Dual Gaze as a Proxy for Collaboration in Informal Learning

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Abstract: Interactive displays are increasingly employed in informal learning environments as a technology for enhancing students' learning and engagement. Interactive displays allow students to collaborate and interact with the content in a natural and engaging manner. Despite the increased prevalence of interactive displays for learning, we know very little about how students collaborate in such settings and how this collaboration influences their performance. In this dual eye-tracking study, with 36 participants, a two-staged within-group experiment was conducted to investigate students' collaboration and learning gains in an interactive display. The results show that collaboratively, pairs who have high gaze similarity have high learning outcomes. Individually, participants spending high proportions of time in acquiring the complementary information from images and textual parts of the learning material attain high learning outcomes. We show that the gaze is an effective proxy to cognitive mechanisms underlying collaboration not only in formal settings but also in informal learning scenarios.

Keywords: interactive displays, informal learning, collaborative learning, dual eye-tracking

Introduction

There is growing interest in investigating the use of interactive displays in a plethora of domains, due to their decreasing cost and increasing commodity/availability. Interactive displays have been used for supporting informal learning activities (Klopfer et al., 2005; Dillenbourg & Evans, 2010), among other purposes. However, little evidence exists on how to create and put into practice engaging, efficient, and highly collaborative activities on interactive displays. There have been numerous studies that point out that utilization of interactive displays proved to be an excellent tool to promote collaboration and cooperation while learning (e.g. Schäfer et al., 2013); and since work and interactive displays, such as a tabletop surface, can be considered as a ubiquitous feature of learning, the software that accompanies such displays could be augmented to adapt to various scenarios (Dillenbourg & Evans, 2010).

There is an emerging literature on interactive displays for collaborative interaction and their use in educational settings. In their review, Higgins et al. (2012) propose a typology of features of this technology and offer an analysis of the pedagogic potential of these features. Researchers have to pay attention to two common mistakes that have been repeated each time a new technology is introduced in education: over-generalization and over-expectation (Dillenbourg & Evans, 2010). For instance, in Zaharias et al. (2013) empirical study, researchers assessed the learning performance and user experience between a group that followed the traditional learning procedure in a museum and a group in which students interacted with a multi-touch application dedicated to the museum. Although their results show statistically non-significant differences in the learning performance, the second group reported significantly higher levels of fun and engagement than the first group. Most studies are focused on the experience, fun, enjoyment and engagement of the users (e.g. Schneider et al. 2012; Schäfer et al, 2013). It seems that in order to better understand the way that users learn and collaborate on an interactive displays, further tools and studies are needed.

Based on recent studies regarding collaboration and learning, one important tool that could be used to unveil the cognitive mechanisms underlying collaboration is the dual eye-tracking (DUET). There are studies explaining the expertise (Jermann et. al. 2010), collaboration quality (Sharma et. al 2015), learning outcome (Jermann and Nueslli, 2012), and the task-based performance (Nuessli et. al., 2009) using dual eye-tracking data. However, to the best of our knowledge, DUET has not yet been applied to investigate collaborative gaze patterns in a combination of physical and digital collaborative spaces. This was our main motivation behind this study. In this contribution, we combine the two aforementioned research areas: interactive displays in informal educational settings and DUET for collaborative learning. We designed an experiment where participants were asked to go through a set of posters and play a game (both in collaborative and competitive ways) using content from the area of Neuroscience. We recorded the gaze of the participants while they were watching the posters and while they were playing the game. In this contribution, we focus on how to explain the relation between the learning gains in an informal learning setting and collaboration, using DUET. Precisely, we address the following research questions:

1. How can the individual and collaborative gaze patterns explain the learning gains?
2. What is the relation between the collaborative gaze patterns in two different contexts of the experiment (physical versus digital)?

Related work

In this section, we will briefly report on the studies using the interactive displays in education, and the dual eye-tracking studies in the collaborative settings. This section is not exhaustive in terms of the studies reported, but it contains the grounding necessary for this paper.

Interactive displays in informal educational settings

One of the first studies on touch technology applied to education was "Read-it", a game-based application, designed to support the development of reading skills in children aged 5-7 years old (Sluis et al., 2004). The results of the pilot experiment showed that children enjoyed playing the game and that the technology was not an obstacle to learning. Different design practices like gamification elements (badges, achievements, points and levels) (Lo et al., 2013) were used in interactive display applications that allow students to engage and collaborate with the application. Schafer et al. (2013) developed a multi-touch learning environment and designed a game that consists of multiple learning and playing modes in which teams of students can collaborate or compete against each other. This multiplayer approach of supporting competition, collaboration and cooperation is perceived as motivating and "fun". Greater playfulness and enjoyment have been indicated while students were working with the multi-touch display. In a more recent study, Ardito et al., (2013) proposed a new educational format, inspired by the Discovery Learning Technique, which integrates educational games, designed to be played on large multi-touch displays, with other types of formal and informal learning. Ardito et al., (2013) showed that their proposed educational format is effective and that games on these novel multi-touch systems engage users, stimulate collaboration and help consolidating knowledge.

Antle et. al., (2011) developed the tabletop game Futura (reported effective and enjoyable by the majority of the general public), with a focus to identify and understand key design factors of importance in creating opportunities for learning. In this study, some special affordances of a multi-touch display are depicted, for instance, the fact that the interface allows all the players to see how and what their co-players are doing. Besides, Watson et al. (2013) suggests that there may be something inherently more appealing about the direct nature of multi-touch interaction, particularly when applied to a game. Kirriemuir and McFarlane (2004) claim that before games can take on a meaningful role in formal or informal education, the education sector and the wider public and media need to better understand the potential and diversity of such 'tools'. In this study we investigate these 'tools' with the use of dual eye-tracking.

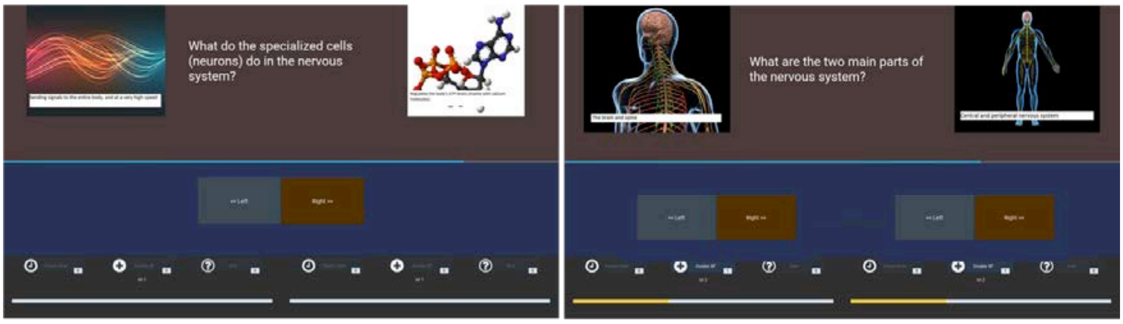
Dual eye-tracking (DUET)

Previous research has shown the importance of DUET to unveil the cognitive mechanisms underlying collaboration. In a dual eye-tracking study concerning listening comprehension, Richardson and Dale (2007) showed that the pairs having high cross-recurrence (probability to look at the same object at the same time) have high comprehension results. Jermann and Nueslli (2012) showed similar results in a pair program comprehension tasks. The pairs which had high cross-recurrence also had high understanding levels (Jerman & Nuessli, 2012). Nuessli et al. (2009) used DUET data to predict the task-based success in Raven matrices and Bongard problems. The authors used gaze density and fixation dispersion of the pair to predict the success of the pair with an accuracy of 78%. In a collaborative version of Tetris, Jermann et al. (2010) predicted the pair configuration (expert-novice, novice-novice, expert-expert) using the DUET data with and accuracy of 75%. Sangin et al. (2008) used a Knowledge Awareness Tool (KAT) to inform the peers about their partner's knowledge in a collaborative concept map task. The results show that the gaze on the KAT was correlated to the relative learning gain of the pairs. In a pair-programming task, Sharma et al. (2011) showed that the pairs with a high level of understanding look at the data flow of the program while the pairs with a low level of understanding read the program as if it was English text. In another DUET experiment with collaborative concept map, Sharma et al (2015) showed that the gaze similarity (the probability to look at the same set of objects in the same time-window) is higher for the pairs with a high collaboration quality than that for the pairs with a low collaboration quality.

All the aforementioned studies show that using dual eye-tracking data, one can explain the expertise, collaboration quality and the task-based performance. In the present study, we utilize dual eye-tracking to explain pairs' learning gains in an informal learning context.

Experiment

In this section we will present the details of the experiment and the variables involved in the analysis. In the experiment, the participants were asked to fill in a pretest about the content they were going to learn. Then they went through five posters about the structure of neurons, different areas of the brain and their functions, three neurological disorders, and the limbic system (two examples are shown in Figures 3.a and 3.b). The next phase was the first individual posttest. The next phase was a gamified quiz application played in an interactive display and focusing on the same content as the posters. The game had two modalities: in one modality the team played collaboratively while in the second, the members of a team played against each other (the interfaces for the collaborative and the competitive versions of the games are shown in Figures 1.a and 1.b respectively). The order of the game modalities was balanced among the teams. Finally, the participants individually took a second posttest. All the tests and the quizzes in the games were multiple-choice questionnaires. The poster phase was 12-15 minutes long and each modality of the game (collaborative/competitive) was 6-7 minutes long. The gaze of the participants was recorded during the poster phase and the game phase using SMI and TOBII eye-tracking glasses at 60 Hz.



(a) (b)

Figure 1. Interfaces for the (a) collaborative, and (b) competitive versions of the game. The elements for the two versions were identical except in the collaborative version there was only one set of buttons to select the correct answer, while in the competitive version there were two different sets of buttons for each player.

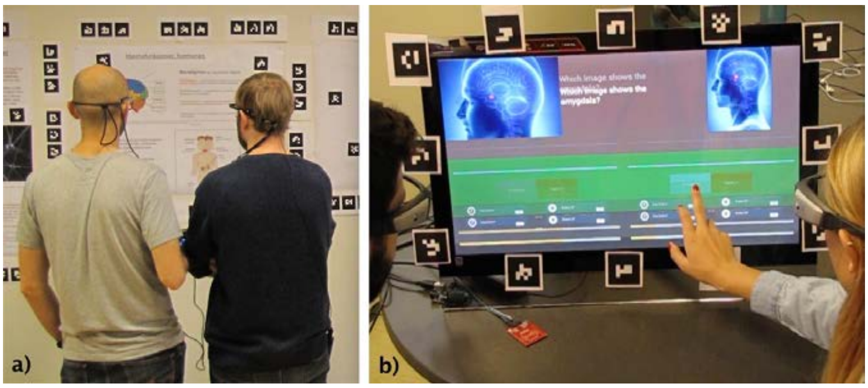


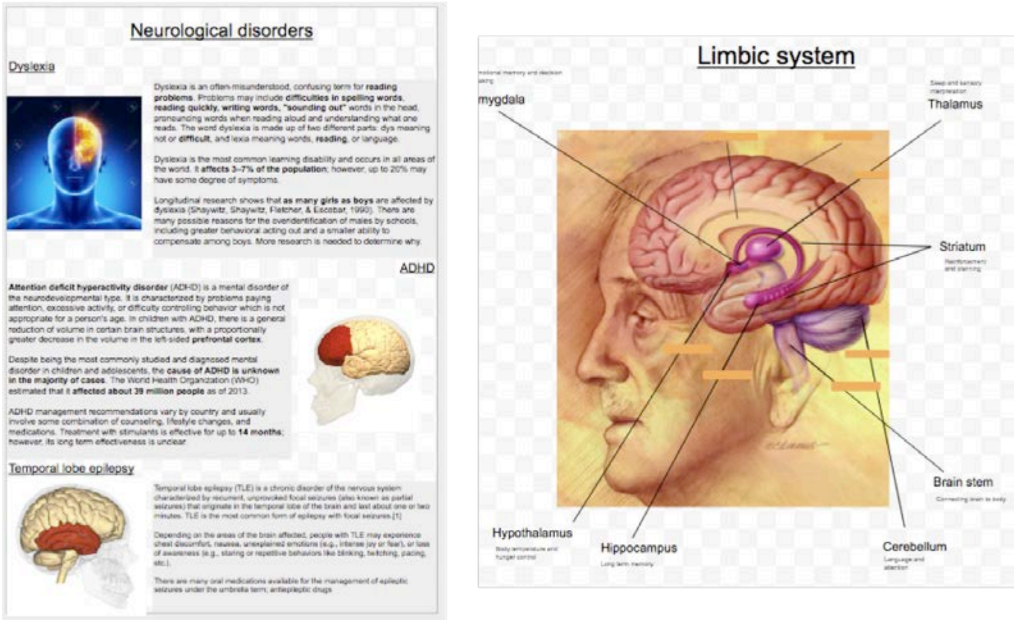
Figure 2. Experiment screenshots, (a) Teams are watching the posters as they would do in a museum, and (b) Teams are playing gamified quizzes (collaborative/competitive) on interactive display.

Participants and procedure

There were 36 university students (18 randomly formed dyads), who participated in the experiment; there were 13 females among the participants. The average age was 24.4 years (SD = 5 years). Upon their arrival in the lab, they filled in a pretest about the poster content; afterwards, they watched the five posters. The simple instruction for the poster phase was "go through all the posters as if you were visiting a museum with your friend". The participants were allowed to discuss the content of the posters with their partners (figure 2.a). The dyads were not mandated to stick to each other, however, most of them went through the posters together. Once they finished watching and discussing the posters, the participants individually filled the first posttest. Further, they played the gamified quiz (collaborative/competitive) where they received one of the three power ups for each correct answer: "double xp", "pause time", and "hint" (figure 2.b). During the game phase, the participants had a maximum of 30 seconds to answer each question; they were allowed to go back to the posters and look for the answers. Once they finished both the modalities of the game, they filled in a final second posttest. All the participants were rewarded an equivalent of $10.

Dependent variables

We normalized test scores to be between 0 and 1. The two dependent variables are the scores in the first and the second posttests. We do not consider the learning gain in this experiment, as we observed a floor effect on the pretest scores (Mean = 0.2, Median = 0.1).



(a) (b)

Figure 3. Examples of the posters, (a) Neurological Disorders, and (b) The Limbic System.

Process Variables

Performance in the game: The participants received individual experience points (xp) during the game (both collaborative and competitive) when they replied correctly to a question. We consider the xp value as their game performance index.

Individual Gaze - AOI Transitions: We divided the posters into different Areas of Interests (AOIs), for example, text blocks and image blocks. Next, we computed the proportions of the gaze transitions from the images in the poster to the corresponding text and also the proportions of the gaze transitions from the text to the corresponding images. For example, in the Figure 3(a), an image to text transition would be a shift of gaze from the top left image to any of the first three paragraphs and the opposite for the text to image transitions. Any transition from the top-left image to any paragraph other than the first three ones would not be counted as a valid image to text transition. The opposite is also true for the text to image transitions.

Collaborative Gaze - Gaze Similarity: To compute the metric for the collaborative gaze patterns, we used the same measure as used by Sharma et al., (2012 and 2015). This measure is called the gaze-similarity and is computed as the cosine similarity of the proportionality gaze vector. The proportionality gaze vector is the vector denoting the proportion of the time spent by each participant looking at the different elements of the visual stimulus for a small window of time (in our case 10 seconds). A gaze similarity value of 1 will depict that the two peers spent exactly the same proportions of 10 seconds on different AOIs. Whereas, a gaze similarity value of 0 will depict that the two peers were looking at completely different elements during a given time window of 10 seconds.

Results

In this section, we will present the various relations we find among the process and dependent variables. We observe the following relations:

Improvement in the knowledge from pretest to the first posttest: we observe a significant improvement from the pretest score to the first posttest score for all the participants ($t(69.96) = -7.91, p < .0001$). The scores in the first posttest are significantly higher than the pretest scores (Figure 4).

No improvement in the knowledge from the first to second posttest: however, we do not observe significant improvement from the first to second posttest ($t(69.88) = 0.39, p > .05$). The scores in the two posttests were similar for almost all the participants (Figure 4).

Correlation between the game score, the first and the second posttest: we observe three significant correlations: 1. The scores in the first and the second posttests are correlated ($r(34) = 0.69, p < .0001$). The participants who score high in the first posttest also score high in the second posttest (Figure 5.a). 2. The score in the game is correlated to the score in the first posttest ($r(34) = 0.42, p = .01$). The participants who score high in the first posttest also perform well in the game (Figure 5.b)). 3. The score in the game is correlated to the score in the second posttest ($r(34) = 0.34, p = .04$). The participants who perform well in the game also score high in the second posttest.

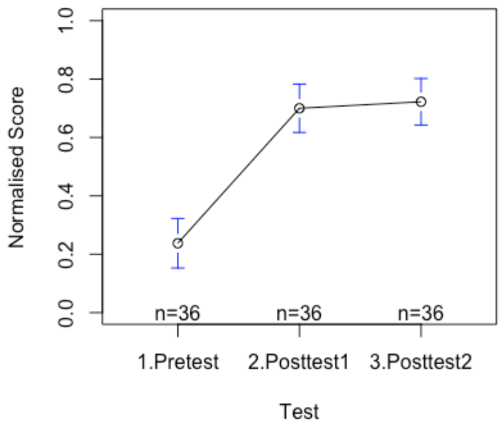


Figure 4. Comparison of scores from the pretest, the first and the second posttest. All values are normalized between 0 and 1. The points show the mean values among all the participants and the blue bars show the 95% confidence intervals.

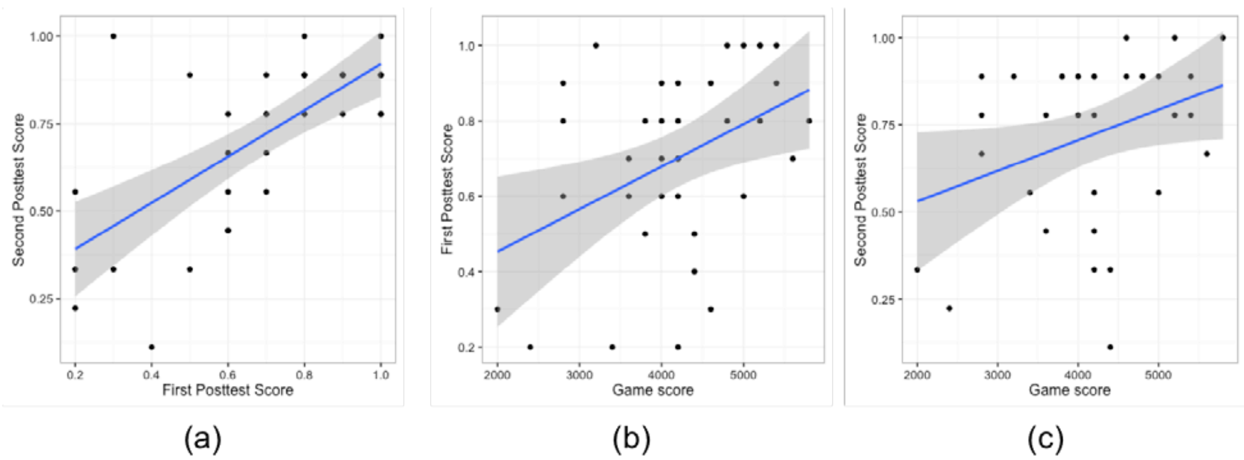


Figure 5. Scatter Plots for (a) first and second posttest score, (b) game score and the first posttest score, and (c) game score and the second posttest score. In all the plots the blue line shows the linear model for the variable on y-axis given the variable on the x-axis. The grey area shows the 95% confidence interval.

AOI transitions and the first pretest score: next, we consider the individual gaze patterns during the poster phase. We observe a significant correlation between the transitions from image to text and the first posttest score ($r(34) = 0.47, p = .003$). The participant having high proportion of the image to text transitions, score high in the first posttest (Figure 6.a). Moreover, we also observe a significant correlation between the transitions from the text to image and the first pretest score ($r(34) = 0.48, p < .002$). Participants that have high proportion of the text to image transitions score high in the first posttest (Figure 6.b).

Gaze similarity and the first pretest score: further, concerning the collaborative gaze patterns, we observe a significant correlation between the gaze similarity during the poster phase and the first posttest score ($r(16) = 0.51, p = .03$). The pairs having high gaze similarity have high average first posttest score (Figure 7.a).

Gaze similarity during posters and during the game: moreover, we also observe a significant correlation between the gaze similarity during the poster phase and the gaze similarity during the game phase ($r(16) = 0.49, p < .04$). The pairs having high gaze similarity during the poster session also have high gaze similarity during the game phase (Figure 7.b).

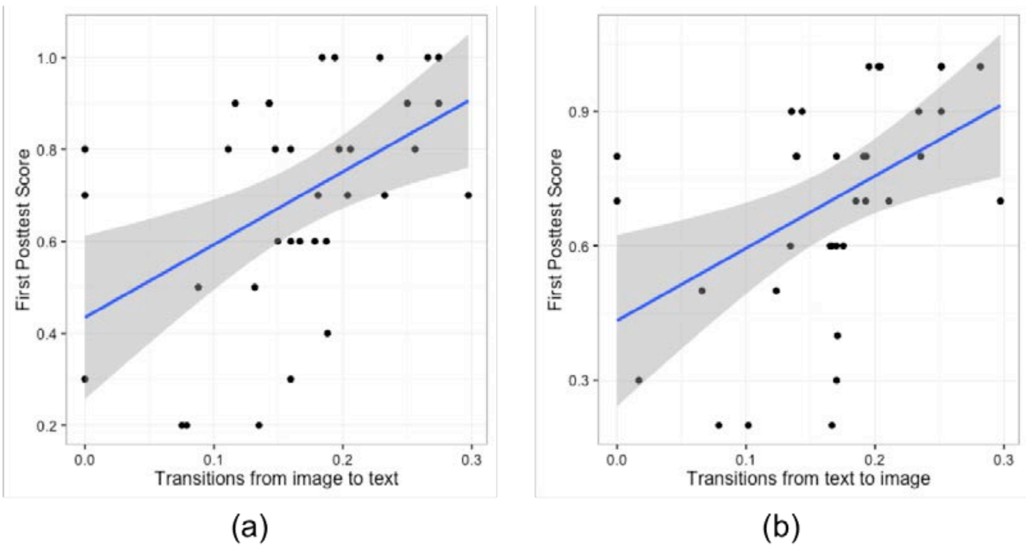


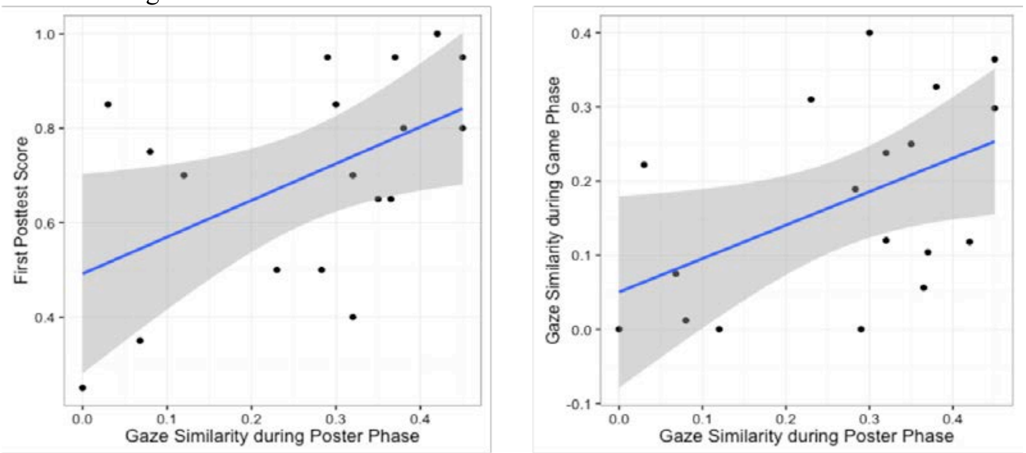
Figure 6. Scatter Plots for the individual transitions (a) image to text, and (b) text to image; and the score in the first posttest. In all the plots the blue line shows the linear model for the variable on y-axis given the variable on the x-axis. The grey area shows the 95% confidence interval.

Discussion and conclusions

The results presented in the previous section represent two behavioural gaze patterns (individual AOI transitions and collaborative gaze similarity), both of which are correlated to participants' learning outcomes (Question 1).

The first behavioural gaze patterns we report on are the individual transitions to and from the images and the text chunks. The results show that the participants having more such transitions have a higher score in the first posttest than those who have fewer images to text and text to image transitions. One plausible explanation for this relation is that the image to text and text to image transitions translate to the behaviour of combining the information present in the images and the text. The complementarity of the two information sources is necessary to understand the content. Those participants who understood the relation between the two information sources got high first posttest scores. This result is inline with an eye-tracking study by Shrama et al. (2015) where the authors showed that the understanding the complementarity of the graphical and textual elements in a video lecture was a key process to attain high learning gain.

The second behavioural gaze patterns we report on are the collaborative gaze patterns. The gaze similarity denotes the proportion of time the peers spent looking at the same set of objects within the given time window. While looking at the same areas, the peers reflect together on the content of the posters and thus build upon a mutual understanding about the learning material; hence attain higher learning outcomes than the pairs who have lower gaze similarity. This result was also found by Richardson and Dale (2005), Jermann and Nuessli (2012) and Sharma et al. (2013 and 2015). In different contexts, these contributions have shown that the gaze similarity (or gaze cross-recurrence) is correlated to the task-based performance and/or learning outcomes in collaborative settings.



(a) (b)

Figure 7. Scatter Plots for (a) collaborative gaze similarity during the poster phase and the first posttest score, and (b) collaborative gaze similarity during the poster phase and the game phase. In all the plots the blue line shows the linear model for the variable on y-axis given the variable on the x-axis. The grey area shows the 95% confidence interval.

The fact that there is no significant improvement from the first posttest scores to the second posttest scores has its roots in the level of scores the participants attained in the first posttest (Mean = 0.70, SD= 0.24). This leaves a small room for improvement in the second posttest. However, we see a slight (statistically non-significant) improvement in the second posttest (Mean = 0.72, SD = 0.23). We also see a correlation between first and second posttest scores, suggesting that the interactive application did not hinder the learning process. This is inline with the results found by Sluis et. al (2004) and Zaharias et al. (2013) who also found that interactive displays were not an obstacle for the learning processes. We also found that the learning outcome was correlated with task-based performance (game xp). This is also inline with the findings of Sangin (2009) who found that task-based performance was correlated to learning gains in a collaborative concept-map task.

Finally, considering the relation between collaborative gaze patterns during the two experimental phases (Question 2), we find a positively significant correlation (Figure 7.b) between the gaze similarity during the poster phase (physical) and the gaze similarity between the game phase (digital). The two phases were quite different from each other: in the poster phase the participants collaborated voluntarily while in the game phase they were told to collaborate. Despite this fact, pairs with high gaze similarity during the poster phase, also have high gaze similarity during the game phase. This supports the interaction style hypothesis of Sharma et. al. (2015), which states that there are two different interaction styles in collaborative settings: "Looking AT" and "Looking THROUGH". The former appears when the peers are interacting with the content only, while the later appears when the peers are using the content as a medium to interact with their partners. In the present study, we find the same two profiles: the pairs having low gaze similarity during both the poster and game phases appear to interact with the content only (looking AT), while the pairs having high gaze similarity during both the phases appear to use the content as the medium to interact with their partners (looking THROUGH).

In this contribution, we showed that there are individual and collaborative gaze patterns, which can explain the learning outcomes of the participants in a collaborative informal educational setting. These explanations are coherent with studies conducted in more formal educational settings. This motivates us to interlace these findings with dialogues and actions on the touch technology and interactions to understand more about pairs' collaborative dynamics. Moreover, these results will also lead us to design more hands-on activities with interactive displays within the informal settings to study their influence on the learning outcomes.

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