his device at the intended recipient with no need for a complex network configuration. Unlike the bizarre translation of IP numbers to the classmates, the physical proximity decides the counterpart in using beaming. Just as the social protocol of a handshake or an exchange of business cards is the most basic action of attention for collaboration, beaming through a simple button click can easily initiate the collaboration with the person in front of them.

However, the IR implementation of "Look" enforced overt monitoring by the need to align the handhelds physically and by the repeated notification messages. On the other hand, the Bluetooth wireless technology allowed participants to monitor covertly neighbored devices with its omni-directional signaling, longer distance communication, and concealed transmission. Bluetooth protocol provides standardized discovery mechanism using the inquiry procedure. In this study, "Look" was implemented with IR technology for experiment 1 and implemented with Bluetooth technology for experiments 2 and 3.

Experiment 1 focused on the side-assistant, who is like a teacher or peer commenter in an actual classroom environment. Facilitating the side-assistant's common ground with central discourse participants is important when we consider teachers' need for interactive formative assessment to students in a classroom. The result of experiment 1 showed the students' as well as side-assistant's improvements in naming of Korean characters with "Look." That is, "Look" might improve the instructional judgment of side-assistants in handheld-mediated collaborative activities. However, unexpectedly, performance difference in the recognition quiz of Korean characters between “Look” users and non-users was not significant. All participants with “Look” recorded only slightly fewer errors than those without “Look” in the recognition quiz. This might be because without “Look,” participants should spend more time to find out the right characters on their screen. Spending more time by looking for the characters might help them remember the figures of characters, although they were not able to match the right name to the right character at the proper moment.

Experiment 2 focused on an overhearer who was paying attention to a conversation between a speaker and an addressee but could not actively join the conversation between them. In our experimental setting, an overhearer was also a latecomer. According to previous psycholinguistic research, overhearers had disadvantages over addressees in understanding, and late overhearers had additional disadvantages over overhearers because, unlike overhearers, late overhearers could not witness the creation of common ground (Schober and Clark 1989; Clark and Schaefer 1992; Wilkes-Gibbs and Clark 1992). In experiment 2, I was interested in how “Look” might overcome these additional disadvantages of late overhearers. During the process of matching icons, late overhearers with “Look” engaged in periodic visual review and self-monitoring and so, they could pinpoint and retain focused working objects. However, without “Look,” the low fidelity of handheld-screens made it difficult for late overhearers to check whether they understood correctly what was said by central participants. In experiment 2, late overhearers in the group that had access to “Look” experienced significantly fewer errors in understanding the conversation through all three trials than did those who were not supported with “Look.” Additionally, based on the accurate understanding of a conversation, late overhearers with “Look” could more correctly learn names of Korean characters than ones without “Look.”

The result of experiment 2 is more interesting than the results of experiment 1 or 3. In experiments 1 and 3, peripheral participants were allowed to talk with central participants. However, in experiment 2, overhearers could not talk at all. Therefore, in measuring the effect of the shared visual context on peripheral participants, the possible partial-influences by verbal communication were minimal in experiment 2.

Experiment 3 focused on side-participants. The role of side-participants was slightly different with the role of side-assistants or of overhearers. Unlike side-assistants (whose main job was to interact dynamically with central participants to help them) or overhears (who could not talk with central participants), side-participants themselves controlled over how much or little they participated in the conversation. In my experiment, the active participation from side-participants happened once in a while, although side-participants seemed to prefer to be more passive role in the process of grounding information. Experiment 3 simulated most likely my original interest of supporting students to actively switch their roles between peripheral participants (i.e. passive overhearers) and central participants (i.e., active entrants) with "Look." However, the active conversational role change was not fully analyzed in the present work. Instead, I focused on investigating the effects of the shared visual context on the learning and understanding of side-participants. In order to study the smooth conversational role changes with "Look," comprehensive video-analysis will be required as a future work.

Due to the result of no significant difference in matching test in experiment 3a, I repeated the experiment 3b by making icons visually more complex. Then, the statistically significant difference in understanding the conversation was achieved. This fact shows that the shared visual context can produce greater benefits as tasks become visually more complex. However, the difference for learning involved the naming and recognizing quiz between "Look" users and non-users was not significant in experiment 3.

The average task completion time for the "Look" condition and the one for the "no-Look" condition were significantly different: side-participants finished much faster with "Look" than they did without "Look." The comparison of task completion time was one of the most common methods to argue for the efficiency of sharing visual context in previous psycholinguistic and CSCW research (Kraut, Fussell et al. 2003; Fussell, Kraut et al. 2000; Kraut, Gergle et al. 2002; Monk and Gale 2002; Clark and Krych 2004).

Interestingly, although the previous research did not find any significant difference in the task correctness, my experiment showed that side-participants with "Look" performed significantly better than ones without "Look" in the first trial and marginally better in the second trial. Unlike the case of sharing visual space through computer monitors or video cameras, in handheld-mediated collaboration, verbal-only communication doesn't seem to be good enough to perform the job perfectly for visually complex task.

Through the experiments, six specific hypotheses were tested:

H1: "Look" functionality, compared to its absence, will help early side-assistants learn Korean characters, as evidenced by naming and recognition of Korean characters. As predicted, early side-assistants who had access to "Look" had significantly small number of errors in naming Korean characters when compared to those who had no access. With "Look," they made fewer than half the number of errors. However, unexpectedly, the difference in correctly identifying Korean characters between early side-assistants with "Look" and those without "Look" was not significant.

H2: The nature of early side-assistants' experiences—whether positive or negative—will be more favorable if "Look" is available to early side-assistants. As predicted, early side-assistants with "Look" had more positive experiences and those without "Look" had more negative experiences. Early side-assistants working under the "no-Look" condition pointed out the limitation of their interaction with central participants.

H3: "Look" functionality, compared to its absence, will help late overhearers gain common ground, as evidenced by accurate placement of the icons. As predicted, late overhearers whose handhelds were equipped with the "Look" functionality were able to rearrange the icons more correctly than did those who were not supported with it. Through all three trials, late overhearers in the group that had access to "Look" experienced significantly fewer errors than did those who had no access.

H4: "Look" functionality, compared to its absence, will help late overhearers learn the Korean characters, as evidenced by naming and recognition of the Korean characters. Overall, as predicted, late overhearers performed better in naming Korean characters when they had access to "Look" than did those without "Look." In trial 4, an analysis of variance yielded a significant advantage of "Look" and in trials 3 and 5, the results were marginally better. In spite of this, the difference in correctly identifying Korean characters between late overhearers with "Look" and those without "Look" was not significant.

H5: "Look" functionality, compared to its absence, will help late side-participants gain common ground, as evidenced by accurate placement of the icons

and the use of less time to complete the task. Overall, as predicted, late side-participants whose handhelds were equipped with "Look" functionality were more able to rearrange the icons correctly and quickly than did those who were not supported with it. In all trials, late side-participants in the group that had access to "Look" completed tasks significantly faster than did those who had no access. In trial 3, late side-participants with "Look" were significantly more correct than those without "Look" and in trial 4, marginally more correct.

H6: "Look" functionality, compared to its absence, will help late side-participants communicate efficiently, as evidenced by fewer turn-takings and overlappings in conversation. As predicted, late side-participants whose handhelds were equipped with "Look" functionality communicated with central participants with fewer turn-takings and overlappings of utterances than did those who were not supported with it. All differences in turn-taking and overlapping in conversations with and without "Look" were statistically significant.

Chapter 9: Conclusions

As cost-effective alternatives to fixed-station computers, handhelds hold much promise for increasing a potential to turn a traditional classroom into a more advanced collaborative learning environment. Handhelds are simply handy to have around and can widen the opportunities for social interaction. In fact, even for the far future, handhelds likely will not disappear and remain complementary for other forms of computers in nature. Considering these facts, this “Look” project created appropriate user experiences and promised a way to incorporate handhelds into classrooms of the future in order to facilitate collaborative learning and cooperative work. In particular, this project suggested how handhelds could be used for seamless exchange of information and support face-to-face connectivity in the collaborative learning environment.

Understanding the context and creating common ground is critical to the cooperative work and collaborative learning process. Both in Piaget’s theory of equilibrium for the dual process of assimilation-accommodation and in Vygotsky’s zone of proximal development theory, socio-culture-historical contexts are central to the learning process. Contemporary human-computer interaction (HCI) theories also emphasize the importance of context in the user’s interaction with the system (Nardi 1996). Clark straightforwardly proposed that the intrinsic context for joint activity is the common ground between participants (Clark and Carlson 1992). “Look” adopted as its design rationale these context and common ground theories in education, HCI, and psycholinguistics researches, while also reinforcing the validity of those theories by offering concrete evidence of achievement in participants’ learning and understanding. Any results or findings from this “Look” project can be applied to similar co-located collaborative work situations such as meetings, shared offices, lab environments, or field trips—essentially, any situation involving people in the same location.

Previous research indicates that monitoring addressees’ faces or head gestures did not create measurably greater efficiency in task-oriented dialogues (Whittaker 2003; Clark and Krych 2004). On the other hand, monitoring the addressees’ workspaces during their assigned tasks was critical as this process prevented eight times as many errors, and also saved double the time needed for the work (Clark and Krych 2004). Classroom learning has long been oriented toward face-to-face interaction, and handheld-mediated collaborative learning makes sharing the workspace challenging, especially when we consider that handhelds possess such small screens and permit activities of a distributed nature. “Look” is one possible solution for this problem. By sharing visual co-presence of workspaces, “Look” facilitates the acquisition of mutual understanding between discourse participants.

In a more practical way, this study showed how the use of “Look” could achieve the benefits of formative assessment. Making students’ thinking visible by providing frequent opportunities for assessment, feedback, and revision is important in their development of coherent, well-organized knowledge. This project explored the potential for the new handheld network service “Look” to provide opportunities for incorporating formative assessment in an efficient and user-friendly fashion.

In addition, this study showed how “Look” allowed a latecomer to catch up with the accumulated understanding in a discussion and to seamlessly enter into group activity. Such engagement occurred because, using “Look,” the latecomer could observe other members and, in the context of ongoing activities, pick up pointers and support. In fact, researchers argue that changing the student role from passive listener to active participant brings a number of benefits. The benefits accruing from this participatory learning include better abstract reasoning skills (Taba 1966), enhanced preservation of information (McConnell 1934), improved ability to apply principles (Lahti 1956), assurance in problem-solving abilities (Kagan 1965), and increased capability for creative thought (Chomsky 1968). With “Look,” people seeking to join an activity could understand the context of the discussion quickly and easily, and then begin to participate in the conversation without interruption.

Finally, this study explored the various design options of proper Wireless Local Area Network (WLAN) architecture to ensure that the one chosen would fit the need of new network services and applications for future classrooms. From a diversity of networking options, this study investigated the widely-deployed standards for short-range wireless technologies: infrared (IR) communication and wireless LAN Bluetooth technology.

Table 19 summarizes the statistical results from the experiments.

		n	Task Correctness (%)			Task Completion Time (mm:ss)			Naming Quiz Correctness (%)			Identification Quiz Correctness (%)		
			Trial 3	Trial 4	Trial 5	Trial 3 (Trial 1 for ESA)	Trial 4	Trial 5	Trial 3 (Trial 1 for ESA)	Trial 4	Trial 5	Trial 3 (Trial 1 for ESA)	Trial 4	Trial 5
Early Side Assistants (ESA) – Experiment 1	With Look	10	N/A	N/A	N/A	8:34 (5:15)	N/A	N/A	70.0 (30.91) +	N/A	N/A	65.0 (22.73)	N/A	N/A
	Without Look	10	N/A	N/A	N/A	5:54 (1:53)	N/A	N/A	37.0 (21.63) +	N/A	N/A	68.0 (25.30)	N/A	N/A
Late Overhearers – Experiment 2	With Look	25	90.94 (17.57) *	93.48 (14.64) **	96.74 (7.43) ***	4:40 (1:26)	3:52 (1:34)	3:12 (1:39)	29.17 (23.44)	43.40 (29.38) ++	56.16 (33.35)	36.33 (23.92)	42.67 (22.35)	49.65 (25.83)
	Without Look	22	69.58 (24.22) *	73.11 (27.09) **	77.63 (28.06) ***	4:54 (1:10)	3:59 (1:37)	3:18 (1:35)	18.94 (13.41)	27.27 (23.74) ++	41.67 (28.53)	39.39 (17.29)	55.30 (32.99)	58.71 (28.81)
Late Side Participants – Experiment 3a	With Look	19	100 (.000) +++	98.25 (5.26)	100 (.000)	5:44 (2:32)	4:09 (1:13)	3:02 (0:38)	33.33 (27.92)	48.25 (31.50)	63.02 (29.81)	40.35 (25.04)	53.07 (29.94)	50.0 (31.48)
	Without Look	19	88.16 (21.03) +++	96.49 (8.92)	94.91 (17.88)	6:20 (2:39)	4:13 (1:20)	3:26 (1:25)	28.51 (28.91)	45.18 (30.85)	57.41 (32.95)	41.67 (23.07)	57.02 (27.11)	67.13 (26.73)
Late Side Participants – Experiment 3b	With Look	16	88.25 (9.96) #	94.75 (7.83)	N/A	10:52 (2:33) ##	6:54 (1:23) ###	N/A	5.25 (6.15)	11.73 (8.35) ####	N/A	N/A	N/A	N/A
	Without Look	16	72.75 (26.94) #	85.5 (19.32)	N/A	18:43 (10:19) ##	10:42 (3:05) ###	N/A	8.75 (7.19)	21.0 (15.70) ####	N/A	N/A	N/A	N/A

Table 19: Summary of Results for Four Experiments.

Each cell represents mean (standard deviation), * p < .002 , ** p <.003, *** p <.004, + p<.013, ++ p <.05, +++ p <.03, # p <.04, ## p<.006, ### p<.000, ####p<.06

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Appendix A: Questionnaire

Korean Character Matching Game---Form A

Participant Number:___________
Date/Time:___________________

Please circle the **number** that is closest to representing your feeling about the question.

1. How complex was this task the first time?

1	2	3	4	5	6	7	8	9	10
Not complex at all									As complex as possible

2. How complex was this task subsequently?

1	2	3	4	5	6	7	8	9	10
Not complex at all									As complex as possible

Late side-participant, please go to question 10. Director and Matcher, please answer questions 3-9. Please circle the NUMBER that is closest to representing how YOU feel about your interaction:

3. How well did you work with your partner (the director or matcher)?

1	2	3	4	5	6	7	8	9	10
Not at all well									As well as possible

4. How much did you interact with your partner (the director or matcher)?

1	2	3	4	5	6	7	8	9	10
Not interacted at all									Interacted intensively

5. How much did you cooperate with your partner (the director or matcher)?

1 2 3 4 5 6 7 8 9 10

Not cooperated at all — As much as possible

6. How well did you work with the late side-participant?

1 2 3 4 5 6 7 8 9 10

Not at all well — As well as possible

7. How much did you interact with the late side-participant?

1 2 3 4 5 6 7 8 9 10

Not interacted at all — Interacted intensively

8. How much did you cooperate with the late side-participant?

1 2 3 4 5 6 7 8 9 10

Not cooperated at all — As much as possible

9. How intrusive was the late side-participant to your main task?

1 2 3 4 5 6 7 8 9 10

Not intrusive at all — As intrusive as possible

Director and Matcher, please go to question 21.

Late side-participant, please answer questions 10-20 and go to question 26. Please circle the NUMBER that is closest to representing how YOU feel about your interaction:

10. How well did you work with the director?

1 2 3 4 5 6 7 8 9 10

Not at all well — As well as possible

11. How much did you interact with the director?

1 2 3 4 5 6 7 8 9 10

Not interacted at all — Interacted intensively

12. How much did you cooperate the director?

1 2 3 4 5 6 7 8 9 10

Not cooperated at all — As much as possible

13. How responsive was the director towards you?

1 2 3 4 5 6 7 8 9 10

Not responsive at all — As responsive as possible

14. How well did you work with the matcher?

1 2 3 4 5 6 7 8 9 10

Not at all well — As well as possible

15. How much did you interact with the matcher?

1 2 3 4 5 6 7 8 9 10

Not interacted at all — Interacted intensively

16. How much did you cooperate the matcher?

1	2	3	4	5	6	7	8	9	10

Not cooperated at all — As much as possible

17. How responsive was the matcher towards you?

1	2	3	4	5	6	7	8	9	10

Not responsive at all — As responsive as possible

18. How well were you able to do your task?

1	2	3	4	5	6	7	8	9	10

Not at all well — As well as possible

19. How comfortable were you doing your task?

1	2	3	4	5	6	7	8	9	10

Not comfortable at all — As comfortable as possible

20. How intrusive did you feel you were being to the matcher and director?

1	2	3	4	5	6	7	8	9	10

Not intrusive at all — As intrusive as possible

Late side-participant, please go to question 26.

Director and matcher, please answer questions 21-25.

21. What problems, if any, did you experience interacting with the late side-participant?

22. Thinking about the whole experiment, was there ever a point at which you provided feedback (i.e., response) to the late side-participant? When? What did you clarify?

23. How comfortable would you be working with someone in the future on a similar task who could find out what you were doing, using a facility like Look, if you knew that they might be using it?

1	2	3	4	5	6	7	8	9	10
Not comfortable at all									As comfortable as possible

24. Why or why not?

25. What benefits, if any, do you anticipate for a person such as the late side-participant if they could find out what you were doing using a facility like Look?

Thank you!

Late side-participant, please answer questions 26-33.
26. What problems, if any, did you encounter interacting with the matcher and director?

27. Thinking about the whole experiment, was there ever a point at which you sought feedback (i.e., response) from the matcher or director? When? What did you ask about?

28. How comfortable would you be working on similar tasks using Look to find out what other people were doing, if they **knew** that you were doing so?

1	2	3	4	5	6	7	8	9	10
Not comfortable at all									As comfortable as possible

29. Why or why not?

30. How comfortable would you be working on similar tasks using Look to find out what other people were doing, if they **did not know** that you were doing so?

1	2	3	4	5	6	7	8	9	10
Not comfortable at all									As comfortable as possible

31. Why or why not?

32. What, if any, problems did you encounter using Look?

33. What, if any, benefits did you get from using Look?

Thank you!

Appendix B: Institutional Review Board Approval Memos

Virginia Tech
VIRGINIA POLYTECHNIC INSTITUTE
AND STATE UNIVERSITY

Institutional Review Board

Dr. David M. Moore
IRB (Human Subjects)Chair
Assistant Vice President for Research Compliance
CVM Phase II- Duckpond Dr., Blacksburg, VA 24061-0442
Office: 540/231-4991; FAX: 540/231-6033
email: moored@vt.edu

DATE: January 18, 2005

MEMORANDUM

TO: Deborah Tatar Computer Science 0106

FROM: David Moore

SUBJECT: **IRB Expedited Approval:** " Tuple-Space Project" IRB # 05-023

This memo is regarding the above-mentioned protocol. The proposed research is eligible for expedited review according to the specifications authorized by 45 CFR 46.110 and 21 CFR 56.110. As Chair of the Virginia Tech Institutional Review Board, I have granted approval to the study for a period of 12 months, effective January 18, 2005.

Virginia Tech has an approved Federal Wide Assurance (FWA00000572, exp. 7/20/07) on file with OHRP, and its IRB Registration Number is IRB00000667.

cc: File

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