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# Exploratory study on collaborative interaction through the use of Augmented Reality in science learning

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**Abstract**

This paper reports the exploratory study's finding based on the participants' behaviors while interacting with Augmented Reality based system in group learning environment. Technology has long been used to enhance group learning, often known as Computer-Supported Collaborative Learning (CSCL). Recent research in this area showed that technology somehow hinders the communication and interaction of group members. Therefore, as suggested by many researchers, introducing back the physical interaction could reduce these obstacles. Augmented Reality (AR) is the technology whereby the physical and virtual objects can co-exist in real time. The physical objects can be used to interact with the system. However, literature showed the number of the papers that explore the interaction and communication process which occurred while using AR to support group learning relatively low. Therefore, this paper is aimed to fulfill that gap. Conducting a science experiment on electricity topic was used as a case study. Eight groups of two students participated in this study. The primary data used in this study was collected from the analysis of video recording of students' behavior as well as from the survey questionnaire on the user awareness of communication and interaction. The video were then annotated and coded to extract information by using Actogram2 software. Results showed that several types of natural interactions were exhibited. Both verbal and non-verbal communication cues were observed. Physical objects were the main interacting material that group members referred to and used. These results suggested the importance of incorporating physical objects in collaborative AR based system. Further, this study showed positive evidence to strengthen the raised conjuncture that AR could be one of the effective tools to support collaborative learning.

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*Keywords:* Augmented Reality; Education; Computer-Supported Collaborative Learning; Learning Process

## 1. Introduction

Computer-Supported Collaborative Learning (CSCL) refers to the use of computer and its technology to support group learning [1]. CSCL has proven as one of successful learning approaches which could benefit in

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both academically and socially [2]. Various technologies were used to support CSCL. However, different technology provides different collaboration environment [3]. Many researchers reported on the drawback of using the computer in CSCL e.g. the interference of computer in interaction and communication among group members, the difficulty in making references and the accessing of information etc [3, 4, 5]. With the current technology, some of the interaction and communication cues were hidden especially the non-verbal communication cues [3]. Besides that by using a computer, only one group member will have chance to interact with the task at hand at one time, the rest of group members tends to stand and look on, therefore, reducing their attention and engagement to the lesson [4]. As suggested by Chastine, and Zacharie, introducing back the physical interaction could reduce the problem caused by using computer alone [5, 6].

Augmented Reality (AR) is one of the technologies which allow the co-existing of physical and virtual objects and support real time interaction. AR based system permits users to use the physical object to interact with the virtual content in real-time [7]. AR shows significant benefit to support learning e.g. supporting visualization [8], conceptual learning, spatial learning [9], kinesthetic learning [10], individual engagement [11] etc. besides that, few comparison studies also revealed that AR offers learning environment which similar to natural collaborative learning environment [12, 13].

The research exploring the use of AR to support CSCL is relatively low in number [14]. Despite the important of collaboration, researchers seem to overlook the necessity in exploring how the interaction and communication happened during the collaborative learning. Besides that, putting students around a computer does not confirm that collaboration will occur. Therefore, it is important to explore the group interaction during the collaborative activity. The overall aim of this exploratory research is to investigate the possible use of AR technology as a CSCL interface for supporting collaboration processes in group learning. The question on how and what type of interaction could be supported by AR technology were raised in order to explore the affordance offered by AR technology. Next section presents background of study, followed by the methodology used in gathering and analysis the data. Section 4 presents the finding of this research and finally the work will be concluded in section 5.

## 2. Background of Study

Two different aspects were explored in order to investigate the used of AR to support collaborative learning which are CSCL and AR.

### *2.1. Computer-Supported Collaborative Learning (CSCL)*

Previously, various types of technology have been studied to facilitate group learning e.g. [15, 16, 17, 18]. However, using different technology generates different collaboration environment [3]; Virtual Reality (VR) technology offers immersive learning environment. It supports the visualization for the learner. However, the non-tangible nature of virtual object introduces interaction challenge and even creates the difficulty in a simple task manipulation [5] as well as introduces some constrains in interaction [15, 19].

Price & Rogers explored the collaboration in digital learning setting and they found that young children tend to work alone while the other group members were just look on [19]. Similarly, Scott et al., [4] also pointed out that in collaboration on typical computer, only one person can control and interact with system.

Besides that Chastine's work, face-to-face collaboration on different computers may also create problem even in doing basic task, especially when collaborators apply different perspective of viewing which create difficulty in making reference to specific objects [5]. Moreover, collaborators who have disparate view can no longer rely on many of the non-verbal communication cues such as gesture, eye gaze etc. Likewise, Lipponen, also emphasized the important role of physical material. Recently, this role has seen a decline in CSCL research; even though physical object could offer rich learning resource and referential anchor [1]. Physical objects support collaboration both by their appearance, physical affordances, their semantic representations, their spatial relationships and ability to help focus attention [1]. Real objects are also more than just a source of information but they also the constituents of the collaborative activity, especially in multi-participants setting. In contrast, most computer interfaces for co-located collaborations create the artificial seam. Based on Ishii's study people looking at a projection screen or crowded around a computer monitor are less able to refer to the real object or use natural communication behaviors. The observation on large display have found that simultaneous interaction rarely occurs due to the lack of software supported and input devices for co-present collaboration.

Moreover, Price & Rogers also suggested that physical interaction creates the active learning environment which will increase the level of motivation and attention in learning [19]. Therefore, introducing back the natural physical interaction could leverage the problem faced in virtual collaboration [5, 19]. On the other hand, Zacharia, also pointed out that study on combination of real and virtual environment to support learning is still very lacking [6]. In order to effectively design and utilize the existing technology to support collaborative learning, a clear understanding of the interaction and collaboration activities supported by the technology is necessary.

### *2.2. Augmented Reality (AR)*

AR creates and offers new type of interaction and learning experience by creating the co-existence of physical and virtual objects [10]. However, the potential of AR to support collaborative learning environment is left unexplored, especially, researches on the process which occur during the collaboration [14].

In natural unmediated face to face paradigm users supposed to be able to freely control and navigate their interaction with the object. Correspondingly, Tallyn and his team's work also revealed that the availability of controlling the shared devices among group members also has impact on acquisition of knowledge. The comparison between using CD-ROM, physical book and AR book reveals that in Physical book, children have freely control and navigation on the book which results in more creative ideas [12]. Similarly, Waldner et al., also conducted a comparative study between the use of paper, touch screen and Tangible Tiles of AR system [13]. The study showed that the use of paper for collaboration is the most efficient approach for problem solving. However, the Tangible Tiles and touch screen based system created more enjoyment in collaboration.

Besides that, Tangible Tiles offered interaction which is closely similar to the paper based condition [13]. Member of effective group learning naturally take turns to interact and play with the system. Hence, it introduces the collaborative learning environment that is similar to natural collaboration.

## 3. Methodology

As stated by Collazos et al., the quality of collaboration process is important to be carefully analyzed [21]. Moreover, Hsu et al., highlighted that quality of group interactions influences learning outcome [22]. Therefore, the experiment was carried out in order to capture the collaboration activities during the learning using AR application.

### *3.1. Experimental Design*

In this experiment, electricity topic was chosen as a case study. The prototype called AR Circuit was developed by using ARToolkit tracking libraries wrapped into C#. Black and white squared paper called "marker" was used for interaction. In this experiment, participants were required to design the experiment in order to investigate the relationship of the elements in an electric circuit.

16 participants voluntarily participated in the study. They were grouped into pair to conduct the science experiment. All actions of participants were video recorded.

### *3.2. Data Analysis Method*

In collaborative learning environment, learning occurred through social interaction of group members [1, 20, 21, 23, 24]. However, exploration on the learning process such as association of social interaction in collaborative learning environment, especially when using AR technology as well as the role of technology itself to support collaboration process such as the use of referencing, communication, interaction during collaboration is still very much lacking [5, 14]. According to Collazos et al., the traditional evaluation of collaborative learning is generally made through the performance measurement [21]. More concern of this type of measurement is on how much students have learnt. Only few work which explored on the collaboration that occur during the learning process. However, performance alone cannot confirm that collaboration among group members exist. Therefore, the quality of collaboration process is essential to be explored. Nevertheless, few investigations have been done to evaluate the quality of the collaboration process [21]. Furthermore, many researchers claimed that the interaction analysis contribute to the understanding and developing of the effective collaborative learning environment [25, 26]. Therefore, in this study the collaboration and interaction processes which occurred during the experiment were video recorded and analyzed.

Process measurement captures the collaboration process occurs during the collaboration [27]. According to Billinghurst et al., this information can be extracted from the video recording and note taking during the collaboration activities [27]. The process of extracting information and analysis the video recorded is called “annotation” [28]. Annotation requires to extract and classify the features which could be used to characterize the action or event occurred [29]. This is generally referred as “coding”.

The steps taken in order to analyze the observed data is different, depends upon the software used. In this research, Actogram2 was used to annotate the video records. It is a video annotation tool which could be used to extract information from the video recorded [30]. It is suitable for assisting researcher in making the coding scheme [28]. This software allows the user to define the observation protocol based on the “state” and “event” of the action [30]. Based on Rasoulifar et al., generally annotation process comprises of 3 steps which are configuration, coding and analysis [28]. Table 1 presents the coding scheme which defines the interaction and communication cues which indicate collaboration activities.

Table 1. Coding scheme

| Class | Description |
|---|---|
| Turn taking [3, 29] | Three types of turn taking were observed based on this research which are<br>• Turn taking by participant1: the interaction carried out by participant 1.<br>• Turn taking by participant2: the interaction carried out by participant 2.<br>• Collaboration turn: the action that occurs at corresponding to one’s action such as the picking up of the object and passed to other participants. |
| Gesture [3, 29, 31] | Gesture refers to the non-verbal communication manner which exhibited to achieve, maintain the focus of joint-attention as well as to reinforces and extends the meaning carried by the participants’ conversation [31], pointing is the natural gesture behavior. Some of other gesture exhibition are such as the use of hand to draw the direction of the graph etc. |
| Task performance | Different types of task were exhibited by the participants such as select object, locate the object, rotate the object, sharing object etc. |
| Gaze [3, 29] | Gaze shows the focus of the participants. Three types of gazes are observed which are to the physical object, virtual object and partner. |

## 4. Result and Discussion

Based on observation and the coding scheme identified in section 3, the interaction and communication cues observed during the study are presented in the following section.

### *4.1. Turn Taking*

The turn taking were used to interact mainly to the physical object in order to manipulate the virtual objects. Hence, the number of physical object picking up is observed. Furthermore, physical object picking up can be to select the markers, locate, rotate or refresh the markers.

Select marker: refers to the action where the participants pick up several markers at one time and choose one of them. In some situation participants firstly lay out all the markers on the table, in this case, to select. Most of the time participants took sometimes to look through the markers and pick up one. Sometimes, participants pick it up and place it back simultaneously.

Locate marker: refers to the action where the participants place down the selected marker on the AR Circuit.

Rotate marker: refers to the situation where participants rotate the angle of the marker in order to view the different perspective of the virtual 3D model.

Refresh marker: refers to the action that allows for the program to re-detect the marker. The interaction was observed when participants cover up the marker by their hands/finger and open it simultaneously. In some case participants do pick up the marker from the AR Circuit and directly place it back to observe the changes.

Turn taking could also be for the purpose of writing or reading the lab worksheet. Each group shows different number of turns in each activity. The differences in number of turn taking among partners depend on the collaboration styles of each group too. In group01 and group05, one participant is taking role of recording hence the number of turn taking for writing is higher as compare to the other participant. Meanwhile, another participant showed more turn taking in interaction with the system as can be observed through the number of selecting and locating the markers. Another example of collaboration style is group02, the role of recording as well as the turn taking were shifted among the participants in order to interact with the system. The following figure presents the average number of turn taking for different types of interaction.

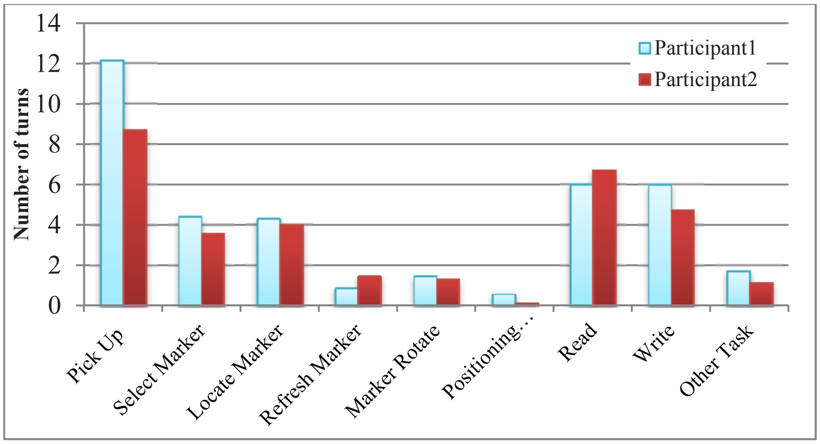


Fig. 1. Average turn taking of each activity

Among the interaction, pick up is the most frequently exhibited interaction during the experiment. Participants pick up both markers and worksheet. Hence, reading and writing activities showed relatively high practice among group members. For the use of marker, selecting and locating the markers is one of the common tasks performed by the participants. Participants select markers and place it in the AR Circuit in order to observe the changes. The sequences of pick up the physical object followed by locating/placing the markers on the circuits were observed for eight times while six times were observed when the participants pick up physical object for selecting the marker. Six times were coded when the participants select the markers before pick it up. This result indicated that the participants interacted with the physical object by using their natural behavior of interaction.

However, the number of turn taking is different among groups. This is due to the time taking to complete the experiment, the steps and styles of doing experiment. For example, group08 noted down the steps that need to take in order to complete the experiment while group02 discussed the steps and begin the experiment immediately, the recording began after the experimentation was complete. Hence, for group02 they need to refer back to the experiment for some missing information such as the amount of the current for each respective resistor, therefore they need to re-apply the different markers to observe the changes again. Therefore, the numbers of turn taking is higher and the time taking is longer.

### *4.2. Pointing Gesture*

Participants used the physical and virtual objects to create the joint of attention and shared ideas through the use of pointing gesture. According to Agrawala, gestures are used to create the shared context of the group members [32]. Pointing is aimed to make other group members aware of the referencing objects which usually were used to complement deictic speech [5]. Hence, the use of pointing gesture towards the physical and virtual objects creates awareness of the shared point of reference and attention and coordination among group members [5]. In this context, the participants pointed to the markers and workbook as well as the virtual object as presented in Figure 2.

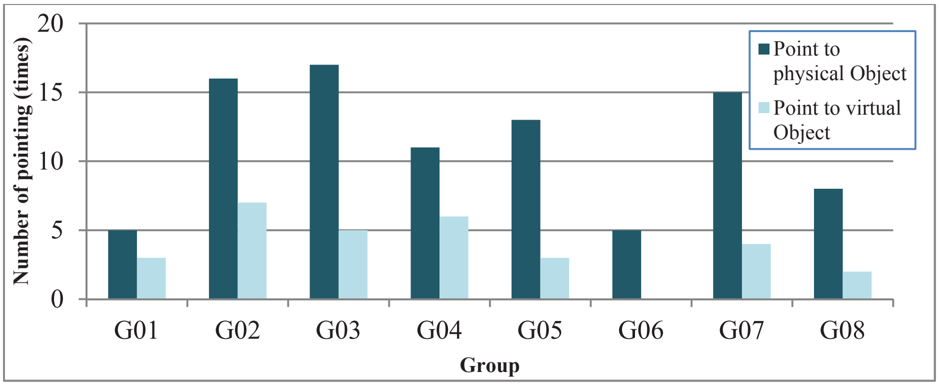


Fig. 2. Numbers of pointing towards the object of each group

In every group, participants referred to the physical objects which are worksheet and markers more frequently as compared to the virtual object. This is due to the physical objects consist of 2 different elements which are the lab worksheet and the markers. Besides, as mentioned by Billinghurst et al., the physical object is often serve as the focused of group collaboration [33]. The pointing gesture occurred when the participants discussed on the question asked in the lab worksheet. Sometimes participants point to the physical marker to refer to the virtual object as was reflected from the sequence of pointing and the gaze. The result shows that workbook, marker and the virtual objects were all referred to by the participants.

### *4.3. Parallel and Collaboration Tasks*

Based on the observation, participants were freely interacting and sharing objects. Simultaneous activities that were carried out are presented in Table 2.

Table 2. Parallel and collaborative tasks observed

| Parallel and Collaboration Activities | G01 | G02 | G03 | G04 | G05 | G06 | G07 | G08 |
|---|---|---|---|---|---|---|---|---|
| Pick up physical object and pass to other member | X | X | X | X | X | X | X | X |
| Pick up physical object at the same time | | X | X | X | X | X | X | |
| Point to the same types of object | | X | X | X | X | | | |
| Read and write | X | X | X | | X | X | X | X |
| Pick up physical object and point | X | X | X | X | | | X | |
| Pick up physical object and read | | | X | X | | X | | X |
| Pick up physical object and write | X | X | | | X | X | | X |
| Point and read | | X | X | | X | X | X | X |
| Point and write | X | X | X | | | X | X | |
| Other parallel tasks | | | X | X | X | X | | |

This table shows that various parallel and collaboration tasks were able to be carried on at the same time without the need to wait for one's turn. Among this, Pick up physical object and pass to other member activities were exhibited by almost every group. This could be pick marker or worksheet and pass it to other group member. Most of the time, when one partner was writing, another partner tend to read what have been written and give comment to towards the question.

This observation result indicates that AR space is capable to offer a space for flexible sharing of object. As the work of Tallyn et al. point out that the flexibility of sharing the objects has an effect on the acquisition of knowledge in group learning [12]. This further shows that AR space allows learning or acquisition of knowledge to occur.

The parallel and collaborative tasks which were observed are picking up the physical object and pass it to other group members show the collaboration interaction among group member. Moreover, it frequently observed that when one participant was writing, another participant tends to read along and point out what have been left. Also participants tend to use hand language to further explain their meaning of conversation. For example when they were asked to draw the graph to represent the relationship between two elements, participants 1 try to explain verbally and using hand to draw the direction. This result suggested that in AR space, participants can natural interact with the system.

### *4.4. Gaze*

Gaze refers to the non-verbal communication cues which present the focus of attention [34, 35]. In normal conversation between two persons, about 60% of conversation involves gaze and 30% involve the mutual gaze [35]. Furthermore, the focus of the viewing towards to objects as well as the partner is one of the indicators of the joint focus of attention towards the learning context [35]. Subjects were keeping in touch by looking at the same object [35]. The following Table 3 presents the gaze of participants.

Table 3. Gaze of participants

| Group | Gaze by participant 1 | | | Gaze by participant 2 | | | Gaze to each others |
|---|---|---|---|---|---|---|---|
| | Gaze to physical object | Gaze to virtual object | Gaze to participant 2 | Gaze to physical object | Gaze to virtual object | Gaze to participant 1 | |
| G01 | 25 | 17 | 2 | 23 | 24 | 6 | 1 |
| G02 | 61 | 36 | 16 | 66 | 36 | 17 | 11 |
| G03 | 53 | 37 | 8 | 41 | 36 | 4 | 6 |
| G04 | 15 | 17 | 2 | 13 | 12 | 1 | 1 |
| G05 | 59 | 50 | 8 | 58 | 45 | 14 | 4 |
| G06 | 21 | 16 | 2 | 22 | 14 | 5 | 1 |
| G07 | 33 | 29 | 5 | 27 | 27 | 5 | 1 |
| G08 | 9 | 11 | 1 | 8 | 11 | 2 | 1 |

The most frequent gaze of participants shows toward the physical objects while the focus toward partners shows relatively low. This is due to the tangible manner of physical object which create the focus of attention among group members. The less amount of gaze towards partners shows that participants tend to focus more on the task at hands. However, they also pay attention to their partners. Kiyokawa et al. suggested that the less amount of focus toward partners could be because of the use of desktop based display [3].

In every group interaction, the gaze was often observed to follow the other partner's pointing gesture. As the linear sequence analysis result of Actogram2 application presented in Figure 3 shows that after the use of pointing gesture by participant1, partcipant2 gaze to the object.

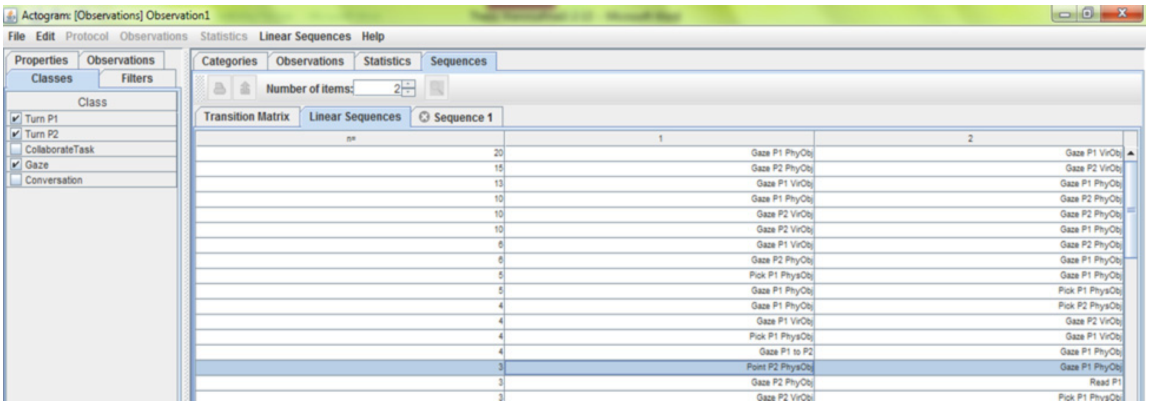


Fig. 3. Linear sequence of gaze

Figure 3 also showed that participants interact with the physical object to manipulate the virtual objects. As the linear sequence of action based on the turn taking and gaze relationship showed that directly before/after pick up the physical object, the gaze shifted to focus more on the virtual object. This is because of the physical markers were designed to manipulate the virtual object. Furthermore, it is often observed that the writing process occurred alternately with the shifting of gaze to the virtual object. This is due to the requirement of changes observation during the experimentation.

## 5. Conclusion

The importance of learning approach is undeniable as it will shape future education. As suggested by many researchers, introducing the physical interaction among group learners can create joyful and engaging learning environment as well as supporting natural communication and interaction. AR offers a combination of physical and virtual object interface. Users can interact with the physical environment in natural ways while they can view the simulations occurs in real time. However, before applying AR in the formal learning environment, research needs to be carried out to investigate and explore the potential and drawbacks of this technology.

This research aimed to explore the affordance of AR technology to support collaborative learning process. Communication and interaction are essential process for collaboration to occur as it had been investigated by many researchers. To create the collaborative learning interface, the designed prototype should provide the space for collaboration, hence, support the interaction among group members and interaction towards the system. The exploratory observation from video transcript shows that various types of interaction among group members had occurred. The interaction of group members is reflected through the communication and action exhibited by group members. As it had been discussed, AR offers various types of collaboration interaction which can occur concurrently or simultaneously, meanwhile, participants can also continue with their task at hand personally as it had been explored by [12]. This collaboration action is verified to be one of the essential elements in or to support collaboration activity.

## References

[1] Lipponen L. Exploring Foundations For Computer-Supported Collaborative Learning. In: Proceedings of the Conference On Computer Support For Collaborative Learning: Foundations For A CSCL Community, International Society Of The Learning Sciences, 2002, pp. 72-81.

[2] Kasirun, Z. M., & Salim, S. S. Potential Of Computer-Supported Collaborative Learning Application Use In Malaysian Schools. International Arab Journal Information. Technology 2004; **1**(2): 187-195.

[3] Kiyokawa K, Billinghurst M, Hayes SE, Gupta A, Sannohe Y, Kato H. Communication Behaviors Of Co-Located Users In Collaborative AR Interfaces. In: Proceedings of the International Symposium on Mixed And Augmented Reality ISMAR 2002, pp. 139-148.

[4] Scott SD, Grant KD, Mandryk RL. System Guidelines For Co-Located, Collaborative Work On A Tabletop Display. In: Proceedings of the Eighth Conference on European Conference on Computer Supported Cooperative Work, 2003, pp. 159-178.

[5] Chastine JW. On Inter-Referential Awareness In Collaborative Augmented Reality. Phd. Dissertation. Georgia State University, 2007.

[6] Zacharia ZC. Comparing And Combining Real And Virtual Experimentation: An Effort To Enhance Students' Conceptual Understanding Of Electric Circuits. *Journal Of Computer Assisted Learning* 2007, **23**(2): 120-132.

[7] Kaufmann H.(2003). Collaborative Augmented Reality In Education, Institute of Software Technology and Interactive Systems, Vienna University of Technology, 2003.

[8] Billinghurst M, Grasset R, Looser J. Designing Augmented Reality Interfaces. ACM SIGGRAPH Computer Graphics - Learning Through Computer-Generated Visualization 2005; **39**(1): 17-22.

[9] Woods E, Billinghurst M, Looser J, Aldridge G, Brown D, Garrie B, Nelles C. Augmenting The Science Centre And Museum Experience. In: Proceedings of the 2nd international conference on Computer graphics and interactive techniques in Australasia and South East Asia. ACM 2004, pp. 230-236.

[10] Krauss M, Riege K, Pemberton L, Winter M. Remote Hands-On Experience: Distributed Collaboration With Augmented Reality. In: Proceedings of the Learning In The Synergy Of Multiple Disciplines, EC-TEL 2009, Vol. 5794, Berlin/Heidelberg: Springer.

[11] Ucelli G, Conti G, Amicis RD, Servidio R. Learning Using Augmented Reality Technology: Multiple Means Of Interaction For Teaching Children The Thoery Of Colours. In M. Maybury Et Al. (Eds.): INTETAIN,2005, LNAI 3814, pp. 193-202.

[12] Tallyn E, Frohlich D, Lynketscher N, Signer B, Adams G. Using Paper To Support Collaboration In Educational Activities. In: Proceedings of Conference on Computer Support For Collaborative Learning: Learning 2005: The Next 10 Years, 2005; pp. 672-676.
[13] Waldner M, Hauber J, Zauner J, Haller M, Billinghurst M. Tangible Tiles: Design And Evaluation Of A Tangible User Interface In A Collaborative Tabletop Setup. In: Proceedings of the 18th Australia Conference On Computer-Human Interaction: Design: Activities, Artefacts And Environments. ACM 2006, pp. 151-158.
[14] Dünser A, Grasset R, Billinghurst M. A Survey Of Evaluation Techniques Used In Augmented Reality Studies. In ACM SIGGRAPH ASIA 2008; pp.1-27.
[15] Stanton D, Neale H, Bayon V. Interfaces To Support Children's Co-Present Collaboration: Multiple Mice And Tangible Technologies. In: Proceedings of the Conference On Computer Support For Collaborative Learning: Foundations For A CSCL Community, 2002; pp. 342-351.
[16] Lingnau A, Hoppe HU, Mannhaupt G. Computer Supported Collaborative Writing In An Early Learning Classroom. *Journal Of Computer Assisted Learning* 2003, **19**(2): 186-194.
[17] Johnson A, Roussos M, Leigh J, Vasilakis C, Barnes C, Moher T. The NICE Project: Learning Together In A Virtual World. In: Proceedings of the Annual International Symposium Virtual Reality, IEEE 1998; pp. 176-183.
[18] Echeverría A, Améstica M, Gil F, Nussbaum M, Barrios E, Leclerc S. Exploring Different Technological Platforms For Supporting Co-Located Collaborative Games In The Classroom. *Computers In Human Behavior* 2012; **28**: 1170-1177.
[19] Price S, Rogers Y. Let's Get Physical: The Learning Benefits Of Interacting In Digitally Augmented Physical Spaces. *Journal Of Computer & Education* 2004; **43**: 137-151.
[20] Suthers D. Technology Affordances For Intersubjective Meaning-Making: A Research Agenda For CSCL. *International Journal Of Computer Supported Collaborative Learning* 2006; **1**(3):.315-337.
[21] Collazos CA, Guerrero LA, Pino JA, Ochoa SF. A Method For Evaluating Computer-Supported Collaborative Learning Processes. *International Journal Of Computer Applications In Technology* 2004; **19**(3): 151-161.
[22] Hsu MH, Chen IYL, Chiu CM, Ju TL. (2007). Exploring The Antecedents Of Team Performance In Collaborative Learning Of Computer Software. *Computers & Education* 2007; **48**(4): 700-718.
[23] Dillenbourg P, Järvelä S, Fischer F. The Evolution Of Research On Computer-Supported Collaborative Learning: From Design To Orchestration. In Technology Enhanced Learning: Principles And Products. Springer Verlag 2009; pp. 3-19
[24] Kreijns K, Kirschner PA, Jochems W. Identifying The Pitfalls For Social Interaction In Computer-Supported Collaborative Learning Environments: A Review Of The Research. *Computers In Human Behavior* 2003; **19**(3): 335-353.
[25] Anjewierden A, Gijlers H, Kolloffel B, Saab N, De Hoog R. Examining The Relation Between Domain-Related Communication And Collaborative Inquiry Learning. *Computers & Education* 2011; **57**(2): 1741-1748.
[26] Soller A. Supporting Social Interaction In An Intelligent Collaborative Learning System. *International Journal Of Artificial Intelligence In Education* 2001; **12**: 40-62.
[27] Billinghurst M, Belcher D, Gupta A, Kiyokawa K. Communication Behaviors In Collocated Collaborative AR Interfaces. *International Journal Of Human-Computer* Interaction 2003; **16**(3): 395-423.
[28] Rasoulifar R, Meillon B, Thomann G, Villeneuve F. Observation, Annotation And Analysis Of Design Activities: How To Find An Appropriate Tool?. In: Proceedings of the 17th International Conference On Engineering Design, 2009, Vol. 5, pp. 193-204.
[29] Billinghurst M. Shared Space: Explorations In Collaborative Augmented Reality. Phd. Dissertation. University Of Washington. 2002
[30] Kerguelen A. Actogram 2 Reference Manual, 2012. Available: http://www.Actogram.Com/Resources/Actogram2-En.Pdf
[31] Reynolds FJ, Reeve RA. Gesture In Collaborative Mathematics Problem-Solving. *The Journal Of Mathematical Behavior* 2001; **20**(4): 447-460.
[32] Agrawala M, Beers AC, McDowall I, Frohlich B, Bolas M, Hanrahan P. The Two-User Responsive Workbench: Support For Collaboration Through Individual Views Of A Shared Space. In: Proceedings of the 24 th annual conference on Computer graphics and interactive techniques, 1997, pp. 327-332.
[33] Billinghurst M, Kato H., Poupyrev I. Collaboration With Tangible Augmented Reality Interfaces. In International HCI 2001, Vol. 1, pp. 5-10.
[34] Mukawa N, Oka T, Arai K, Yuasa M. What Is Connected By Mutual Gaze?: User's Behavior In Video-Mediated Communication: Proceedings of the CHI'05 Extended Abstracts On Human Factors In Computing Systems ACM 2005. pp. 1677-1680.
[35] Vertegaal R, Slagter R, Van Der Veer G, Nijholt A. Eye Gaze Patterns In Conversations: There Is More To Conversational Agents Than Meets The Eyes. In: Proceedings of the SIGCHI'01, 2001, Seattle, WA, USA. pp. 301- 308.