# The Effect of Undergraduate Library Users' Dyadic Diversity Attributes on Interactive Tabletop Collaboration, Performance, and Perception

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**Abstract**
Sixty undergraduate students were paired up and participated in a usability study of the Library Explorer software on a Microsoft PixelSense Tabletop. Specific investigation into the impact of diversity attributes on collaboration style, collaboration quality, task performance, and participants' perception revealed interesting patterns. Problem solving ideas were coded as suggestions. Gender composition and task performance were found to be significantly associated with the frequency of suggestions' non-acceptance. Results show that during participants' collaborative discovery on interactive tabletops, gender and racial diversities, while directly influenced their collaboration styles and processes, did not impact their team performance. Diversity attributes that significantly correlated with team effectiveness included native language diversity, differences in tabletop use experiences, usability ratings, and the frequency of suggestions not being accepted. Findings of the study not only enrich the understanding of the connection between team compositional diversity and collaboration styles, but also provide insights on how team members' suggestion behaviors may help capture the dynamics of collaboration on interactive tabletops.
**Keywords:** diversity attributes, collaboration styles, quality of collaboration process, problem solving suggestions, team performance, user perception
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## 1 Introduction

In April 2012, a private university located in the northeast region of the Unites States installed the Microsoft SUR40 tabletop (SUR40 henceforth) in three of its libraries, featuring the open source software "Library Explorer" (LE henceforth) developed by the Brown Graphics Group in collaboration with the university library. The LE software enables users to view collections of large format 2D artwork on a large touch screen table. LE also allows librarians to "prepare content and appropriate metadata and related assets to be viewed" by patrons (LADS User's Guide, 2011, p.1). For an overview and video demonstration of features and functions of LE, readers are referred to follow the hyperlinks under item (Harvard Library UX, 2012-13) in the "References" section. Shortly after the installation of the SUR40 and LE, a multi-phased usability research study was conducted with Phase I involving 29 participants completing tasks individually and Phase II featuring two participants working collaboratively on tasks during a test session. This paper reports the results that pertain specifically to the impact of diversity attributes on collaboration characteristics and performance outcomes as participants work together to learn a new library tool on an interactive tabletop.

While the existing research on interactive tabletops addressed the topic of users' collaboration styles when using tabletops in a particular context (e.g., Akerman, Puikkonen, Huuskonen, Virolainen, & Hakkila, 2010; Marshall, Morris, Rogers, Kreitmayer, & Davies, 2011; Rick, Marshall, Yuill, 2011), seldom has any study investigated how library users collaborate on an interactive tabletop to explore library digital collections. Meanwhile, even though there is abundance of research on the relationship between team composition and team performance (e.g., Bell, 2007; Cannon-Bowers, Salas, & Converse, 1993; Fisher, Bell, Dierdorff, Belohlav, 2012; Klimoski & Mohammed, 1994; Rentsch & Klimoski, 2001; Webber & Donahue, 2011), such investigation has not been thoroughly extended to the impact of dyadic diversity on collaboration process, task performance, and user perceptions. Furthermore, although there are a number of research studies on collaborative learning discussions and verbal participations, (e.g. Flecker et al., 2009; Shaer et al., 2011), there is almost no research that had correlated the number and state of team member's suggestions (i.e., accepted or not accepted) with team diversity attributes, collaboration styles, and team performance.

The present research has been guided by a number of theoretical frameworks. Using the operational definitions and models of (1) collaboration profiles (Shaer et al., 2011), (2) collaboration process scaling (Meier, Spada, & Rummel, 2007), (3) collaborative learning mechanisms framework (Flecker et al., 2009), and (4) multi-level diversity and team mental model similarity (Fisher et al., 2012; Harrison, Price, & Bell, 1998; Miliken & Martins, 1996), this paper reports sets of results concerning the association between various diversity dimensions and collaboration style and team performance. In particular, dimensions of diversity include those that pertain to demographic (gender, race, and native language), academic (status and discipline), and use experience. Use experience consists of participants' experience with tablet and smart phones, and their experience with the SUR40 or other types of interactive multi-touch tabletops.

In this paper, the term "diversity" refers to "differences between individuals on any attribute that may lead to the perception that another person is different from self" (van Knippenberg, De Dreu, & Homan, 2004, p.1008). Diversity research typically examines demographic attributes such as gender, age, race/ethnicity, and job-related diversity attributes such as organizational and group tenure, educational background and functional background (van Knippenberg et al., 2004; Williams & O'Reilly, 1998; Wolff, Ratner, Robinson, Oliffe, & Hall, 2010]. In this study, where dyadic composition is formed by experimental set up instead of based on a participant's own choices, the term diversity is used to describe categorical heterogeneity that appear both at the surface level and at less visible levels (academic background, use experience, etc.), "as opposed to hierarchical differences (i.e., disparity) or differences along a continuum (i.e., separation)" (Fisher et al., 2012, p.831).

Note also that in this paper, the scale for evaluating dimensions of collaborative process is frequently referred to as quality of collaboration. The phrase "collaboration style" is frequently used in place of "collaboration profile." As was observed from the 30 research sessions, most of the dyads did not just have one single consistent collaboration profile throughout their sessions. Instead, as they progress through their tasks, participants often switched between two or more collaboration approaches. Consequently, the term "style" was deemed more appropriate to describe the dynamic nature of participants' interaction and collaboration behavior.

## 2 Literature Review

There is a rich set of empirical research focusing on collaborative learning on interactive tabletops. In the field of social psychology, human factors, and management, there is also a wealth of literature on team composition, team mental model, and task performance. For the purpose of this paper, the review covers two relevant schools of empirical research: (1) collaborative styles/process and diversity levels, and (2) team composition and performance.

### 2.1 Collaborative Styles and Processes on Interactive Tabletops

A great number of previous research studies on interactive tabletops explored users' social behavior when using a tabletop as a group (e.g., Meier et al., 2007; Piper & Hollan, 2009; Rick et al., 2011; Shaer et al., 2011). Papers by Shaer et al. [31] and Schneider et al. [30] on collaboration profiles are directly relevant to this study. Based on their research on the dyadic interaction using G-nome Surfer 2.0 on an interactive tabletop, Shaer and her team (Shaer et al., 2011) developed a typology for collaboration profiles. Recently, Schneider and his coauthors (Schneider et al., 2012) conducted a study comparing students' learning of phylogenetic trees under two conditions: a multi-touch tabletop interface and a pen & paper activity. It was found that the tabletop implementation produced significantly higher collaboration activities such as dialogue management, information pooling, technical coordination, and individual task orientation. Table 1 describes the four categories of dyadic collaboration using Shaer et al.'s (2011) taxonomy of collaboration profiles and Schneider et al.'s (2012) adopted description.

| Profile | Description |
|---|---|
| Turn-Taker | Both users make and accept suggestions and observations |
| Driver-Navigator | Both users are engaged. The navigator contributes with suggestions and observations |
| Driver-Passenger | The driver is fully engaged, the passenger is not focused on the task |
| Independent | Users are absorbed in their own activity; minimal verbal communication |

Table 1: Collaboration Profiles and Their Brief Descriptions, Sources: (Shaer et al., 2011; Schneider et al., 2012)

Also of salience to studies of collaborative learning is the mechanics of collaboration outlined by Pinelle, Gutwin, and Greenberg (2003) as primitives for Collaborative Usability Analysis (CUA). Two broad categories of activities were described: communication and coordination. Communication consists of explicit communication and information gathering. Coordination involves shared access and transfer. Similarly, Meier, Spada and Rummel (2007) incorporate communication and coordination as two of the five dimensions of collaboration. The five process dimensions contain a total of nine attributes; See Table 2 for a full list of attributes and dimensions. Authors applied a five point scale ranging from -2 (very bad) to +2 (very good) for their assessments of 40 collaborating dyads. Meier and her colleagues concluded that the rating scheme they developed may be used as "generic assessment methods" for computer supported collaborative learning (Meier et al., 2007, p.81).

| Dimensions | Attributes |
|---|---|
| Communication | 1) Sustaining mutual understanding |
| | 2) Dialog management |
| Joint information processing | 3) Information pooling |
| | 4) Reaching consensus |
| Coordination | 5) Task division |
| | 6) Time management |
| | 7) Technical coordination |

| | |
|---|---|
| Interpersonal Relationship | 8) Reciprocal interaction |
| Motivation | 9) Individual task orientation |

Table 2: Collaboration Process Dimensions, Source: (Meier et al., 2007)

In addition to profiling and measuring collaborative learning, researchers also observed how participants collaborate through their verbal exchanges (Shaer et al., 2011) and making and accepting suggestions (Flecker et al., 2009). Shaer and her colleagues (2011) investigated the verbal and physical participation of 24 dyads when they used G-nome Surfer software through a multi-touch tabletop and a multi-mouse computer GUI. Authors grouped the levels of verbal participation using the categories of insight, coordination, brief response, syntax, problem solving, and disengagement. In an earlier study, Fleck and her research team (2009) conducted a case study of 27 school children in groups of three when using a classroom seating plan software on a DiamondTouch tabletop. Based on the data, authors validated and extended their Collaborative Learning Mechanisms (CLM) framework. Table 3 covers only the verbal aspects of the CLM framework.

| Verbal Aspects of Collaboration Discussion | |
|---|---|
| Making and accepting suggestions | |
| Presentations | • Making verbal suggestions and giving opinions |
| Acceptances | • Listening to others' suggestions and opinions |
| | • Asking for clarification of verbal or physical suggestions |
| Negotiating | |
| Making, listening to and responding to each other's suggestions | |
| Making alternative suggestions | |
| Disagree | • Explanation of own ideas |
| | • Justification of own actions |
| | • Verbal blocking |
| Maintaining joint attention and awareness | |
| Narrations | • Inform others about your actions |

Table 3: Mechanisms for Coordinating Collaborative Discussion and Action, Source: (Flecker et al., 2009)

## 2.2 Levels of Diversity, Team Process, and Team Performance

Another relevant set of research on collaborative interaction is the work on group cognition and team mental models. Klimoski and Mohammed (1994) created a framework to explain the role of the team mental model in team performance. In their framework, an individual's potential for performance is linked to team capacity, then team process, and then leads to team performance. Klimoski and Mohammed (1994) specify that team capacity is the result of team members' individual potential interacting with two team level parameters: composition/size and resources. Team composition is defined as "the (gender/ skill/ age/ experience) make-up of the team" (p. 430). While team capacity may have the impact on an effective team process and thus high levels of team performance, the authors argue the factors of team mental model and leadership also contribute to the team process and thus lead to high performance.

In operational research and organizational theory, scholars proposed different taxonomies to describe team composition diversity. Miliken and Martins (1996) suggest that in addition to observable diversity such as race and gender, the underlying diversity such as differences in values, skills and knowledge and cohort membership holds different degree of impact on team cognitive outcomes, communication-related consequences and team performance. In the similar vein, Harrison et al. (Harrison et al., 1998; Harrison, price, Gavin, & Florey, 2002) outline two levels of diversity: *surface level* which is defined as differences in demographic characteristics among team members such as age, sex and race/ethnicity, and *deep leve*l which refers to differences in psychological characteristics such as attitudes, personalities and values. Yet another distinction was made by Pelled and her colleagues (Pelled, 1996; Pelled, Eisenhardt, & Xin, 1999; Simmons, Pelled, & Smith, 1999) which separate those diversity attributes that are highly job related such as education, functional background, and industry experience from those that have low job relatedness such as age, race and gender. Pelled proposed that low job related diversity attributes could lead to high affective conflict and thus negatively influence cognitive task performance. On the other hand, high job related diversity variables are seen as positively correlated with substantive conflict which is also positively associated with high group performance on cognitive tasks.

Several researchers investigated composition diversity as antecedents of team member schema agreement (Rentsch & Klimoski, 2001), team decision making quality (Cannon-Bowers et al., 1993), and team mental model similarity (Fisher et al., 2012). Cannon-Bowers and her colleagues (1993) believe that the construct of "shared mental models" would explain the compatibility of team member's expectations and thus lead to high quality of team decision making and team performance. They further argue that four types of mental models are useful for team effectiveness: (1) equipment model (i.e., technology), (2) task model, (3) team interaction model, and (4) team model. The fourth component, team model is concerned with teammates' knowledge, skills, abilities, preferences and tendencies.

Empirical results specifically relevant to gender and racial diversity produced inconsistent results. Racial diversity was found to be negatively associated with team mental model similarity (Fisher et al., 2012) and team schema agreement (Rentsch & Klimoski, 2001), whereas gender was not found to have significant correlations. On the other hand, when studying the supervisors' performance rating of their subordinates, Tui and O'Reilly (1989) found that "the subordinates in mixed-gender dyads were rated as performing more poorly and were liked less well than the subordinates in the same gender dyads" (p. 414). Authors found no support for the race effect. Yet, Kraiger and Ford's (1985) meta- analysis research indicates a significant rate race effect in performance ratings: higher performance scores were given to people of raters' own race. Meanwhile, empirical work on cross-country/culture collaboration (e.g., Binder, 2007; Xie, Song, & Stringfellow, 1998; Zagorsek, Jaklic & Stough, 2004) has also compared participants of different countries based on cultural dimensions such as power distance, uncertainty avoidance, individualism and collectivism, long term orientation, and more as per Hofstede (2001).

Overall, a multitude of empirical constructs and frameworks has been developed to describe collaborative learning on interactive tabletops or the diversity factors which impact team process or performance. However, seldom has any empirical investigation been performed on library users' collaborative discovery process using interactive tabletops. Furthermore, seldom have any studies linked team diversity attributes of different levels (surface versus deep level) with collaboration profiles, quality of collaboration processes, and team performance. In addition, the measurement of team members' suggestion and its acceptance or non-acceptance status have never been operationalized as a variable to be associated with diversity attributes as well as team performance measures.

## 3 Research Questions

Focusing exclusively on dyadic collaboration process, authors of this paper seek to explore the relationship among diversity attributes, collaboration style and process, and team performance. Relevant research questions are:

1. How do various types of diversity impact on the dyadic collaboration style formation?
2. How do various types of diversity impact on the quality of dyadic collaboration?
3. How do various types of diversity impact on the number of suggestions made by a team member and whether the suggestions were accepted or not accepted?
4. How do various types of diversity impact on participants' ratings on system's usability, usefulness, future use and their likelihood to recommend the tool?
5. Do various types of diversity correlate with team performance both in terms of efficiency and effectiveness?

## 4 Research Variables

Relevant to this paper, a number of variables pertaining diversity and team process, performance, and user perceptions are considered. These variables are listed in Table 4.

| Categories | Items | | |
|---|---|---|---|
| Diversity | Surface Level | Academic | Use Experience |
| | • Gender<br>• Race<br>• Native language | • Discipline<br>• Status/class | • Tablet experience<br>• Tabletop experience |
| Team Collaboration Process | Collaboration Style | Collaboration Quality | Suggestions |
| | • Turn Taker<br>• Driver Navigator<br>• Driver Passenger<br>• Independent | • Sustaining mutual understanding<br>• Dialog management<br>• Information pooling<br>• Reaching consensus<br>• Task division<br>• Technical coordination<br>• Reciprocal interaction<br>• Individual task orientation | • Suggestion accepted<br>• Suggestion not accepted<br>  • Suggestion negotiated<br>  • Suggestion ignored<br>  • Suggestion disagreed |
| Team Performance | Efficiency | Effectiveness | |
| | • Time on task | • Percent of tasks completed successfully<br>• Percent of tasks completed with ease<br>• Percent of tasks completed with difficulty<br>• Percent of tasks failed to complete | |
| Perception Rating | • Overall usability experience<br>• Usefulness<br>• Likelihood for future use<br>• Likelihood to recommend | | |

Table 4: Research Variables Relevant to Diversity, Collaboration, Performance, and Perception

## 5 Method

Thirty usability study sessions took place at the university's science library from October to December 2012, in a small staff training room on the second floor of the library. The sessions were video recorded with two cameras, one connected with Morae software to capture the SUR40 screen as well as participants' hand movements, the other linking to a laptop to record participants from another angle.

Undergraduate students were recruited as the target participants. Participants were informed as they signed up for a session that they would be working in a two-person team. As a participant signed up, he/she was paired up with another person according to specified date/time preferences. An effort was made to maintain an equal number of three pairings: female and female, male and male, and female and male as the mixed team. In the end, there were 11 female teams, 11 mixed teams and 8 male teams.

Each research session consisted of three parts: (1) a pre-session interview, (2) a usability test, and (3) a post-session interview. The pre-session interview asked for participants' demographic information, their use of tablet and touch screen devices, their library use pattern, and their vision of the characteristics of an ideal multi-touch tabletop. The post-session interview inquired about participants' overall usability experience with the SUR40 and LE, their favorite and least favorite features, whether they learned new things about the library, and whether their experience matched their imagined ideal tabletop.

The actual usability test involved going through a scenario to perform eight tasks on LE. Each task consisted of three to four subtasks (see Appendix A for the full usability test scenario containing tasks and subtasks). Participants were encouraged to think-aloud while completing tasks with the moderator sitting next to them. The screen movements, the sound, and participants' behavior were logged by Morae Recorder. The body language and sound were also captured from a different angle via Quicktime recording. Study sessions were run by research assistants, with the second author as a consistent moderator for all sessions and additional research assistants as note-takers and data loggers. On average, a research session lasted 34 minutes. Participants were each awarded a $15 gift card.

## 6 Data Processing, Coding and Analysis

Data processing involved transcribing pre and post session interview data into a spreadsheet as the coding sheet. After the initial coding was done, further processing was carried out to record the team average scores. For instance, a team's overall usability experience score was obtained as from the average of ratings by two persons in that team.

For collaboration related variables, the collaboration profile typology (Shaer et al., 2011) was used to code each task for a dyadic session. The collaboration style for the overall session was also coded. The collaboration process scale (Meier et al., 2007) was used to assess the quality of collaboration using a five point scale ranging from -2 (very bad) to +2 (very good). The quality of collaboration was coded by session, not by individual tasks. Since participants were not given a time limit, the attribute of "time management" was not included in the coding, making for a total of eight attributes.

For each session, any occurrence of suggestion was coded through the Morae marker feature where suggestions were grouped into the format of verbalized, gestural, and verbal and gestural combined based on the suggestor's behavior. Based on the suggestee's reaction, suggestions were coded into four types: suggestion accepted, suggestion negotiated, suggestion ignored and suggestion disagreed. Because of the limited frequency of the suggestions other than those accepted, in the analysis, suggestions "negotiated," "ignored," and "disagreed" were all grouped into the category of "suggestion not accepted."

The coding process involved two researchers (both authors and a research assistant alternated which two individuals performed the coding and evaluation) watching video, and deciding on the dyadic profile for individual tasks first, then deciding on an overall profile for that session. After the profile coding for a given session was done, researchers continued on to assess the quality of collaboration based on the session they just reviewed by using the five point scale.

A second round of coding was performed to check the reliability of the first round coding. In the second round, 44% of the whole data set was randomly sampled, and researchers coded the sampled data for collaboration profile and collaboration quality independently. The round two and round one intercoder agreement ratios, based on Cohen's (1960) kappa statistic, were .63 for collaboration styles, .50 for collaboration quality, and .83 for suggestions. According to scholarly literature about the measurement of inter-rater agreement (e.g., Altman, 1991; Viera & Garrett, 2005), the kappa value in the range of from .81 to .99 is considered as "almost perfect agreement," from .61 to .80 as "substantial agreement," and from .41-.60 "moderate agreement." It appears that researchers are in almost total agreement in coding the occurrences of suggestions, a strong agreement in coding collaboration styles but only moderate agreement in giving collaboration quality scores. Note that when using a numeric rating of collaboration quality, it is more difficult to get the exact same coding score than when using semantically coded categories. Note also the first round of coding, which was used in the data analysis, was the result of two coders working together to reach consensus. Consequently, the coded data should be viewed as solid with the proper level of inter-coder agreement.

## 7 Results

In this section, a brief demographic description of the participants, a report of participants' post-session perception of the interface, and various statistical results pertaining to the relationships among a number of diversity attributes, collaboration style, quality of collaboration process, team performance indicators, and participants' perceptions will be presented.

### 7.1 Participants

Among the 60 participants, 33 were female and 27 were male. The racial makeup of the team was coded simply by two categories: same (n=12) and different (n=18). Among sixty participants, 52 were native English speakers while 8 were not. Consequently, both members of 22 teams were native English speakers, whereas 8 teams were composed by one native speaker and one non-native speaker. Fifty-nine participants were in the range between 18 and 23 years of age, whereas one participant was in the age range of 24 to 34. It was obvious there were not a lot of age differences among participants. Table 5 summarizes the demographic makeup of the 30 dyads.

| Team Diversity Attributes | | | | | | |
|---|---|---|---|---|---|---|
| Gender | | | Racial Composition | | Native Language | |
| Female & Female | Male & Male | Female & Male | Same | Different | Both Native English Speakers | One Native & One non-Native |
| 11 | 8 | 11 | 12 | 18 | 22 | 8 |

Table 5: Demographic Makeup of the 30 Dyads

Over 51% of the participants were freshmen, 23% sophomores, and 12% each for juniors and seniors. In terms of their academic major, although the majority specialized in sciences, biomedical sciences and engineering (38%), the social sciences (23%) and humanities (12%) also had good representations. Sixteen participants (27%) had not yet declared their majors. The age of all but one participant was in between 18 and 23 years old.

Participants were asked about their experiences in using tablet devices and smart phones. Over 70% had used an iPhone and over 55% had used an iPad. Figure 1 illustrates their responses. The majority of the students who owned or used an iPhone had used it for about two years (29%), some used more than

two years (18%) and others used more than six month but less than a year (18%). In terms of their experience with the SUR40 or other types of multi-touch interactive tabletops, the majority of the participants had not used any type of interactive tabletops (72%), 14 participants (23%) used it at various library hosted events, and 3 participants (5%) used other types of interactive tabletops.

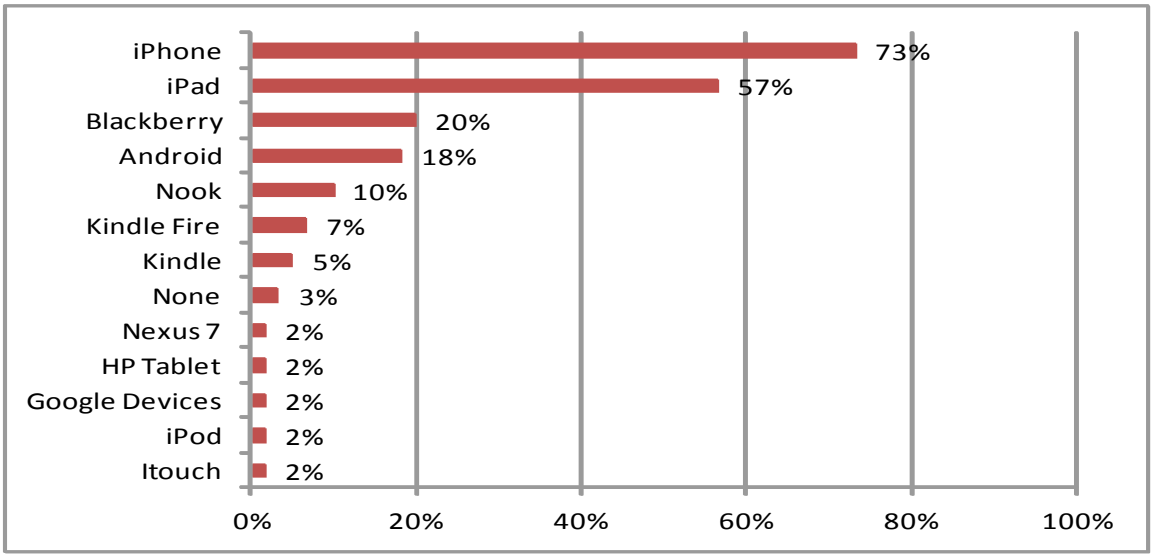


Figure 1: Participants' experiences with tablet devices and smart phones.

## 7.2 Post-Session Perceptions

Participants rated their overall usability experience after they completed eight pre-defined tasks. They also commented on a variety of things related to the use of the SUR40 and LE. When they were asked to rate certain aspects of their experience, a seven-point scale was consistently used, with "7" being the highest value and "1" being the lowest. The average overall usability experience rating was 4.4, usefulness rating 4.1, likelihood to use LE in the future was 3.8, and likelihood to recommend the tool was 4.3.

## 7.3 Collaboration Styles (Profiles)

All four collaboration styles (or profiles as per Shaer et al., 2011) were observed in the 30 sessions. Collaboration styles were coded by task and then by session. When looking at task-based collaboration styles as well as overall collaboration profiles by session, the most frequently used style at both levels was "turn-taker," followed by "driver passenger." Note that out of 30 dyads, one pair failed to complete the task of "taking a snapshot" and subsequently had to skip the next task. Consequently, the total number of task-based collaboration style is 239 instead of 240 (30 session x 8 tasks). Table 6 provides counts of each style at both the task level and the session level.

| | Turn Takers (TT) | Driver-Passenger (DP) | Driver-Navigator (DN) | Independent (ID) |
|---|---|---|---|---|
| By Task | 154 (64%) | 54 (23%) | 18 (8%) | 13 (5%) |
| By Session | 15 (50%) | 11 (37%) | 1 (3%) | 3 (10%) |

Table 6: Frequency of Collaboration Style Observed By Task and By Session

## 7.4 Diversity Attributes and Collaboration Styles

### 7.4.1 Surface Level Diversity and Collaboration Styles

A Chi-square test based on the gender pattern of the team make-up and frequency of collaboration styles used for individual tasks revealed a significant dependence ($\chi^2(6, N = 239) = 17.97$, $p < .01$) of collaboration style used and the kind of team make-up. Table 7 shows the frequency of collaboration styles and different pairings. Whereas the turn takers (TT) style had the largest representation in all three kinds of teams, the mixed groups had no occurrence of the "independent" (ID) style. The male groups had a larger portion of the "driver-navigator" (DN) style, although the "driver-passenger" (DP) style was used the second most frequently in all three kinds of teams. Meanwhile, there was no significant difference among the three gender-based team make-ups and quality scores of any of the eight attributes of collaboration process.

| Gender Diversity | Collaboration Style | | | |
|---|---|---|---|---|
| | TT | DN | DP | ID |
| Female & Female | 58 (66%) | 2 (2%) | 21 (24%) | 7 (8%) |
| Male & Male | 36 (56%) | 10 (16%) | 12 (19%) | 6 (9%) |
| Female & Male | 60 (69%) | 6 (7%) | 21 (24%) | 0 (0%) |

Table 7: Team gender make-up and collaboration style

The 30 dyads were grouped into "same" and "different" to distinguish the racial diversity of the team. Even though both groups had the highest frequency in using the TT style (same 75%; different 57%), significant differences were found ($\chi^2(3, N = 239) = 16.08$, $p < .01$) where ethnically diverse groups used more the DP style (29%) than homogenous racial group (14%); and they also used more the "independent" style (8%) than homogeneous racial groups (1%). Dyads with same racial origin used more the DN style (10%) than groups that were different (6%). Figure 2 displays the raw frequency counts.

With regard to native language diversity, the frequency of collaboration style use is significantly dependent on whether the team had two native English speakers or mixed ($\chi^2(3, N = 239) = 15.47$, $p < .01$). While the teams made up by one native and one non-native speaker had a higher frequency use of the ID (14%, compared to 2% of the both native speaker group) and DN styles (11%, compared to 6% of the both native speaker group), the teams made up of both native English speakers had a higher frequency of the TT (67%, compared to 57% of the mixed group) and the DP (24%, compared to 18% of the mixed group) styles.

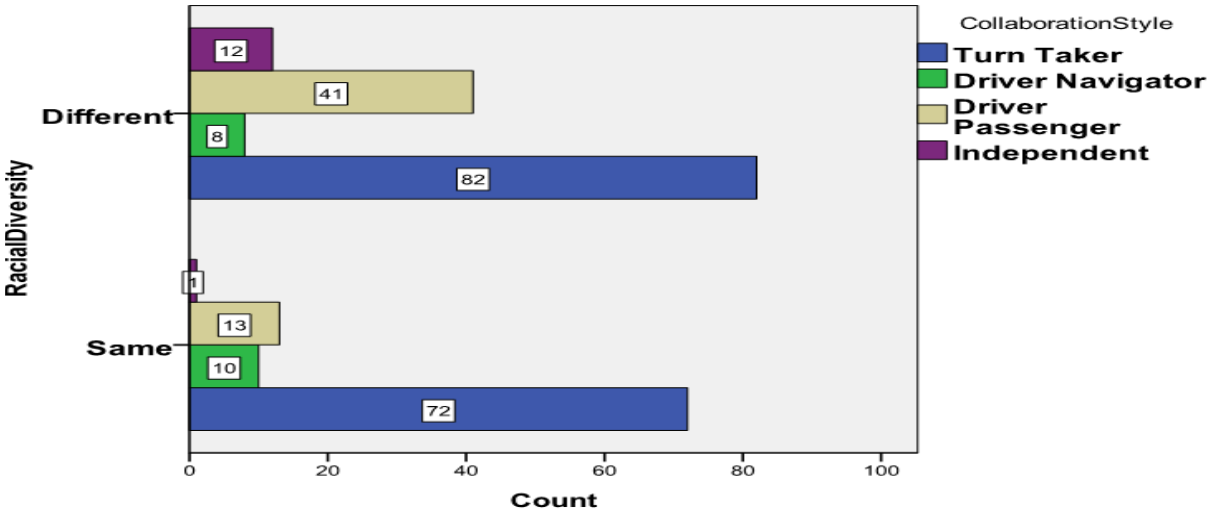


Figure 2: Racial diversity and collaboration style use by task.

### 7.4.2 Academic Status/Interests and Use Experience Diversity and Collaboration Style

The academic diversity aspect is measured through the differences in participants' academic status and areas of interest. Nine teams were from the same status, while 21 were not. No significant dependency of collaboration style on class level diversity was found.

Fields of study were coded according to academic domains of sciences, social sciences and humanities. Further coding of disciplinary diversity grouped participants into the category of "same" (both from the same academic domains of sciences, social sciences, arts and humanities), "mixed" (e.g., one from science, one from the humanities), and "both undeclared" (both participants had not yet declared their majors). There were 20 dyads that were from different domains, five from the same domain, and in the remaining five teams, neither participants had not declared their major.

Disciplinary diversity has been shown to influence the adoption task-based collaboration styles ($\chi^2(6, N = 239) = 33.38$, $p < .01$). While all three kinds of teams had the highest frequency in using the TT style, teams with members with both undeclared majors had the highest percent of usage (83%), whereas teams with members from the same domain of academic interest had the lowest frequency in using the TT style (45%). Dyads with mixed areas of interests had a high frequency of the DP style, whereas teams with the same academic interests applied the independent style as well as the DP style. Teams whose members were both undeclared with their majors had no independent style.

| | Same Domain | | Mixed Domain | | Both Undeclared | |
|---|---|---|---|---|---|---|
| | Count | Percent | Count | Percent | Count | Percent |
| TT | 18 | 45% | 103 | 65% | 33 | 83% |
| DN | 4 | 10% | 12 | 8% | 2 | 5% |
| DP | 9 | 23% | 40 | 25% | 5 | 13% |
| ID | 9 | 23% | 4 | 3% | 0 | 0% |

Table 8: Disciplinary Diversity and Collaboration Styles

Participants' experience with interactive tabletops may be grouped into three categories: both had used the SUR40 or other types of tabletops prior to the study session; neither of them had any experience with

interactive tabletops; and one had experience and the other did not. The majority of the dyads (60%) had not used the technology, seven teams (23%) had mixed experience (i.e., one used and one did not use), and both members of five teams (17%) used interactive tabletops.

Teams with different levels of tabletop use experience adopted various collaborative styles in significantly different frequencies ($\chi^2(6, N = 239) = 18.72$, $p < .01$). While the teams with both members having used interactive tabletops before never applied the ID style, they had significantly higher frequency in using the DN style (20%). Dyads with neither member that previously used the interactive tabletops frequently used the DP style (28%), whereas the ID style was used most frequently by the teams with mixed use experiences.

Participants' post-session ratings of their overall experience of LE's usability were coded by the paired discrepancy in their ratings. While the majority of the rating discrepancies was a one point difference (16 teams, 53%), members of 11 teams gave the same rating (37%). The remaining teams had 2, 2.5 or 4 point differences in the rating. Correlation analysis revealed that such rating differences are negatively associated with the use of the TT style ($r$ = -.57, $p < .01$) and positively associated with the use of the DP style ($r = .67$, $p < .01$).

#### 7.4.3 Suggestion Behavior and Collaboration Style

Throughout the study sessions, participants were observed making suggestions to their partner when they encountered a difficult task. Out of all 30 sessions, 29 teams had occurrences of making suggestions. The total number of suggestions made is 77, out of which, 57 suggestions were accepted and 20 were not. Forty-three suggestions were made in verbal format, 17 were gestural only, and 18 were made with verbalization in combination with gestures. Thirteen pairs made 1 suggestion during their study sessions, whereas 7 sessions had 2 suggestions, and 4 sessions had 6 suggestions.

In the case when the suggestion was not accepted, there was a difference in opinion about the problem solving idea. In such a situation, the non-accepted suggestions may be viewed as an indicator of diversity in opinions or perspectives, as opposed to the notion of the "shared cognition"(Cannon-Bowers & Salas, 2001). The frequency of suggestion not accepted was found to be positively associated with the frequency of the pair using the "driver navigator" style ($r = .54$, $p < .01$)

### 7.5 Diversity Attributes and the Quality of Collaboration Process

Among the three surface level diversity variables, gender and native language diversity showed no effect on the ratings of collaboration quality. Significant differences were found between racial make-ups of the teams and a good number of collaboration process ratings, with the exception of the "task division" and "individual task orientation." Teams with both members of the same race had higher ratings in terms of "Sustaining Mutual Understanding" ($t(28) = 2.42$, $p < .05$); "Dialogue Management" ($t(28) = 2.95$, $p < .01$); "Information Pooling" ($t(28) = 3.45$, $p < .01$); "Reaching Consensus" ($t(28) = 2.45$, $p < .05$); "Technical Coordination" ($t(28) = 2.25$, $p < .05$); and "Reciprocal Interaction" ($t(28) = 2.50$, $p < .05$). Figure 3 shows the differences in means of the teams of same racial make-up versus diverse make-up.

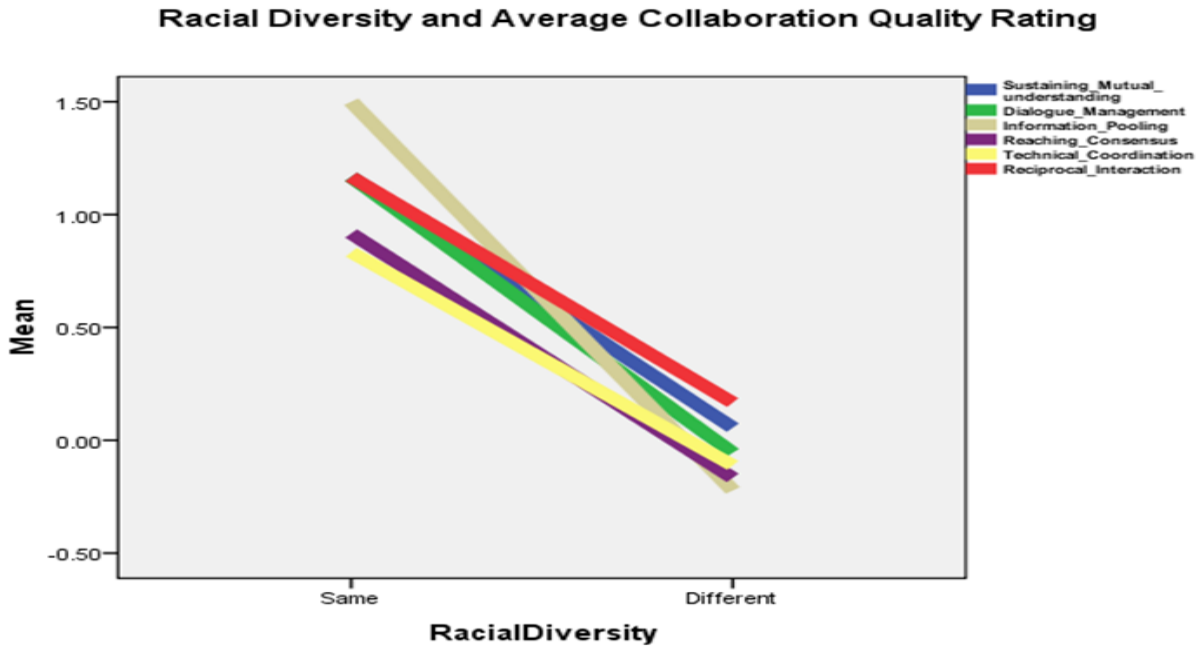


Figure 3: Racial diversity and collaboration quality rating.

Beyond the surface level diversity, the discrepancies in team members' overall usability rating were found between two racial compositions of the teams and several collaboration process ratings, with the exception of the ratings for "Sustaining Mutual Understanding" and "Individual Task Orientation." The rating discrepancy was negatively correlated to "Dialogue Management" ($r$ = -.40, $p < .05$); "Information Pooling" ($r$ =- .43, $p < .05$); "Reaching Consensus" ($r$ = -.430, $p < .05$); "Task Division" ($r$ = -.38, $p < .05$); and "Reciprocal Interaction" ($r$ = -.57, $p < .01$).

## 7.6 Diversity Attributes and Suggestion Behavior

Interesting patterns emerged when considering surface level diversity variables with dyadic suggestion behavior. Significant gender effects were observed both in terms of the total number of suggestions made ($F(2, 27) = 3.71$, $p < .05$) and suggestions not being accepted ($F(2, 27) = 9.95$, $p < .01$). While male only teams made on an average the highest number of suggestions, they were also on average the highest non-acceptance teams. On the contrary, female pairs made both the lowest number of suggestions and had the lowest number of non-acceptance frequency. The mixed gender group fell in between the male and female only teams. Figure 4 is the means plot for suggestions not accepted. The means plot for total number of suggestions shows a very similar pattern as the one in Figure 4.

With regard to the format of suggestions, teams with mixed native speakers had significantly higher frequency in verbalizing their suggestions than pairs with both members as native English speakers ($t(28) = 2.37$, $p < .05$).

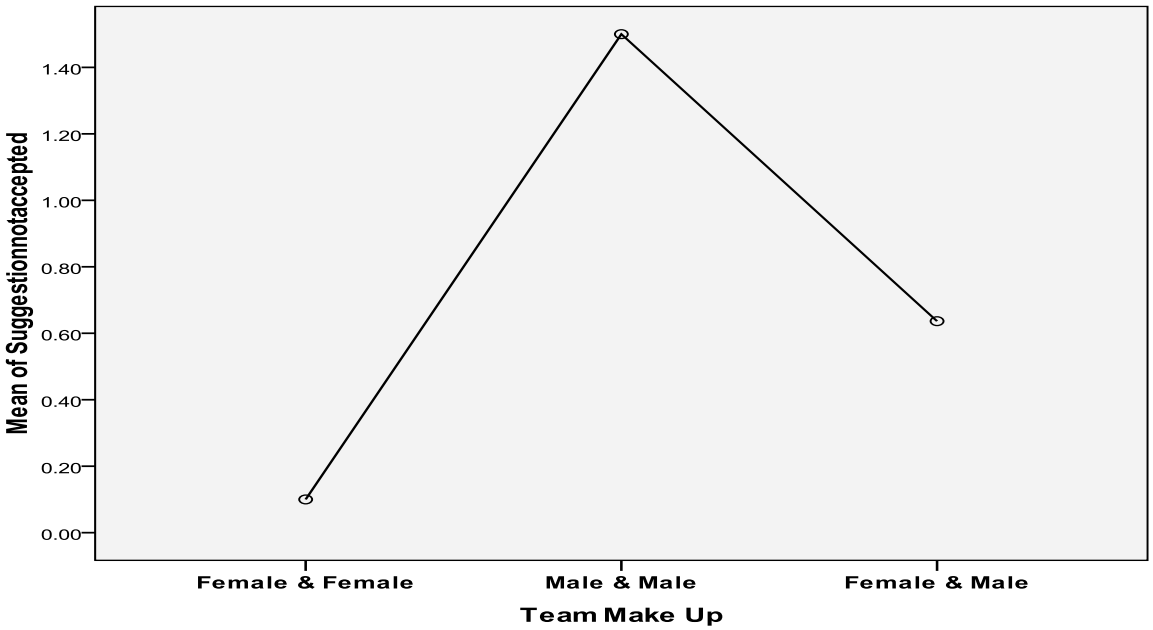


Figure 4. Gender diversity and number of suggestions not accepted.

## 7.7 Diversity Attributes and Perception Rating

Gender make-up had a significant influence on the recommendation rating ($F(2, 27) = 3.92$, $p < .05$). In contrast with the patterns in suggestion behavior, male teams gave a lower rating for recommendation than female teams. The mixed gender teams were once again in between male only and female only teams. Such an inverse pattern would make sense as male teams were found to be more critical than female dyads.

Participants' use experience with tablet devices was grouped into the categories of (1) both used iDevices (e.g., iPad, iPhone, iTouch, etc.), (2) one used iDevices and the other used other types of tablets, and (3) one used iDevices and the other had not yet used any tablet devices. A majority of the teams was those that both participants had used various Apple products (n = 22), followed by iDevices and other devices (n = 6), and iDevices and none (n = 2). In answering the question "Based on your experience today, on a scale of 1 to 7, with 7 being extremely useful, how useful do you think Library Explorer is to you in your learning and creative use of library resources?", a significant difference was found among three tablet use experience groups in their usefulness rating ($F(2, 27) = 4.10$, $p < .05$). Teams with both members having used iDevices gave the highest usefulness rating, whereas the groups that had one member used iDevices and one never used any tablet gave the lowest usefulness rating. Figure 5 presents the means plot of the usefulness rating by groups with different use experiences.

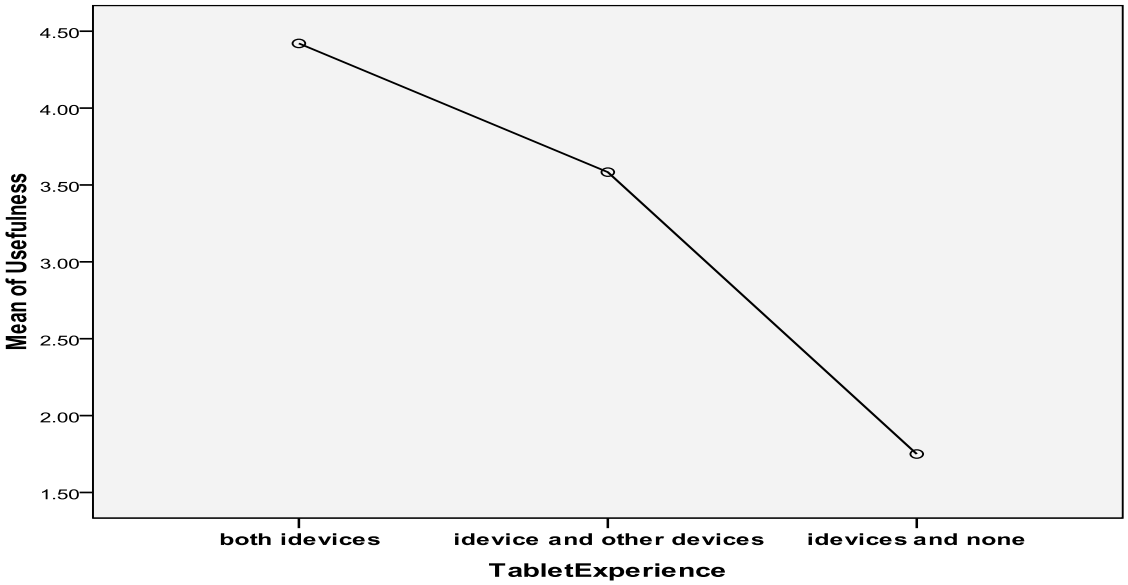


Figure 5: Tablet use diversity and participants' usefulness rating

## 7.8 Diversity Attributes, Suggestions, and Team Performance

As shown from Table 4, among the list of variables, the team performance is specified through the variables of task time as an indicator of "efficiency," and four "effectiveness" measures: percent of tasks completed successfully, percent of tasks completed with ease, with difficulty, or failed to complete.

### 7.8.1 Diversity and Task Time

Among the surface level diversity variables, the only variable that has significant impact on task completion time is the native language diversity ($t(28) = -2.50$, $p < .05$). On average teams with both native English speakers completed various subtasks significantly faster ($M = 36.36$, $SD = 7.40$) than teams with mixed native speakers ($M = 48.02$, $SD = 18.61$).

The total number of suggestions correlates positively with the task time ($r = .44$, $p < 0.05$). The frequency of suggestions being accepted also correlates positively with task time ($r = .45$, $p < 0.05$).

### 7.8.2 Diversity and Effectiveness

Once again, among the surface level diversity variables, the only variable that has significant impact on task effectiveness is the native language diversity. Teams with both members as native English speakers completed various subtasks with significantly higher ratios of ease than teams with mixed native speakers ($t(28) = 3.21$, $p < .01$); they also had lower ratios of tasks failed to complete ($t(28) = -2.27$, $p < .05$), and higher ratios of tasks completed successfully ($t(28) = 2.07$, $p < .05$).

The diversity in academic status holds an impact on percent of the tasks completed with difficulty ($t(28) = -2.18$, $p < .05$). Teams with both members from the same class level (i.e., freshmen, sophomore, junior, and senior) experienced a significantly lower percentage of task difficulty ($M = 1.4\%$, $SD = .03$) than those teams with members of mixed class levels ($M = 5.1\%$, $SD = .05$).

Participants' previous experience with an interactive tabletop also made a difference in their task success ratios ($F(2, 27) = 5.00$, $p < .05$). Teams with both members not using an interactive tabletop before the research session ($M = 99\%$, $SD = .02$) and teams with both members who used the SUR40 or other types of tabletops ($M = 98\%$, $SD = .02$) had significantly higher percentages of task success than teams that had mixed tabletop use experiences ($M = 95\%$, $SD = .06$). Figure 6 shows the means plot of the success ratio and groups with different levels of experiences of using tabletops. This might suggest that

teams of the same tabletop use experience (both used or neither used) can formulate a shared mental model more efficiently, whereas those with mixed experiences would require longer time to develop a common mental model they both would accept and use for performing tasks.

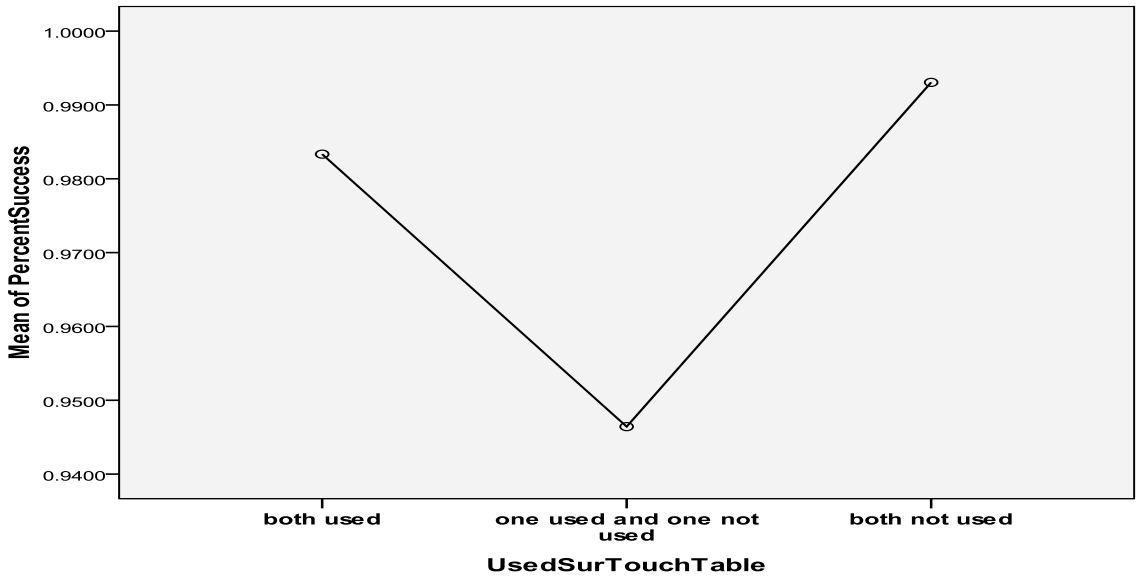


Figure 6: Tabletop use diversity and percent of tasks completed successfully.

The total number of suggestions made is positively associated with the percent of tasks failed to complete ($r$ = .42, $p$ < .05) and negatively associated with percent of action tasks completed successfully ($r$ = -.48, $p$ < .01). The frequency of suggestions not being accepted is negatively correlated with percent of action-based tasks completed successfully ($r$ = -.43, $p$ < .05).

The differences in dyadic ratings of overall usability were found to be negatively associated with the percent of tasks completed successfully ($r$ = -.57, $p$ < 0.01).

## 8 Discussion

A number of interesting patterns emerged from examining various diversity attributes and their impacts on dyadic collaboration styles, collaboration quality, problem-solving suggestions, task performance, and participants' perceptions. With regard to research question 1, most of the diversity variables, with the exception of the diversity in academic status, were found to have significant variations in the use of collaboration styles. There are no consistent directions, but with the exception of native language diversity, the mixed groups in gender, race, and discipline applied the "driver passenger" (DP) style more frequently. Differences in participants' usability ratings are also positively associated with the frequency of the DP style. Various measures of suggestions, including suggestion not accepted, are a good indicator for the "driver navigator" (DN) style. This seems to make sense, as one would assume that there would be more suggestions from the navigator, and the suggestions may be discussed, negotiated or disagreed between the driver and the navigator.

Diversity attributes do not seem to have a strong connection with collaboration quality. While racial diversity and differences in participants' usability rating were found to be both negatively associated with several dimensions of collaboration quality, gender, native language, discipline, status, use experience, and suggestions were not significantly linked with collaboration quality ratings.

There were gender and native language effects on problem solving suggestions. The former is linked to the total number of suggestions made and suggestions being not accepted, and the latter is connected

with the format by which the suggestion was delivered. It is interesting that the mixed gender dyads was in between the male and female pairs with regard to the number of suggestions made and number of suggestions not being accepted. It seems that the mixed gender team can be a good balance for suggestions being made and being otherwise not accepted.

Associated with the fact that male dyads offered more suggestions and debated on the suggestions, they also gave the lowest ratings for recommendation. Female dyads were least frequently to reject a suggestion, and they offered the highest rating for recommending the tool. Teams with both members prior use of Apple tablet products, offered the highest usefulness rating for the SUR40 and LE, whereas groups with mixed experience (one used and one not used) gave the lowest rating.

None but one diversity variable was related to the task completion time, however, more underlying diversity variables such as differences in academic status, tabletop use experience, usability rating, and suggestions not accepted are associated with effectiveness measures such as success ratio, percent of tasks failed to complete or completed with difficulties. In most cases, the dissimilar groups (mixed class levels, mixed experiences in tabletop use, suggestion not accepted) appeared to be associated negatively with the percent of tasks completed successfully. For instance, in terms of tabletop use experience, two kinds of "same" use experience teams (i.e., both members never used or both members used) had significantly higher success rates than the teams where one member used tabletops before and one had not. Based on the theory and research on team schema agreement or mental model similarity, teams with mixed experiences would likely to have some level of difficulty to instantly form a shared mental model and thereby could experience a reduced success rate.

Overall, results seem to confirm the "similarity attract" paradigm (Byrne, 1971), but while diversity attributes at all levels seem to influence the collaboration style, the significant diversity impact on team performance came mostly from the underlying attributes such as tabletop use experience, suggestions not accepted, and usability rating. It is understandable that the surface level diversity attributes would influence how teams interact and collaborate, but they do not directly associate with task performance outcome. It is the substantive underlying diversity attributes, be that experience, problem solving skills, and team members' opinions that are the antecedents for similarity in team mental model, and therefore team cohesiveness. These diversity attributes have been viewed as highly task-related (Pelled, 1996; Pelled et al., 1999; Simmons et al., 1999), and they would therefore determine the team performance.

Native language diversity is an exception that exhibited direct associations with both team efficiency and effectiveness. In this particular study, the language variable might have served as an indicator of whether the communication would be carried out smoothly and effectively to complete tasks in a controlled setting. However, there was no significant difference between the two groups (both native speakers versus one native and one non-native speaker) on their collaboration quality ratings.

## 9 Conclusions

In presenting the results of diversity attributes and collaboration patterns of 30 dyads working with the LE interface on the SUR 40, some aspects of the previous empirical theories on team composition diversity and team mental model similarity were confirmed, while new questions arose that require further investigation and confirmation. A noticeable originality of this study is the integration of tabletop collaborative learning frameworks with theories of team composition diversity, team mental models, and team performance. Another innovative perspective that this paper introduces is the empirical construct of problem solving suggestions. The analysis of suggestion behavior produced significant insights that would lead to a greater understanding of the collaborative discovery process on interactive tabletops.

Even though examining team composition diversity and collaboration behavior is not the only goal of the Phase II study, it is a valuable phenomenon that is worthy of substantial and advanced intellectual analysis. In another paper (Tang, Quigley, Guillette, & Erdmann, 2013), we reported the impact of

collaboration style on collaboration quality and team effectiveness, this paper focuses on the effect of dyadic diversity. One of the major limitations of the present study is that in both pre and post session interviews, no specific inquiries were made regarding participants' past experience and how they feel about the quality of the collaboration when they used the SUR40 and LE. Nevertheless, further analysis on participants' qualitative preference data, their verbal exchange, and their coordination activities as per Pinelle et al.'s (2003) model is currently on-going. Additional qualitative analysis on participants' physical behavior such as their hand gesture types and their screen touch rates, their territoriality (i.e. spatial partitioning) and conflict as per Tang and his colleagues (Tang et al., 2010) is also in plan. Advanced qualitative analysis will help to reveal deeper layer insights of dyadic collaboration processes that pure quantitative results, such as the ones presented in this paper, are unable to. As more and more libraries adopt new devices for their users, the trend will be that more similar devices will be developed for supporting group learning and collaborative discovery. Understanding the team composition diversity and the multiplicity of collaboration factors and their interplay will enable us to better serve our users as collaborative learners.

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## 11 Table of Figures



## 12 Tables of Tables



## 13 Appendix A. Usability Test Scenario: SUR40 & Library Explorer

*For this study, you and a partner who is assigned to work with you in this research session will be interacting with a touch table called the Microsoft Surface (SUR40) and using software developed by the Harvard Library and Brown University. For the test scenario, there are no right or wrong answers. We are not testing your knowledge or skills. We are simply interested in learning how you interact with the technologies presented in the test. We are also interested in learning how you and your partner collaborate to figure out how to complete various tasks.*

*As an undergraduate student at Harvard University, you are familiar with the Cabot Science Library and have used the facility and collection in the past. You and your partner are both taking a course at Harvard University and your professor has asked the class to participate in a special two person team project. You and your partner (who is your teammate) are to browse selected images from the Harvard Library's digital collections by using Cabot's SUR40 and create a short report of your findings.*

NOTE: You will be performing 8 tasks, and each contains 1 to 4 questions. As you perform each task according to the instruction, please remember to speak out aloud of what you are thinking, and answer the questions for each task verbally. Any questions?

**TASK 1.** You wish to find an application on the SUR40 table that will help you browse the digital collections of the Harvard Library. You turn the table on (or wake it from sleep mode) and find the icon menu screen.

a. What do you do to get to the icon menu? _____

b. Which application would you choose to browse the library's digital collections? _____

c. What tells you that you have found the right application?_____

**TASK 2.** Launch the ***Library Explorer*** application. *From now on, we call the application screen that you will be interacting with as the "interface."*

a. What particular part of the interface would you use to search and filter images with? _____

b. Select a category or date from filter menu. Now, list the interface options that are available to you, in different parts of the interface.

Options: _____

c. Select three different categories. [**Make participants to try out different categories so as to add more images to the screen.**] In the filtered result set of images (the thumbnails displayed in the center of the screen), what particular action would allow you to see a description of one of the images? _____

What tells you that you have found the image description section of the interface?_____

**TASK 3.** Your professor has instructed you to use **Medieval Chart image** for the project. Find the image using the category filter and select the image from the results. From the image description section, open the image in full screen.

a. What action did you take to open the image in full screen?_____

b. Explore and find out what options are available to you in the current (full screen) view. _____

c. Now, zoom in and out of the image. What action did you take to zoom in and out? _____

**TASK 4.** Learn more about the image by using **hotspots**.

a. What do you think hotspots are? _____

b. Turn the hotspots on and off. What did you use to do this? _____

c. How do you view individual hotspots on the image? _____

d. What are displayed in the hotspots? _____

View and read all the hotspots in the medieval chart image.

**TASK 5.** Your professor has asked you to take a **snapshot** of a section of the medieval chart image for your project.

a. Where would you go to find information on how to take a snapshot?

b. Identify a section of the medieval chat image and take a snapshot of it. How did you take the snapshot? _____ [**Moderator asks each participant to try out of taking the snapshot**]

c. You decided that the snapshot is too dark and would like to discard it. How would you discard the image (remove it from the screen)?_____

**TASK 6.** You discarded the snapshot that was too dark. Instead, you wish to take a **brighter snapshot** of the same section of the image and send it to yourself.

a. Adjust the brightness of the image. Which part of the interface did you use?_____

b. Identify the same section of the image you selected before and take a snapshot of it.

Make a note of why you took the snapshot. What did you use to add the note? _____

c. Add your email address and send the snapshot and note to yourself, for the class project. How did you do that? _____

*Note that the email feature has been disabled, but imagine that you have successfully sent yourself the email.*

d. Open one of the hotspots from the chart. Take a snapshot of a part of the hotspot item, make a note and send it to yourself via email for inclusion in your project. How did you do that? _____

*Note that the email feature has been disabled, but imagine that you have successfully sent yourself the email.*

**TASK 7.** Access **associated media** for the medieval chart image, find an appropriate media item and send another snapshot of it to yourself.

a. What would you use to find associated images? _____

b. Select an associated image. What do you think is the relationship between the associated image and the main image? _____

c. Zoom in and out of the associate image. Are there any differences in the zooming functionality between the main image and the associated image?

**TASK 8.** Close the Library Explorer application and return to the main menu screen for the SUR40.

a. What would you do to get back to the main icon menu? _____