

Size Does Matter in Computer Collaboration: Heterogeneous Platform Effects on Human-Human Interaction

Marilyn “Mantei” Tremaine¹, Aleksandra Sarcevic², Dezhi Wu¹, Maria C. Velez², Bogdan Dorohonceanu², Allan Krebs², Ivan Marsic²

¹ *Department of Information Systems
New Jersey Institute of Technology
Newark, NJ 07102
tremaine, dezhi.wu@njit.edu*

² *Center for Advanced Information Processing
Rutgers, The State University
Piscataway, NJ 08854
aleksarc, mariacv, dbogdan, krebs, marsic@caip.rutgers.edu*

Abstract

Because today’s workforce is highly mobile, small wireless devices are being used to support mobile work collaboration. However, do computer platform differences affect such collaborations? This question is investigated through a controlled experiment that examines collaborative problem solving on different combinations of small and large computers. Experiment participants in the study work together on solving 2- and 3-dimensional variations of the popular Tetris™ game. Gender is used as a moderating variable to ascertain if prior observed effects on groups of males would be found among females. The findings indicate that platform differences affect communication and social behavior among both groups. Unexpectedly, collaboration amongst partners using small handhelds was the most cooperative and friendly because of the difficulty of solving the problem with the small device.

1. Introduction

The “Northeast Corridor” refers to the most densely populated region of the United States, which extends from Boston to Washington, D.C. An extensive set of rail lines supports this corridor and people can be found commuting to work from Philadelphia to New York, New York to Washington, D.C. and lesser distances between these major destinations. The rail traffic on this corridor is heavy, and many trains provide drop down tables and electrical connections at every seat to support office work.

One of the authors of this paper commutes daily for two hours on one section of the corridor and has noted the large volume of work communication and collaboration taking place on these rail lines. Stocks are bought and sold, products shipped, individuals hired or fired, and budgets created. Laptops abound and are coupled with the ubiquitous mobile phone, and most passengers own a small personal data assistant (PDA). Communication is by email or telephone but no shared work documents are evident. Why is this so? Technology readily supports

attaching a spreadsheet or text document to email that can then be discussed via phone. The wireless connectivity on this corridor is excellent. It is trivial for a secretary and his or her boss to view a shared calendar and discuss schedule changes to accommodate an important client, yet this type of activity has never been observed. This is also unusual because having phone discussions about shared documents displayed on each person’s computer screen is a common task in offices.

Not having external reference documents for assisting collaborations limits the depth and quality of the office communication that can transpire in mobile settings, and thus, it limits the types of work that can be done. For example, playing “what if” with a budget that is being formed or performing “joint application development” is not viable without support documents.

In this paper, we speculate that a key reason for not using documents to support such collaborations is the cognitive limitations imposed by the environment. We define collaboration as the work activity in which co-workers jointly communicate and make changes to the same work document. Only one person may be making the changes, but both are viewing the work document. The environment affects this collaboration because of external noise, having to pay a certain amount of attention to competing information, e.g., the location of the train in relation to the person’s destination, poor lighting conditions, and the limitations of the mobile devices. We focus on the mobile device and the effect that a limited representation of a document might have on work collaboration.

2. Motivation

In short, we are interested in exploring the effects of computer differences on work collaboration. We are not interested in exploring exactly what effect screen size or using a stylus instead of a mouse has on the collaboration, that is, we are not interested in detailed design issues of a wireless PDA. More generally, because of portability requirements, the representation of a document will

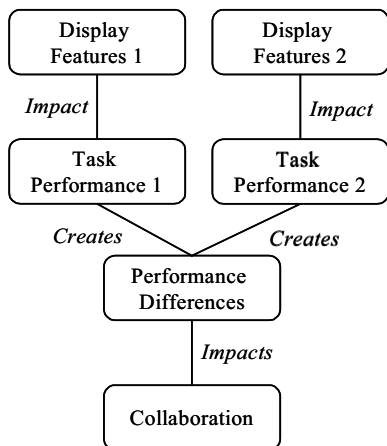


Figure 1. Model of the impact that display features have on collaborative behavior.

inherently be different on a small portable device, and this will give the user of the small device a different picture of the problem being worked on. Thus, we are interested in the effect this different representation will have on the collaboration. This is illustrated by the model in Figure 1. We believe that the more limited representations on the smaller device will create greater cognitive loads for the owner and may even give this person a different and more limited view of the problem. Consider for example two individuals talking about budget changes using the same spreadsheet. The person with the desktop display is likely to see relationships and the effects of changes in a different fashion than the person with the Pocket PC™.

It would be most realistic to study collaboration across computers of different capabilities in a real world situation, but, as indicated in earlier paragraphs, this type of collaboration is not readily found. It would also be difficult to create a realistic situation in which we asked office workers to adapt their work habits to include sharing documents while one or more of them is in commute mode. Instead, we developed a problem solving game that engaged its users and that could be worked on jointly. This allows us to use students as our experiment participants, to create a realistic environment that students are familiar with, and to readily record the collaborative behavior that took place between the experiment participants. We generated a 3-dimensional problem solving game similar to Tetris™ for a desktop computer and a 2-dimensional version of the game that would fit on a Pocket PC™ using the Disciple framework [7]. We called the game Slow Tetris to indicate its origin and to suggest that it is a problem solving rather than a motor performance type game. One key aspect of the game was the forced difference between the representation of the game on a laptop computer and a Pocket PC™. This gave us an ideal example of a representation adding to the cognitive load of the user.

We used this game in an earlier study [9] in which we examined the interaction of platform differences on collaborative exchanges. We found that the social collaboration was negatively affected when the person directing the problem solution had a poor representation (PDA) and the person not in charge had a good representation (PC). However, we were concerned that our somewhat contrived method of putting a person in charge plus the use of young male graduate students as experiment participants might have had some effect on our results. This motivated us to rerun the study to both check our results and address a number of questions that came from the first study. This paper describes this second study.

In the first study, we controlled the collaboration by putting one person in charge of the problem solution. In the study described in this paper, we are interested in what would happen to collaboration if participants were of equal status, and if, instead of requiring one person to make all problem solving moves under the direction of another, we created a truly collaborative situation in which both experiment participants had to participate in the move-making in order to solve the problem. This situation also replicated a true collaboration in which users must collaborate because they do not share the same information. In the case of the game, either person could not solve the game alone, so this ruse forced the collaboration to transpire. We also used only male experiment participants in our first study. Because research has shown women to be more polite and also more talkative [2], [4], we wanted to see if some of the cross-platform differences we observed (impoliteness, takeover and controlling behavior) in our all male collaborating teams would also appear in female teams.

Our approach to studying the effects of platform differences was to run an experiment that assigned collaborating pairs to one of three conditions: (1) collaboration using only PCs (portable laptop computers); (2) collaboration using only PDAs (handheld Pocket PCs™); and (3) collaboration using a PC and a PDA. The key piece of data that we were interested in collecting in these three conditions was the conversational exchange, which we examined for different collaboration styles and levels of politeness.

We also captured secondary information on problem solution times and numbers of rotations to reach a solution. We use this data to demonstrate that the representation differences affect these aspects of the tasks—that the poor representation slows down problem solution, probably because of increased cognitive load. We are not interesting in showing performance differences since they are expected. Our primary focus is showing the effect of the platform differences on the social aspects of the collaboration.

We begin by giving a description of the Slow Tetris game. This is followed by a description of the mixed

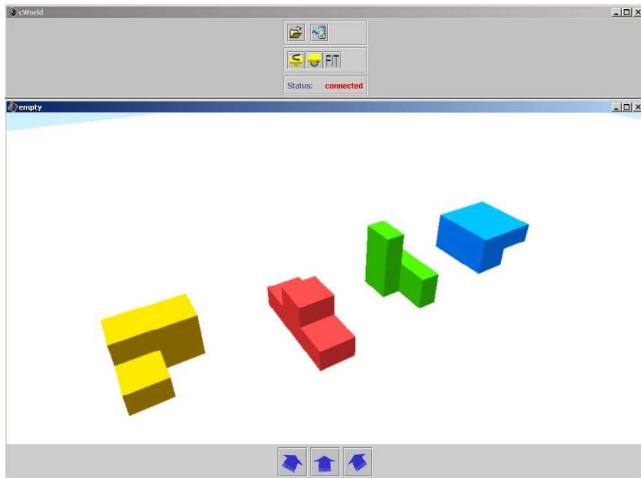


Figure 2. A screen shot showing an example problem in the Slow Tetris game. The menu at the top of the screen allows the user to switch between rotation and fit mode.

platform study we conducted. We then present summary statistics on solution times and number of rotations for different platform combinations. This is followed by a description of the differences we observed in the conversations that took place across the different computer platform setups. We follow this with a summary of our findings and a discussion of some of the limitations of the study we conducted. We conclude by discussing the possible relationship of our results to real world collaboration.

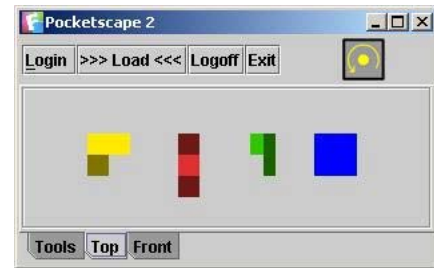
3. Description of Slow Tetris Game

Slow Tetris is a wall-building game. A 3D version of it is shown in Figure 2. The object of the game is to fit a set of odd-shaped blocks together to build a rectangular brick. The game is played as follows: The first block is stationary. The rest of the blocks are laid out in the order in which they are to fit into the brick. They can be rotated counterclockwise either around the x-axis or around the z-axis. Each block must be rotated so that it fits snugly against the block to its left. The game is played with two users. The first user to sign on to the game gets the ability to rotate the block around the x-axis. This person's game partner, who signs on next, is given the ability to make z-axis rotations. To rotate a block, a user clicks on the block. To fit a block into the wall, a user must click on the fit command at the top of the screen and then click on the block to be fitted. A block will not fit unless it is rotated correctly. If a block does not fit, the user returns automatically to rotation mode. Either user can fit the block. The game is played synchronously over the Internet and can be coupled with an audio or chat box connection so that players can coordinate their moves.

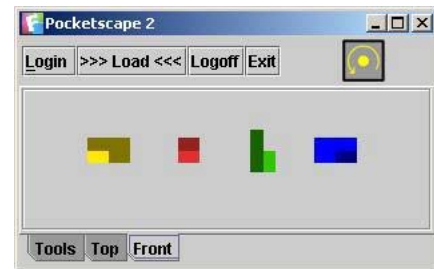
A 2D representation of the 3D game has been designed for a PDA. This is shown in Figure 3. Dark areas indicate shadows and, thus, a missing part of the block structure.



Toolbar



Top View



Front View

Figure 3. Three screen shots (toolbar, top view, and front view) illustrating a sample problem in Slow Tetris as played on a PDA. The user selects rotation or fit mode from the toolbar and can switch between top and front views of the problem to get a better picture of the screen.

(Note: Since the game is played with brightly colored blocks, a black and white version of this paper may not be as interpretable.) The 2D representation is played in the same way as the 3D representation except that users can switch between a top and a front view to gain a better perspective of the 3D block configuration. They use a stylus instead of a mouse to make rotation selections.

We now describe the study we conducted to examine the effect of platform differences. We embed the theoretical basis for our work in this description.

4. The Collaborative Mixed Platform Study

Our study's goal was to determine the effect of platform differences on collaborative problem solving. To achieve our goal, we compare collaborations across equal and non-equal types of platforms. Since our previous study [9] showed that in a free collaboration scenario one person does all the work, we forced collaboration by assigning different rotation tools to the users, and making

the tasks impossible to solve without the use of all the rotation tools. Because collaboration depends heavily on the communication skills of the collaborators, we select a partial within subjects design by assigning individuals to collaborate on both an equal platform combination and a mixed platform combination.

Experiment participants were assigned to the following platform pairs: PC↔PC, PC↔PDA, and PDA↔PDA. (Note: The arrow indicates bi-directional communication.) They were divided into groups of four based on the median time they took to solve Slow Tetris problems on the PDA in the training sessions. Within a group, an experiment participant was randomly assigned to either a PC or a PDA. Two experiment participants then participated in two collaborations, one with a group partner who had the same platform and one with a group partner who had a different platform. Another two experiment participants participated in only one collaboration with a group partner who had the same type of platform. For example, Table 1 shows the collaboration assignments for a group consisting of Joanne, Deborah, Carla and Naomi.

We conducted our experiment using four groups of male partners and four groups of female partners for a total of 32 experiment participants. Thus, we ran a 2×3-factor experiment measuring the effects of gender and platform combination. To show that some of our platform combinations were harder to use, we gathered measures on block placement time, number of block rotations, and user satisfaction. However, our primary research focus was on an in-depth analysis of the conversations that took place during the collaborations.

Table 1. Example platform and collaboration assignments for the Slow Tetris study.

Team Member	Platform Assignment	Collaboration Assignment
Joanne	PC1	Deborah (PC1↔PC2) Naomi (PC1↔PDA2)
Deborah	PC2	Joanne (PC1↔PC2)
Carla	PDA1	Naomi (PDA1↔PDA2)
Naomi	PDA2	Joanne (PC1↔PDA2) Carla (PDA1↔PDA2)

4.1. Experiment Participants

Sixteen males and sixteen females participated in this study. All were graduate or undergraduate students at a large American University. Within the male group, twelve experiment participants majored in computer science or an engineering discipline. Thirteen of the males were between 18 and 24 years old, and the remaining three were between 25 and 40 years of age. The males had 10.5 years on average of computer experience and 11.2 years on average of video game experience.

Female participants came from different fields (i.e., six females majored in computer science, two in math, two in biology, and one each in economics, languages, geology, pharmacy, literature, and sociology). Twelve females were between 18 and 24 years old, and the rest were between 25 and 40. The females had an average of 8.7 years of computer experience. Twelve female participants also had played video games with an average of 8 years experience. None of the participants knew each other prior to the experiment.

4.2. Experiment Procedure

The experiment involved three steps. We first trained the experiment participants on both PC and PDA platforms using a set of thirteen progressively harder tasks. Groups of four were then formed from experiment participants who had approximately equal completion times in the thirteen practice tasks using the PDA platform. We used the PDA practice times because previous experience indicated that they would be more predictive of each experiment participant’s spatial problem solving skills.

The groups were randomly assigned to one of four trials for both males and females. The trials balanced the presentation order of the collaboration combinations. Once experiment participants were assigned to a group, we scheduled the group for a collaboration session. Group members met one-half hour before their session in a lounge area. They were given the task of constructing a Lego™ figure (Yoda), drinks and snacks. The purpose of the Lego™ task was to acquaint the group members with each other and to encourage group members’ collaboration.

After the half-hour Lego™ session, teams of two people were extracted from the group to participate in the collaborative Slow Tetris game. Each team member was assigned a separate office for the game. After signing into the game, team members were directed to work collaboratively on finding the solutions to a set of six problems. The experiment participant pairs were not required to finish all the tasks. Each team member communicated with his or her partner by speakerphone.

One experimenter was in each room making sure the experiment ran correctly. We only videotaped one participant of the pair with the video focusing on the screen display, not the participant. Participants worked for a maximum of thirty minutes on the tasks. Not all teams were able to complete all tasks. At the end of a collaborative session, the team was returned to the Lego™ task and a new team was extracted and run in the experiment until all platform combinations were completed.

Table 2. Average fitting time and standard deviations for platform combinations shown in seconds.

Platform Combinations	Average Block Fitting Time (seconds)			
	Males		Females	
	Mean	Std. Dev	Mean	Std. Dev
PC↔PC	31.8	26.0	62.3	66.9
PC↔PDA	47.6	55.9	65.3	70.2
PDA↔PDA	71.9	92.6	104.1	192.3
Total	48.9	63.3	76.5	122.1

4.3. Expectations

Although we have captured performance time and the number of rotations for each platform combination, we do not deem comparison on these categories as interesting but rather as a necessary step in our study. We are claiming that the poorer representation of a problem generated by the compute power and screen limitations of the smaller device will increase cognitive load. Several studies have found that display size [3], [11], and dimensionality [8] affect performance in a single user scenario. One measure that demonstrates this increase is an increase in task completion time [1]. In addition, the number of rotations should also be somewhat related to cognitive load, that is, a person should take more erroneous steps to problem solution because of the difficulty they have in processing the problem parameters. We do not expect the rotations to be highly correlated with performance time because game strategies may also increase the number of rotations. Thus, it is not as necessary to show significance on this dependent variable to demonstrate that the small size representation was more difficult to process.

Because our Slow Tetris game is a mental rotation game, we expect female teams to perform worse than male teams. A large amount of literature already exists that indicates that this particular spatial ability is weak in women [5], [6], [10]. In addition our female teams had less video game experience. Although we are not testing for gender performance differences in this study, we note that the problem solving may have been somewhat more difficult for the female teams which may have made the collaboration somewhat tenuous.

Of primary interest to us are the conversations that took place among the team members. We expected the females to be more talkative than the males, to generate more affective commentary on the problem and to be more polite in their exchanges than the males. These results are known from other work [2], [4]. In our previous study, the degree of politeness in the male teams exchange depended on the assigned platform combination [9]. If we find that females also change their degree of politeness for different platform combinations, this will reinforce our previous results. *We are using the artifact of*

Table 3. Average number of rotations per block fit and standard deviations for the different platform combinations.

Platform Combinations	Average No. of Rotations per Fit			
	Males		Females	
	Mean	Std. Dev	Mean	Std. Dev
PC↔PC	5.6	7.4	9.1	10.7
PC↔PDA	19.7	25.1	9.1	12.2
PDA↔PDA	13.8	22.5	12.6	34.6
Total	12.9	20.4	10.22	21.5

gender to prove that our results are not just because of gender differences, but are pervasive in society.

In general, for collaborations in which the representation is both equal and easy, we expect the teams to proceed quickly and effortlessly towards the solution without much collaborative exchange. In the mixed platform combination, we expect the person with the better representation to help the other person to solve the problem but not without some unhappiness expressed. In a few cases, we expect the person with the better representation of the problem to take over the solution.

We expect the men to express somewhat more dissatisfaction with their partner. When the problem representation is bad for both collaborating partners, we expect the most conversation and the most collaboration with each person asking the other person for help.

5. Performance Results

5.1. Time and Rotation Data

We ran a multivariate analysis of variance on our time and rotation data. We did not use the mean block placement time of the dyad pairs as our level of analysis because our experiment design did not have enough pairs for this type of analysis (16). Instead, since each of the problems people solved was uniquely different, we used the block placement times for each block being fitted. *We justify this approach since we are only trying to show that the small platforms are harder to use than the larger ones.* Because some of our experiment participants did not complete all tasks in the time allowed, we used only those tasks that were completed by all in our analysis. This gave us a total of 230 block placements.

Our predictions for performance differences were confirmed. The descriptive statistics for this data are shown in Tables 2 and 3. A test for homogeneity of variance allowed us to use an ANOVA to test for statistical significance. The performance times for the platform combinations are overall significantly different ($F(2, 230) = 3.87; p = .02$). A linear contrast analysis shows that the platform combinations (PC↔PC vs. PDA↔PDA and PC↔PDA vs. PDA↔PDA) are significantly different from each other (at least at the $p = .04$ level). The PC↔PC vs. PC↔PDA contrast is not significant. We find

the same results for block rotations, which are overall significantly different ($F(2, 230) = 3.08; p = .05$). In short, the PDA↔PDA combination was the worst performing combination of the three, most likely because of the difficult 2D representation. In terms of performance time, the PC↔PDA combination was significantly better than the PDA↔PDA combination indicating that the person on the PC was probably helping with the problem solution.

6. Conversational Analysis

We transcribed all the conversations that took place in our twenty-four experiment participant teams. Much less conversation was exchanged by the male teams than the female teams. In the following sections we describe the collaborations we observed in each of the three platform combinations.

6.1. PC↔PC Collaborations

The teams that were best at solving the Slow Tetris problems barely spoke in the PC↔PC collaboration. Each member of the team could see the step that was needed and simply performed his or her rotation. The problem solutions were extraordinarily smooth with each person performing the needed rotations in rapid succession. The last person to make a rotation usually carried out a fit. An example of this type of exchange is shown below for the male group. (Note: M stands for Male experiment participant and the numbers following are the numbers we assigned to our experiment participants.)

(M05 on PC, M07 on PC)

M05 Oh God...
 M07 Haha... (Laugh) Alright.
 M05 <M05 rotates in top twice> Go ahead...
 M07 <M07 rotates in front twice>
 M05 <M05 follows with one top rotation>
 M07 <M07 makes one front rotation>
 M05 <M05 rotates once in top> That will do it...
 M07 Yup! <M07 makes a fit>

We found this highly synchronized nonverbal turn taking behavior in many of the male PC↔PC collaborations although it was also seen in the better female teams. The females in the PC↔PC setup also worked smoothly and efficiently but coordinated their moves with verbally guided turn taking, e.g., “your turn,” etc. In contrast to the men, the women were always being careful to announce to their partner what their intended action was at any time. An example of this type of exchange is shown below. (Note: F02 stands for Female experiment participant number 02.)

(F02 on PC, F24 on PC)

F02 Alright... so this is me, right?
 F24 Okay.
 F02 <F02 rotates the third block in front once>
 F24 I'll go now. <F24 rotates the third block in top once>
 F02 Alright.
 F24 <F24 rotates the third block in top once>
 F02 Yeah...<F02 fits the block> ...Okay.

6.2. PC↔PDA Collaborations

Collaboration in the mixed platform combination was very different from the PC↔PC arrangement. One of the changes that was immediately observed was a verbal strategy known as negative politeness. Negative politeness is a way of acting polite while socially performing an act that is considered impolite [2]. For example, “Would you mind if I cut in front of you?” Men and women used negative politeness differently in the mixed platform arrangement. Because the PC user had the better problem representation, it was much easier for this person to plan moves, but, because of the collaborative constraints, the PDA user was needed to execute some of the moves. In some cases, the male using the PDA gave up responsibility for solving the problem and asked to be told what to do next. He requested this transfer of authority with a phrase employing negative politeness. An example of this happening is shown in the transcript below.

(M07 on PC, M13 on PDA)

M07 (After he opens the task) Okay...
 M13 <M13 rotates in front once>
 M13 *You can probably give me better instructions because you're a 3D model so...*
 M07 Alright... I'll let you know what to do...
 M13 Okay...

In some cases where authority was transferred to the PC problem solver, the PDA partner had enough expertise to suggest possible moves. In these cases, the PDA partner used negative politeness to ask if he could make a move or suggest a move. An example of this use of negative politeness is shown in italics in the transcript below.

(M07 on PC, M13 on PDA)

M07 <M07 rotates in top once>
 M13 *Should I do it again?*
 M07 <M07 already started rotating once in top>
 M07 Oh yeah... hold on...
 M07 <M07 rotates in top three times>

M07 Now... now try it... (F19 on PC, F26 on PDA)
 M13 <M13 rotates in front once>
 M13 There is it...
 M07 <M07 tries to fit; fit works> Yup...
 M13 Alright...
 M07 Ahm, I think you should do the next one...
 M13 Yeah...
 M13 <M13 rotates in front three times>
 M13 <M13 rotates one more in front>
 M07 <M07 rotates in top once>
 M13 One more time?
 M07 <M07 rotates in top once> Okay...
 M13 *I mean, should I* turn that one more time...
 M07 Oh, yeah, yeah...
 F19 I think you *should* rotate.
 F26 <F26 rotates in top once>
 F26 *Do you think I should* rotate once more?
 F19 Let's try...
 F26 <F26 rotates in top once>
 F19 Yeah...
 F26 Again?
 F19 No, let me try.
 F19 <F19 rotates in front twice>
 F19 *Could you* rotate?
 F26 <F26 rotates in top once>
 F19 <F19 rotates in front twice>
 F19 <F19 tries to fit; fit works>

In most of the problem solving exchanges, the male on the PC simply took over the solution and told his PDA partner how to move. There was no polite request for taking on this role. In some cases the takeover was rather rude and abrupt, shutting out requests from the PDA partner. These cases formed nearly ninety percent of the PC↔PDA collaborations. An example of this type of exchange is shown below.

(M18 on PC, M21 on PDA)

M21 Does it fit it?
 M18 Yeah, that should work...
 M18 <M18 is about to fit>
 M21 Rotate twice!
 M18 <M18 continues with fitting and block fits>
 M18 There, it's there...
 M21 Oh, okaaaay, that doesn't...
 M18 Did you see it?
 M21 Oh, yeah, yeah, yeah I see it... alright!
 M18 Don't work too fast 'cause we are on different platforms here!
 M21 Okay, aaahhh...

In contrast to the males, the female member with the PC engaged in constant negative politeness behavior. Nearly ninety percent of the exchanges were couched in phrases containing mitigating statements such as "could you," or "would you." The PC partner was faced with the task of directing the PDA partner but used these statements to appear polite rather than aggressively taking over the problem solution. An example of this type of exchange is shown below. The negative politeness statements are in italics. As can be seen after the second rotation, this negative politeness was hard to keep up and the PC partner suddenly steps in with "No, let me try."

A key difference between the male and female groups in the mixed platform combination was the effort made by the female PC partner to involve the PDA partner in the solution. Instead of simply taking over the solution, the PC partner continued to tell the PDA partner what move she was intending to make and then to use negative politeness statements to obtain a rotation from her partner. Although the PC partner was clearly directing the solution, her language hides this and, instead, she treats her partner as a full partner in the solution. An example of this is shown in the transcript below.

(F19 on PC, F26 on PDA)

F19 I will rotate.
 F26 Okay.
 F19 <F19 rotates in front twice>
 F19 So, could you rotate?
 F26 <F26 rotates in top once> Yes.
 F19 Let me see the... <F19 changes views>
 F26 It's the same thing, right?
 F19 Yeah. (Laughter). So, you better try again?
 F26 <F26 rotates in top once>
 F19 Yes. Umm, I will rotate.
 F19 <F19 rotates in front three times>
 F19 Could you rotate?
 F26 Yes. <F26 rotates in top once>
 F19 I will try...
 F19 <F19 rotates in front twice>
 F26 Like that. That is good...
 F19 <F19 tries to fit; fit works>

In both the male and female partnerships in this heterogeneous computer collaboration, the unequal footing is obvious. Although the female partners attempt to lessen the problem through inclusive verbiage, the tension is more obvious in the voice of the female PC partner than in that of the male PC user who simply takes

over. In both teams, this cannot be the most pleasant situation for the PDA partner who is put in a situation of being unable to contribute effectively. In the male teams conflict is observed as the PDA partner sometimes acts on his own or tells the PC partner to slow down. In the female teams we do not see this conflict, but we see a passive-aggressive type response when the PDA partner says “Yes, I will” or “I will try,” as opposed to the “okay” or “alright” responses we saw with the other platform combinations.

6.3. PDA↔PDA Collaborations

What happens when we move to a platform combination where nobody is a winner? We know that this combination is the poorest performer. This does not, however, affect the social enjoyment of the collaboration. Both partners recognize that they have a difficult problem to solve and engage in a large amount of conversation about the task at hand. Unlike either of the other two collaboration scenarios, this one is fun for its participants. There is a considerable amount of joking and meta discussion on the difficulty of the problem. In the male teams, we see a behavior we call “thrashing” as each team member asks to make the next move. An example of this is shown in the conversation that follows.

(M04 on PDA, M13 on PDA)

M04 <M04 rotates in top three times>
 M13 *Let me try a...*
 M13 <M13 rotates in front three times>
Can you ro... rotate that once or twice?
 M04 <M04 rotates in top three times>
 M13 *Let me try... hold on...*
 M13 <M13 rotates in front once>
 M04 *Yeah... let me turn it...*
 M04 <M04 rotates in top once>
There you go... Now you rotate it once...
 M13 <M13 rotates in front once>
 M04 There we go...
 M13 Alright... no...
 M04 <M04 tries to fit; fit doesn't work> No...
 M04 <M04 rotates in top four times>
 M13 *Let me try rotating it... okay...*
 M04 You want me to put it back... (M04 just finished 4 rotations)

In contrast to the male teams, the female teams in the PDA↔PDA collaborations spent their time in problem discussion so that any solution appeared to come from both parties. Much of their discussion was based in questions even when they were suggesting a move. An example of this type of problem approach is shown in the dialogue below.

(F03 on PDA, F11 on PDA)

F11 So, now I am just gonna play with the green piece for a minute...
 F11 <F11 rotates in front once>
 F11 ...because I think... Aaaha! If we flip it so that the top piece, the one that's sticking out, is more flat on the ground... I don't know how to explain this... Mmmhm...
 F03 <F03 rotates in top once>
 F11 No.
 F03 <F03 rotates in top once more>
 F11 No. (Laughter)
 F03 <F03 rotates in top once>

Although both groups engaged in considerably more discussion in this platform combination, a key difference between the men and the women was the way in which men and women viewed their roles in the problem solution task. Men saw themselves as individuals who were guiding the solution or not guiding the solution at any point in time. They openly talked about taking a turn or giving up a turn. In contrast, the women never mentioned turns or discussed who would manage solving the problem. In the PDA↔PDA combination, negative politeness was involved in every exchange among the women but both partners used it as they questioned each other on what should be done next, e.g., “Should I rotate now?” Another striking difference between the PDA↔PDA combination and all other combinations was the frivolity that accompanied the discussions. Because the problems were so much harder with the poor representation, both teammates made the best of their situation and joked about problem difficulty. When a block fit was found, there were often exclamations of joy. We see this in the following two transcripts, one from a female team and a second from a male team.

(F04 on PDA, F26 on PDA)

F26 All right. I will try to fit it. I don't know, for some reason... but let's try it, okay? (Laughter)
 F26 <F26 tries to fit the second block; fit does not work>
 F26 Oh nooo! Ahhh! Can we skip this one and go on to the next one? (Laughter) Okay, try rotating, okay?
 F04 Yes
 F04 <F04 rotates the second block in front once>

The joke below came after a brick-building task that was accomplished with little difficulty compared to all previous tasks the team had undertaken.

(M04 on PDA, M13 on PDA)

- M13 Yeah... (talking about the previous fit)
 M04 That was nice!
 M13 That was really nice!!!
 M04 <M04 rotates the next piece in front twice>
 M13 That was better than my birthday!
 M04 I don't know if I'll put it that far, but...
 M13 No, but my birthday wasn't that great!

Another difference between the PDA↔PDA combination and all other combinations was a higher prevalence of common grounding, that is, conversational exchanges to make sure that people are talking about the same thing. This occurred both among the males and the females but the females engaged in more of it than males. We would have expected more of it with the mixed platform combinations, but we observed more here. This is possibly because the problem solutions were so difficult that both parties wanted to make sure that their partner knew exactly what they were referring to even when both of them had the same view of the problem. An example of this common grounding exchange is shown below.

(F04 on PDA, F26 on PDA)

- F26 In the top, the left part, it's dark. Right?
 F04 From the top view?
 F26 Yeah, in the top view...
 F04 I have... umm... on the right hand side, I have the pink at the top and then at the bottom is the dark purple, the little square...
 F26 Yeah, okay.
 F04 So we need to match...
 F26 ...the green part, which is bright, it should go
 F04 there.
 F26 It should go where this dark part is.
 Yeah. So (unintelligible) we should be... we should use front on top view, ahhh... it's a top one. I think you should do it right now.
 F04 Okay, rotate it?
 F26 Aha!
 F04 <F04 rotates in top once>

7. Discussion

To recapitulate, we present our overall findings in the itemized list that follows.

1. Larger platforms (PCs) improve performance time even in the case when one partner has a smaller platform (PDA) and the second one has a larger one. This is because the person with the good

representation helps the other person with the poor representation.

2. Communication patterns were different in the different platform combinations. The patterns are related to how difficult the problem is to solve and to the heterogeneity of the platform combination in the following ways:
 - a. If one person has a good representation, the conversation will reflect this person helping the person with the poor representation. This will be represented by an increase in negative politeness commands (for females) or an increase in one-sided direction giving (males).
 - b. If both people have a good representation, the task flows smoothly and each person does his or her end of the collaboration. In fact, the flow is so smooth, there may be little to no conversation. This is more pronounced in male teams.
 - c. If both people have a bad representation, there is a constant thrashing in the conversation with either person giving up responsibility for solving the problem and asking for help from their collaborator (in the case of males) or with both people talking and continuing to engage in a complete collaborative solution (in the case of females).
 - d. When both people work with a difficult representation there are more jokes, more conversation and more common grounding than in other combinations.

We first showed through performance time analysis and platform preference measures that the representation of the problem on the PDA made the problem more difficult to solve. Then we performed a conversational analysis of the problem solving strategies of our experiment participants to see what effect this size-imposed difficulty had. The analysis showed that our experiment participants engaged in completely different conversation strategies based on the platform combination they were placed in. The conversation strategy that had the most tension and exhibited highly strained exchanges was the mixed platform combination. This was true for both the men and the women, although the women handled the unequal platform problem differently from the men. These results were relatively straightforward for our student population but some constraints exist in extrapolating these results to the real world.

First, our students were not a well-developed work team. Such a team can generate short conversational forms for dealing with problems that we would not have observed. Second, the problem was not that of a real world problem where a rich collection of information

about the problem may already be stored in the collaborating team's heads. Finally, one could argue that the representation we chose for the PDA to exemplify the inequality was particularly bad, and that real world differences would not be as large.

We concur that a certain amount of this criticism is valid. However, our experiment participants had been trained to a relatively competent level in the Slow Tetris task. In addition, as could be observed on the videotapes, the experiment participants were completely engrossed in the task so that their awareness of their different conversational exchanges could not have been obvious to them. In addition, the gender differences we observed are commonly known so it is not surprising that they were executed in the different platform combinations.

8. Conclusion

What did we learn from our findings that would support collaboration for the Northeast Corridor commuter? If users did not know the difficulty of working with a poorer representation, they would certainly pick this up quickly. In our short collaborative study, experiment participants using a PDA made joking comments against Slow Tetris. They also made negative statements about the usability of the interface. But our studies also show that any mixed platform collaboration puts both people in an uncomfortable situation. Collaborations in the PDA↔PDA condition were fun and partners in the collaboration joked and laughed about the difficulties they had. No jokes were exchanged in the mixed platform arrangement and tension could be felt in the verbal responses of the PC partner who was needed to direct the solution. Tension could also be felt in the verbal responses of the PDA partner who had to give up all control and be directed in the problem solution.

Commuters currently do not collaborate at this detailed work level because support for this type of exchange is not widespread, but our studies suggest that when this support does improve, social considerations may enter into the collaboration. Even with a powerful laptop, a commuter is still at a disadvantage because of competing demands on attention. Thus, we are a long way from anytime, anywhere full collaboration because the commuter will always have more cognitive demand with his/her attention than the office-based collaborator.

Size does matter, so much so, that it is likely to govern what work is done and when.

9. Acknowledgments

The research is supported by NSF Contract No. ANI-01-23910, New Jersey Commission on Science and

Technology, and by the Rutgers Center for Advanced Information Processing (CAIP) and its corporate affiliates, and by the Information Systems Departments of the New Jersey Institute of Technology.

10. References

- [1] W. Ark., D. C. Dryer, T. Selker, and S. Zhai. "Representation matters: The effect of 3D objects and a spatial metaphor in a graphical user interface" *People and Computers XIII, Proceedings of HCI'98*, H. Johnson, N. Lawrence and C. Roast, Eds. Springer-Verlag, Heidelberg, Germany, (1998), pp. 209-219.
- [2] P. Brown, and S. Levinson, "Universals in language: Politeness phenomena", *Questions and Politeness: Strategies in Social Interaction*, E. N. Goody, Ed. Cambridge University Press, Cambridge, UK, (1978), pp. 56-289.
- [3] A. Dillon, J. Richardson, C. McKnight, "The effect of display size and text splitting on reading lengthy text from the screen", *Behavior and Information Technology*, 9 (3), (1999), pp. 215-227.
- [4] C. M. Hanchey. "Labs, learning styles, and gender", *Proceedings of National Educational Computing Conference (NECC '93)*, Orlando, Florida, (1993), pp. 225-258.
- [5] D. Kimura, *Sex and Cognition*. Cambridge, MA: MIT Press, (1999).
- [6] M. C. Linn, and A. C. Peterson, "Emergence and characterization of gender differences in spatial abilities: A meta-analysis", *Child Development*, 56, (1985), pp. 1479-1498.
- [7] I. Marsic, "An architecture for heterogeneous groupware applications", *Proceedings of the 23rd IEEE/ACM International Conference on Software Engineering*, IEEE, Piscataway, NJ, (2001), pp. 475-484.
- [8] M. St John, M.B. Cowen, H.S. Smallman, H.M. Oonk, "The use of 2D and 3D displays for shape-understanding versus relative-position tasks", *Human Factors*, 43 (1), (2001), pp. 79-98.
- [9] M. Velez, M. Tremaine, A. Sarcevic, B. Dorohonceanu, A. Krebs, and I. Marsic, "Who's in charge here?: Communicating across unequal computer platforms", Accepted for publication to ACM TOCHI, 2004
- [10] D. Voyer, S. Voyer, and M. P. Bryden, "Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables", *Psychological Bulletin*, 117, (1995), pp. 250-270.
- [11] Watters, C., Duffy, J., and Duffy, K. Using Large Tables on Small Display Devices", *International Journal of Human-Computer Studies*. 58 (1), 2003.