Round or rectangular tables for collaborative problem solving? A multimodal learning analytics study

Milica Vujovic, Davinia Hernández-Leo, Simone Tassani, Daniel Spikol

ICT Department, Universitat Pompeu Fabra, Barcelona

Smart Learning at the Internet of Things Research Centre at Malmö University

***Milica Vujovic** is a PhD student in the ICT Department of Universitat Pompeu Fabra, within the TIDE research group. Her research interests lie in the fields of multimodal learning analytics and smart learning environments.*

***Davinia Hernández-Leo** is a full professor, Icrea Academia Fellow in the ICT Department of Universitat Pompeu Fabra, Barcelona and director of the TIDE research group. Her interests include technologies for learning design, collaborative learning, analytics and architectures for educational environments.*

***Simone Tassani** is a senior researcher on the Multiscale and Computational Biomechanics and Mechanobiology team in the SIMBiosys group. His research focuses on the multilevel analysis of body motion. He is also an expert in multifactorial analysis.*

***Daniel Spikol** is an associate professor in computer science at Malmö University, Sweden. He is the group leader for smart learning at the Internet of Things Research Centre. His interests include multimodal learning analytics for group work, computational thinking and technology-enhanced learning.*

Address for correspondence: Milica Vujovic, Universitat Pompeu Fabra, Roc Boronat 138, 08018 Barcelona. E-mail: milica.vujovic@upf.edu

Abstract

The current knowledge of the effects of the physical environment on learners' behaviour in collaborative problem-solving tasks is underexplored. This paper aims to critically examine the potential of multimodal learning analytics, using new data sets, in studying how the shapes of shared tables affect learners' behaviour when collaborating in terms of patterns of participation and indicators related to physical social interactions. The research presented in this article investigates this question considering the potential interplay with contextual aspects (level of education) and learning design decisions (group size). Three dependent variables (distance between students, range of movement and level of participation) are tested using quantitative and qualitative analyses of data collected using a motion capture system and video recordings. Results show that the use of round tables (vs rectangular tables) leads to higher levels of on-task participation in the case of elementary school students. For university students, different table shapes seem to have a limited impact on their levels of participation in collaborative problem solving. The analysis shows significant differences regarding the relationship between group size and the distance between students, but there is no substantial evidence that group size affects the level of participation. The findings support previous research highlighting the importance of studying the role of the physical environment as an element of learning design and the potential of multimodal learning analytics in approaching these studies.

Practitioner notes

What is already known about this topic	● There is a gap in the knowledge about how people collaborate in face-to-face environments. ● MMLA can be useful in studying face-to-face collaborative learning processes. ● Dependencies between the learning design, the learning space and students' behaviour are underexplored.
What this paper adds	● An MMLA approach based on motion capture and video analysis. ● Case studies that employ a combination of methods for the analysis of MMLA data and qualitative analysis. ● Evidence about the impact of space design on face-to-face collaborative learning processes.
Implications for practice and/or policy	● The shape of classroom tables has effects on elementary school students' behaviour when collaborating. ● Learning design should be a comprehensive process that includes elements associated with the space. ● Learning space research requires comprehensive multimodal system analysis tools.

Introduction

Designing a space is not just about creating physical frames that define spatial divisions but also about facilitating an activity and reinforcing it with the characteristics of that space (Ching, 2014). In the context of educational space design (Felix & Brown, 2011), the space-activity synergy must be emphasised as relevant where the field of architecture targets sensitive user groups and sensitive objectives (Malinin, 2017). Learning is a complex process and the subject of study in a number of multidisciplinary research areas. Previous research has already explored the physical facilitators of learning activities; however, the empirical evidence is limited (Keppell, Souter, & Riddle, 2011; Yeoman & Ashmore, 2018), especially when considering different active learning methods (Bennett, 2011; Lippman, 2015). This paper investigates the potential of multimodal learning analytics (MMLA) and uses new analytical methods and new data sets to study the impact of these contextual factors in the domain of collaborative learning and in terms of particular characteristics regarding its learning design (table shape and group sizes) and the educational levels involved.

The design of physical spaces for learning

Places and furniture can facilitate, or constrain, possible arrangements for certain teaching and learning strategies. One clear example is the case of collaborative problem solving (CPS), a fundamental skill in modern society (Häkkinen et al., 2016; de Lima & de Souza, 2017) and a widely accepted pedagogical method (Alavi & Dillenbourg, 2012). Teachers' orchestration of collaborative learning in the classroom is influenced by the physical context (Joyce-Gibbons, 2017). It involves the coordination of learners' desired actions, including the use of shared physical artefacts (e.g., tables) in the classroom, in alignment with the needs of learning tasks at different social levels (individuals, groups, the whole class). Dillenbourg & Tchounikine (2007) point out that the extrinsic constraints derived from the educational context are sometimes neglected in classroom orchestration studies. Extrinsic constraints go beyond the constraints that are intrinsic to the pedagogical methods (e.g., group formation, the sequence of tasks) and include the classroom layout, which might not conform with the methodological requirements of learning design (Goodyear & Carvalho, 2014; Pérez-Sanagustín, Santos, Hernández-Leo, & Blat, 2012). Also, research on co-located learning stresses the relevance of shared educational and social spaces (e.g., shared seating and the encouragement of social bonding), for example, in scenarios that gather heterogeneous students (Croker, Fisher, & Smith, 2015). In these scenarios, spaces structured to encourage interaction were reported to be beneficial for improving collaboration and interprofessional rapport. Yee and Park (2005) further identified the problem of reduced awareness between participants in a co-located learning context due to the features of the physical space surrounding them, such as non-transparent partitions and grid-organised desks.

Moreover, previous research shows that various aspects of the physical learning environment influence students' behaviour, pointing out certain differences in shapes, colours and lighting used in spatial design, (Blinne, 2013; Colbert, 1997; Francis & Raftery, 2005). Also, different developmental levels of students seem to express different types of behaviour when exposed to different physical settings in learning contexts (Kumar, O'Malley, & Johnston, 2008). Cognitive psychology research shows that attention, perception and thinking can be influenced by the physical environment. Young children tend to get distracted by different visual features that surround them (Godwin & Fisher, 2011), which can increase the off-task time during the learning activity. For older students, their perception of the physical learning environment has shown to impact behaviour, progress in learning and their involvement (Midgley, 2006; Pai, Menezes, Srikanth, & Shenoy, 2014).

Further empirical evidence needed and the potential of MMLA

There is a body of evidence on how the characteristics of the physical environment affect students' behaviour in CPS tasks. However, this body of evidence does not possess sufficient comprehensiveness in terms of connecting research and practice. Nardi (1996) points out that, when studying the learning context, the durable structures that are used across different situations are very important contributors to learning and not only a simple aspect of particular situations. These permanent physical structures should be addressed in research in order to reach a point where generalisable results can be obtained. Other research argues that the spatial element in educational practice is relatively underdeveloped due to the domination of social aspects, which change faster and require more attention (Gulson & Symes, 2007). Cukurova, Luckin and Baines (2018) also point out certain drawbacks in the literature where factors related to the learning environment do not get proper attention or are presented in a less comprehensible way. The authors explain how the learning context refers to the interaction between learners and multiple people, artefacts and environments, and they draw attention to the importance of comprehensive studies on contextual factors in bridging the gap between research and practice. The emerging use of MMLA, which considers different sensors and computer systems for data collection during learning activities (Pijeira-Diaz, Drachsler, Järvelä, & Kirschner, 2019), offers a methodological approach that can provide further insights into collaborative face-to-face spaces (Ricca, Bowers, & Jordan, 2019). The diversity of data (Spikol, Ruffaldi, Landolfi, & Cukurova, 2017), fusion and analysis methods (Shankar, Prieto, Rodríguez-Triana, & Ruiz-Calleja, 2018) and advanced developments in sensor technology (Schneider, Di Mitri, Limbu, & Drachsler, 2018) bring vast possibilities in terms of studying the effects of learning spaces. Furthermore, a study examining the movement of students and teachers around furniture, using MMLA, provided a better understanding of collaborative learning processes (Healion, Russell, Cukurova, & Spikol, 2017)

Therefore, previous research shows that the learning space is a relevant element of learning designs that aim at offering the best possible methodological and supportive arrangements for students to learn. Moreover, research suggests that the effects of learning space characteristics can vary depending on the educational level. However, more research is needed to provide further evidence about how specific elements of the space affect learners when engaging in active learning methods, such as CPS.

Conceptual framing and research focus

Multimodal analytics can help provide the necessary evidence; however, a literature review by Mangaroska and Giannakos (2018) shows that existing studies present a misalignment between learning analytics and learning design, which is potentially caused by the gap between easily collectible data and data that are meaningful in a pedagogical sense. The analytics layers for learning design (AL4LD) framework (Hernández-Leo, Martinez-Maldonado, Pardo, Muñoz-Cristóbal, & Rodríguez-Triana, 2019) offers guidance to solve this misalignment by compiling meaningful variables into analytics layers that connect analytics with design. AL4LD builds on previously proposed frameworks focused on learning design and/or learning analytics (e.g., Goodyear & Carvalho, 2014; Lockyer, Heathcote, & Dawson, 2013). This study uses AL4LD as the conceptual framing to establish links between measurable aspects of learners' behaviour and features of the learning design (Figure 1).

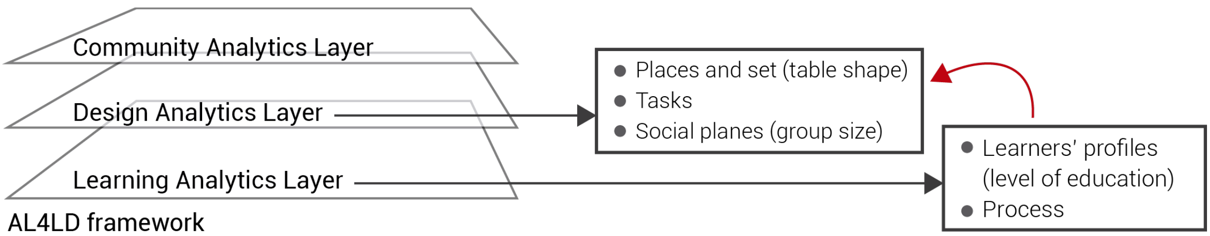

Figure 1. Conceptual framing for the analytics of behavioural aspects in alignment with learning design decisions

In this paper, we study the effects of table shape on human behaviour that relates to learners' interactions and participation in collaborative problem-solving tasks. Shared tables are one prominent physical element present in most collaborative places. The *places and set* of artefacts that support the realisation of a task are one of the data classes in the design layer in the AL4LD framework. The design layer also suggests the consideration of pedagogical constraints intrinsic to the pedagogical method (*tasks and social planes*) and their interplay with data classes in the learning analytics layer, such as those related to *learners' profiles* and the learning *process* (presence and usage behaviour). The design of social planes is particularly relevant in collaborative learning scenarios, where group size is one of the design elements that has been seen to have an impact in facilitating fruitful collaborative learning (Avouris, Margaritis, & Komis, 2004; Pedaste & Leijen, 2019).

Therefore, to define the independent variables, we focus on the main aim of this study, which is in linewith the primary focus of the investigation concerning how the shapes of the tables have different effects on learners' behaviours in terms of patterns of participation and indicators related to physical social interactions. The secondary focus is on two additional variables related to learners' profiles (level of education) and the pedagogical method (group size)—examined in relation to the shape of the tables. In defining dependent variables, this study refers to notions already present in the literature and that belong to the learning analytics layer, such as *the level of participation* (Cukurova, Luckin, Millán, & Mavrikis, 2018), *the distance between students* (Spikol, Ruffaldi, Dabisias, & Cukurova, 2018) and *the range of movement* (Vujovic, Tassani, & Hernández-Leo, 2019).

Therefore, the research question of this study was defined: Do different table shapes have different effects on learner behaviour (measured in terms of the level of participation, the distance between learners and the range of movement) for different group sizes (2 and 3 participants) and for different educational levels (school and higher education)?

Methods

Two cases, focusing on authentic CPS activities, were studied, with each case involving two levels of independent variables, round and rectangular tables, and their interaction with two levels of education (elementary school students and university students) and two group sizes (two and three participants). The students were engaged in design tasks that were conducted in small groups and orchestrated using the broadly accepted Jigsaw pattern (Aronson, 1978; Hernández-Leo et al., 2006). This pattern proposes a collaborative learning flow where, by splitting students into small groups that change, they solve complex tasks in a way that enables positive interdependence and individual accountability to be promoted so as to achieve fruitful learning.

Participants

University students were invited to extracurricular training focused on design tasks in physical computing. During the recruitment process, out of more than 150 volunteers interested in the training, we selected 36 students with no prior knowledge of the topic, from different engineering degrees and in different years of study and with an equal number of male and female participants. The 36 selected students, all aged 18-24, formed 12 (Jigsaw) groups, and we analysed the data from eight of these groups. Out of the eight groups that participated in the data analysis, four of them were assigned to rectangular tables, and the other four were assigned to round tables (Figure 2).

Figure 2. Two sitting arrangements that present different levels of independent variables in the study—university students

In the case of elementary school students, the activity was part of an educational summer school focused on technology. A total of 24 students chose to participate in agreement with and with the consent of their parents. The students, aged 6-9, came in 8 organised groups led by a teacher from the same school, who stayed in the laboratory without interfering in the activity. Four groups were assigned to round tables, and four groups were assigned to rectangular tables (Figure 3).

Figure 3. Two sitting arrangements that present different levels of independent variables in the study—elementary school students

Materials and task description

Both the university students and elementary school students participated in collaborative problem-solving activities. There were two different activities, one for each level of education, similar in nature but adjusted to the age of the students. Both activities represented design tasks where specific artefacts were to be produced. Following a Jigsaw pattern flow structure, each session started with two groups of three members. After an initial phase of instructions regarding a divisible task, they were organised into three different expert groups of two members (each coming from different initial groups) for a second phase of the activity where each group specialised in a sub-task. After finishing the sub-task, students returned to their initial Jigsaw groups and continued work on the overall task. The task was open-ended, which meant that each group could have a different design in the end. At the end of the activity, each group presented their work. The duration of the activity was one and a half hours, and no prior knowledge was required.

University students had to design, program and build an interactive toy with an Arduino electronic platform. The interactive toy was to be designed using electronics connected to an Arduino board and additional elements such as cardboard and paper. The difficulty level was low, and students were provided with the necessary instructions for each step of the process. Students were informed about the data collection and analysis that would follow this experiment and that had been approved by the ethical committee responsible, and consent from students was collected before the experiment.

The elementary school students conducted a collaborative design activity that started with the use of a computer game to motivate a follow-up task on designing cartoon-like artefacts. The objective of the game was to design a carriage for an imaginary king and queen, based on requirements and suggestions from certain characters in the game. Throughout the phases, the participants had to look for cues in terms of which elements to use in the design and make decisions together as a group. The students and parents were informed on the details of the experiment, and consent forms were obtained from the parents.

Measurements

As previously discussed, we identified three independent variables, one of which was viewed as being primary (*table shape*) and the other two as secondary (*level of education and group size*). For each of these controlled inputs, we defined two levels of independent variables and tested their effect on the dependent variables. Two different table shapes—round and rectangular were used and within these two levels of independent variable, we defined two additional levels for each of the secondary independent variables. For the level of education, we had university students and elementary school students. The third independent variable—group size—was introduced as a relevant pedagogical requirement of the Jigsaw-based collaborative learning design and considers group transformation during the activity. Part of the activity was conducted in groups of two and part of it in groups of three. Therefore, there were two levels for the group size independent variable. The effects of changes in the independent variables were measured on three dependent variables—*the level of participation, the distance between students* and *the range of movement*. In this way, we could measure how changes affect student behaviour and the ways in which different changes are connected.

For the level of participation, we measured how active students are in their interaction with other students and the artefacts used during the activity. The distance between students measures the distance between group members throughout the whole activity in order to compare various levels of the independent variables. The range of movement is based on the distances between students, measuring their extremes, and reflects how far students moved from their original sitting positions.

Therefore, quantitative data were acquired to test the influence of the aforementioned factors on student behaviour during collaborative learning. Moreover, to offer an understanding of the phenomena behind the measured behaviours, qualitative data were also collected to observe the nature of participants' actions (on-task/off-task) during the collaboration.

Procedure

To measure the dependent variables in a laboratory setting, we used different equipment to acquire video and motion capture recordings. Ambient factors such as light, room temperature, wall colour, surrounding furniture, researchers present and environmental noise were exactly the same for all the conditions. The acquisition system was adjusted for this study to create a data collection process that was as automatic as possible. Motion features were detected and recorded by a motion capture system (Figure 4), a technology that allows us to measure physical parameters based on a pre-established marker protocol (Vujovic, Tassani, & Hernández-Leo, 2019). Two different marker protocols were used with the two educational levels, but the same types of data were used for the final analysis. The first marker protocol was used with the university students and consisted of headbands with five physical markers (reflective spheres), four placed on the sides of the head and one on the top. In the case of the elementary school students, a second marker protocol was used where markers were placed on the hats worn by the participants, with one top marker on each hat. The movement of the markers was captured by 8 infrared cameras (BTS Smart-DX 700, 1.5 Mpixels 250 fps BTS S.p.A., Milan, Italy) and translated into coordinates. Using the Smart Tracker and Smart Analyser software tools, which are part of the BTS Smart-DX motion capture system, we extracted distances from the top head markers for the range of movement. The range of movement represents the range of displacement of each student's head, and it was calculated as the standard deviation of the distance between learners.

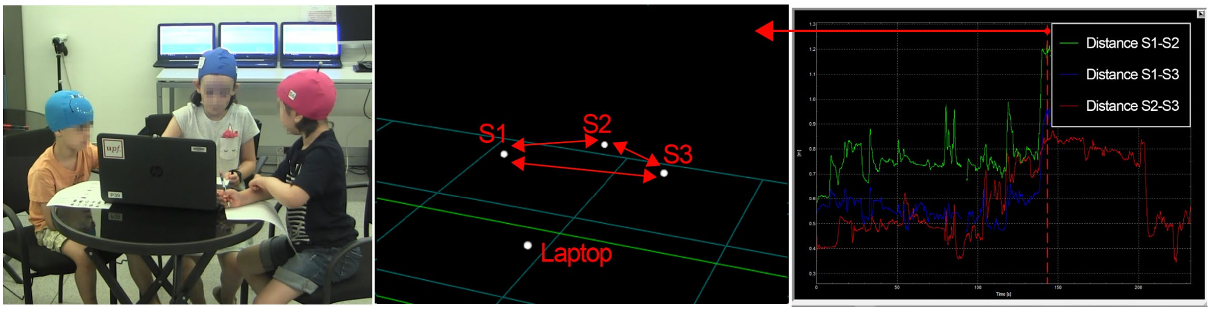

Figure 4. Detecting physical features with a motion capture system

The level of participation was extracted from the video recordings and assessed using the NISPI framework (Cukurova, Luckin, Millán, & Mavrikis, 2018), where physical aspects of the interactions were coded. Video recordings were split into segments of 20 seconds, and for each segment, each participant was assigned a score. Based on the coding scheme (Table 1), we used three different scores (0, 1 and 2) for three different levels of participation (Figure 5). Full participation was assigned to a situation in which, for one segment, all participants scored 2. The level of participation for the whole group was calculated as the percentage of segments with full participation compared to the whole session. We focused on the numerical coding of the participation without further interpretation regarding synchrony or physical interactivity, individual accountability, equality and intra-individual variability. We acted this way in order to obtain quantitative data and use them in a statistical analysis prepared prior to the execution of the experiment. Two observers coordinated their criteria by coding the same parts of the recording and comparing and adjusting the scores.

Table 1. NISPI coding scheme

Score	Description of the activity
0	Active participation (interacting with others, working on a laptop, Arduino or design objects)
1	Semi-active participation (only listening and looking with the engagement in the form of nodding, pointing, etc.)
2	No participation (participant looking in another direction, distracted, doing another activity)

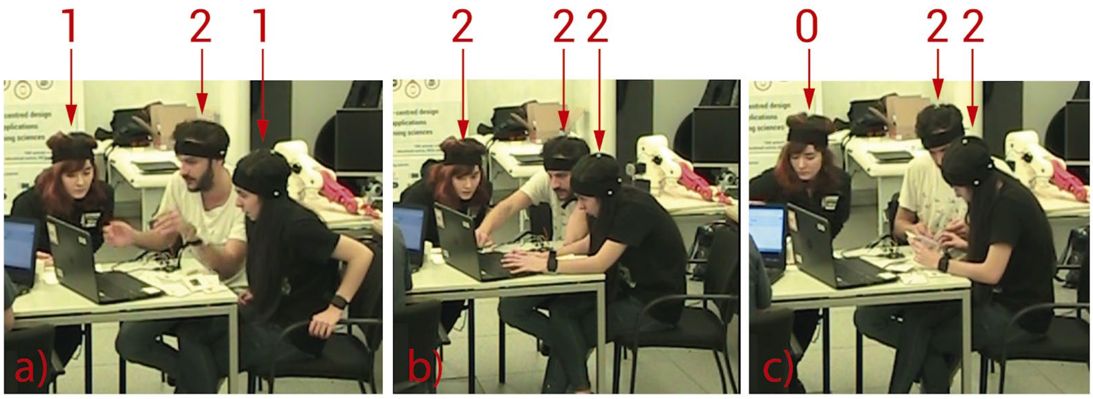

Figure 5. Explanation from left to right: a) 1 - listening/nodding, 2 - talking, 1 - listening; b) 2 - talking, 2 - working on a laptop, 2 - working with Arduino; c) 0 - not participating, 2 - working with Arduino, 2 - working with Arduino

Analysis

In the analysis process, we distinguished three independent variables (table shape, level of education and group size) and three dependent variables (level of participation, distance between students and range of movement). Therefore, three multifactorial analyses of variance (ANOVAs) were performed. Each ANOVA presents the analysis of the independent variables' influence on one of the dependent variables. Normality tests were conducted in order to verify the normality distribution of the residuals. Also, due to the different table sizes (the rectangular tables were 60 cm wide, while the round tables were 69 cm wide), all measures of distance were normalised by dividing them by the width of the tables, and in this way, the data were given the same unit sizes. This was done to avoid biased measurements of the distances between the students and the ranges of their movements. All statistical analysis was performed using SPSS v23 IBM.

The video recordings were qualitatively analysed using visual transcription and open coding (Ramey et al., 2016) to identify on-task and off-task actions. The quantitative results were triangulated with the qualitative observations to illustrate and help understand the trends indicated by the statistical analysis.

Results

The results present the output of the applied analysis methods about the effect that the physical environment has on students' behaviour when collaborating in a design problem-solving task. Three multifactorial ANOVA tests generated the results of the individual or simultaneous influences of the tested factors on the dependent variables.Figure 6shows how many subjects participated in each level of the independent variables. The three following tables paragraphs show the factors and interactions between factors that significantly differ between the levels of the independent variables regarding (1) *the level of participation*, (2) *the distance between learners* and (3) *the range of movement.* The results of statistical analysis are available as open data (see materials in Vujovic, Hernández-Leo, Tassani, & Spikol, 2020 10.5281/zenodo.3843436). Normality tests (Kolmogorov-Smirnov and Shapiro-Wilk) were conducted, and they failed to reject the null hypothesis (normal distribution of the residuals) for two out of the three dependent variables (Figure 7).

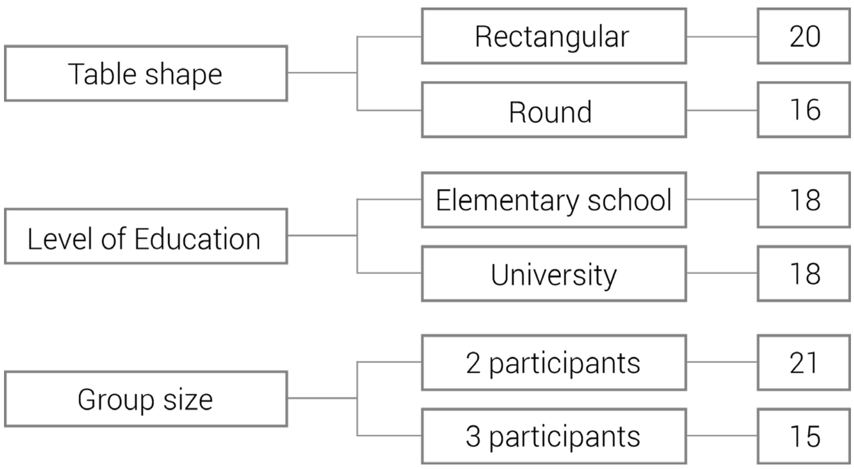

Figure 6. Number of students per level of independent variable

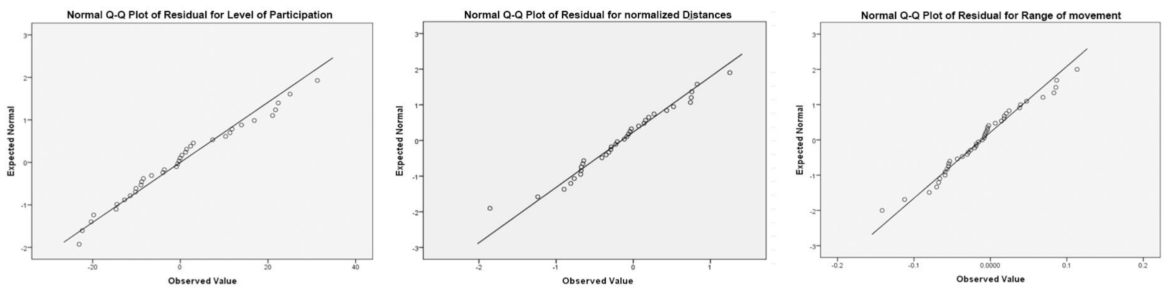

Figure 7. Q-Q plot of the residuals for the three dependent variables

In the case of the range of movement, we had a deviation from normality (Shapiro-Wilk test, $p = .007$), and two points were identified as outliers and were therefore removed from the analysis. The removed points present the values for two elementary school students that belonged to two different groups, with one value belonging to the triad in session 2 and the other to the dyad in session 5. Therefore, the impact on the overall analysis was minimal in terms of imbalances, and we were able to remove them, resulting in a normal distribution (Figure 8).

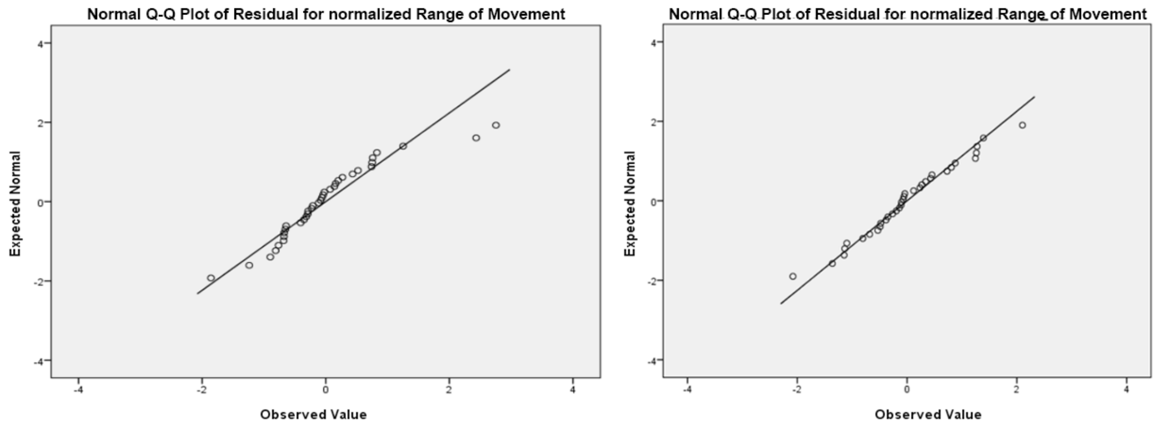

Figure 8. Normality test with (a) all values and (b) outliers removed (range of movement)

Do different table shapes have different effects on learners' levels of participation for different educational levels and for different group sizes?

Significant differences were detected in the level of education (P-value = 0.040) and in the interaction between the shape of the tables and the level of education (P-value = 0.019). Another factor that has a P-value close to the significance level (0.073) is the shape of the tables. Figure 9 shows the interaction between the shape of the tables and the level of education, where the blue line presents elementary school students, while the green line presents university students. The significant difference is visually presented and indicates higher levels of participation for elementary school students when using round tables and for university students when using rectangular tables. However, while the higher participation of the university students using rectangular tables is not considerably greater than those using round tables, the figure displays a considerably higher level of participation in elementary school students using round tables. The interactions between table shape and group size as well as between the level of education and group size were found to be non-significant.

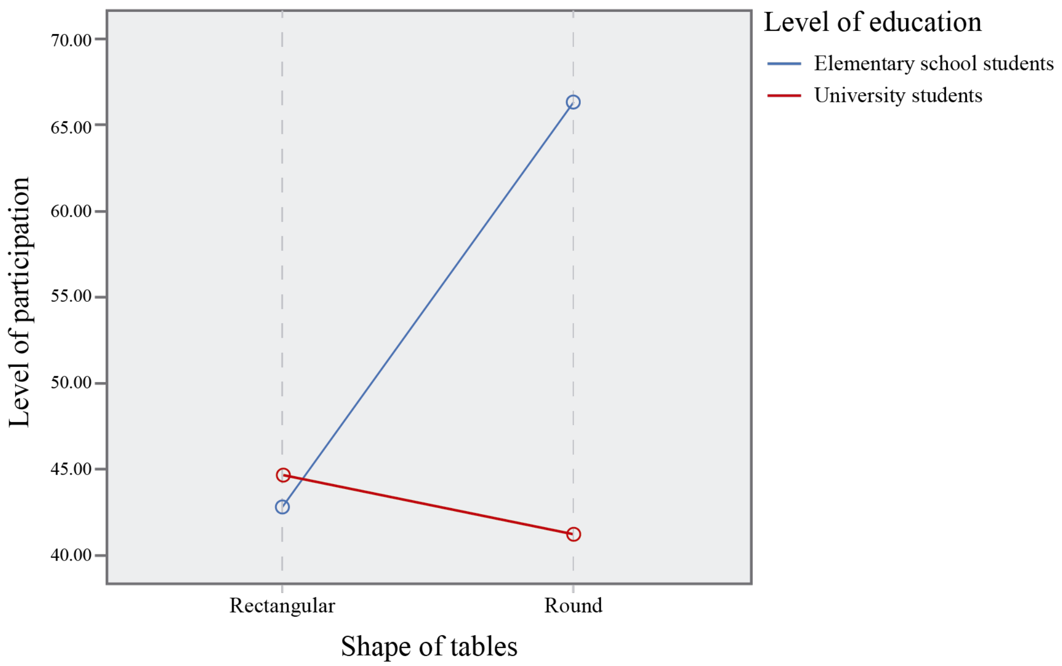

Figure 9. Compared levels of participation for interaction of levels of education and table shapes

Do different table shapes have different effects on the distance between learners for different educational levels and for different group sizes?

Significantly different distances were detected between different group sizes (P-value = 0.006), where shorter distances were noticeable within groups of two participants. No significant differences were found with other factors regarding the distances between learners.

Do different table shapes have different effects on the learners' ranges of movement for different educational levels and for different group sizes?

There is a significant difference between groups of two members and three members, where the range of movement is smaller in groups of two. Also, the range of movement significantly differs when we observe the interaction between table shape and the level of education. This means that for elementary school students the range of movement is higher when using rectangular tables. Quite the opposite effect is observed with university students, whose range of movement is higher with round tables (Figure 10).

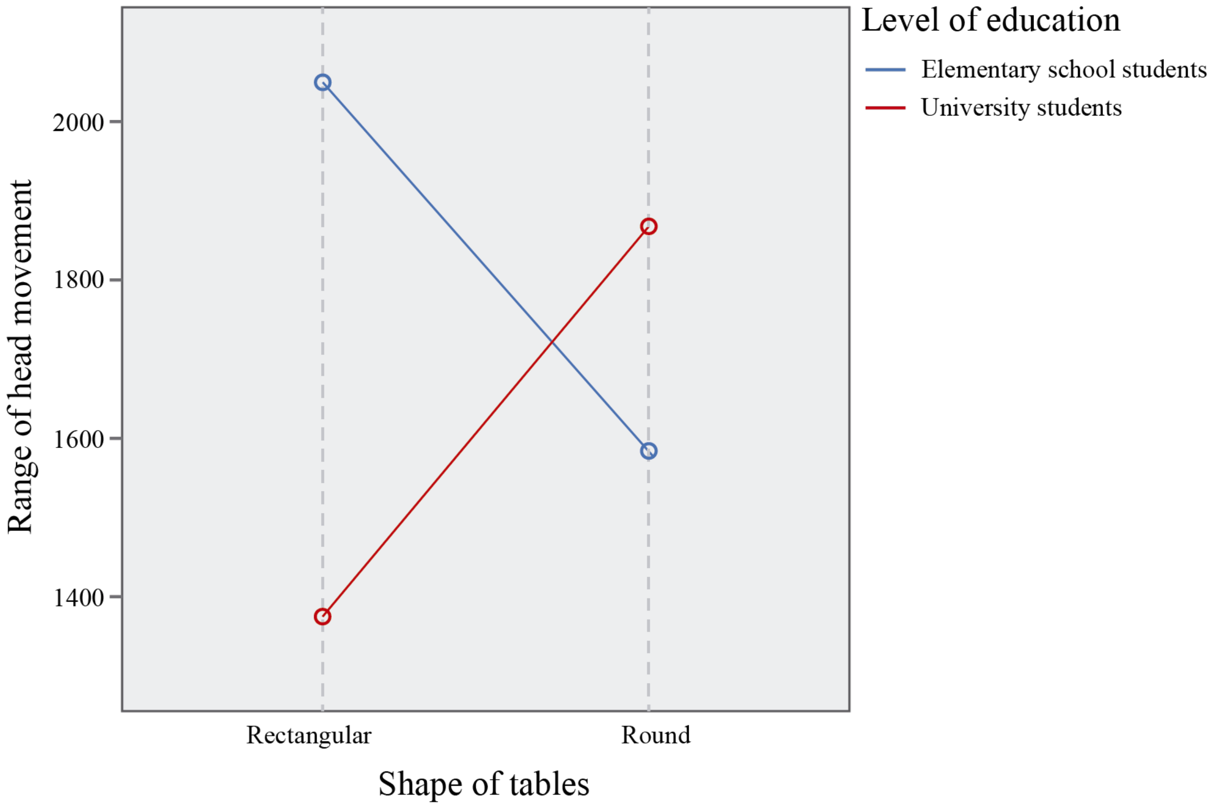

Figure 10. Compared ranges of movement for levels of education and table shapes

Qualitative results and triangulation

A qualitative analysis of the video recordings provided certain insights that could better explain the findings of the statistical analysis. Examples of the coding performed and the whole analysis is available as open data (see materials in Vujovic, Hernández-Leo, Tassani, & Spikol, 2020 10.5281/zenodo.3843436). The main aim of the video data analysis was to identify how students from different levels of education engage in interactions with the learning space in order to shed more light on the results of the statistical analysis, which revealed significant differences between round and rectangular tables in terms of the levels of participation and ranges of movement. The analysis considered distinguishing behaviour related to on-task and off-task actions, where on-task actions included engagement in conversation, actions with artefacts and nodding and pointing, while off-task actions were all actions not directed at the other team members or artefacts involved in the task.

The qualitative analysis showed that the elementary school students, when engaged in on-task actions, display a significant amount of movement and interaction with elements of the environment. They tend to lean on the table a lot and hold onto objects that are in their immediate environment ("A participant (pink hat) was kneeling on the chair and leaning on the table with her full body."; "During the discussion, participants came closer to the screen (very close), leaning over the table, pointing more."). When engaged in off-task actions, elementary school students seem to have equal or more contact with the table than when on-task actions are conducted ("Boy that wasn't participating in certain moments was moving a lot on his chair, sometimes standing up and leaning on the table."). However, when engaged in off-task actions,

university students have less contact with the table and artefacts than when engaged in on-task actions ("The two uninterested participants were distant from the table, passive, not doing anything."). When managing on-task actions, university students tend to be closer to each other and to the table, having more contact with artefacts used in the task ("Close to each other. Close to the table, but not leaning over, only using artefacts on it."). The presented observable behavioural characteristics were qualitatively equally present for both table shapes.
The triangulation of the quantitative and qualitative results implies that the relationship between the physical setting and behaviour is linked to the level of education. As opposed to elementary school students, who show equal or more movement when performing off-task actions, university students practically do not move when they are off-task. This observation also suggests that the statistical results obtained for university students are essentially focused on on-task actions and that the obtained statistical trend (not very different levels of participation in terms of round vs rectangular tables for university students) is valid. The qualitative observations show that for university students, closeness and interaction with the artefacts are indicators of on-task participation. Therefore, we can interpret, in the quantitative results, that higher on-task participation (slightly higher with the use of rectangular tables) is not necessarily accompanied by a higher range of movement (observed when round tables are used). In the case of elementary school students, the quantitative results should be interpreted with caution as students' movement is considerable both during on-task and off-task actions. But, the qualitative observations show that on-task actions cause elementary students to be closer to each other and to the table and artefacts, although they move an equal amount or more when they are off-task. This suggests that the quantitative measurements for levels of participation and their derived findings (round tables support the higher positive participation of elementary students) may be valid. This may also explain why higher levels of on-task participation are not necessarily related to higher ranges of movement, as elementary students move quantitatively more when using rectangular tables, but we observe that they move qualitatively equally or more when they are off-task.

Discussion

The contribution of this paper is multifaceted and connects to and extends previous research into MMLA by critically examining its potential, while using new data sets. The results highlight the importance of certain aspects of physical environments with a focus on student behaviours and their relationships (Blinne, 2013; Colbert, 1997; Francis & Raftery, 2005). These behaviours and relationships clearly illustrate how table shape plays a significant role in the interactions of elementary school students. This paper also offers insights into the relationship between the fields of learning analytics and learning design, which needs further research.

Adding evidence about the effects of learning spaces

Designing for collaboration is not limited to single dimensions of learning design, but rather requires researchers, designers and teachers to consider the physical environment. The results indicate that round tables have positive effects on elementary school students' behaviour when participating in collaborative learning activities by increasing levels of on-task participation. These results are consistent with findings in the literature that suggest that the developmental level and the physical learning environment have an effect on learners' behaviour (Godwin & Fisher, 2011; Kumar, O'Malley, & Johnston, 2008; Midgley, 2006; Pai, Menezes, Srikanth, & Shenoy, 2014). An explanation is found in the qualitative analysis that links this result to students' movement needs and indicates the ability of certain physical forms to facilitate the desired movement more easily and, thus, to promote the comfort of participating in a collaborative activity in the most appropriate way for students. Triangulating the findings of statistical and qualitative analyses, we conclude that elementary school students move more when using rectangular tables, where participation levels are lower. This is in line with research that suggests that forms in the physical environment can cause distractions and increase off-task time for young students (Godwin & Fisher, 2011). These effects are not observed with university students, where table shapes seem to have a limited impact on their levels of participation in collaborative problem solving.

Implications for learning designers and multimodal learning analytics researchers

Overall, our study adds to the evidence that supports the need for considering the characteristics of the physical learning space as a relevant aspect of comprehensive learning design processes (Goodyear & Carvalho, 2014; Yeoman & Ashmore, 2018). The evidence is clearer in the case of elementary school students, and further research is needed in the case of older learners. This conclusion is aligned with research in collaborative learning that points at discrepancies between classroom layouts (external constraints) and pedagogical methods (intrinsic constraints) reflected in learning designs (Dillenbourg, 2013; Pérez-Sanagustín, Santos, Hernández-Leo, & Blat, 2012).

The employment of comprehensive multimodal analysis tools through the use of a motion capture system in conjunction with video analysis has been based on previous research (Cukurova, Luckin, Millán, & Mavrikis, 2018) where physical indicators of collaboration were measured. Differing from previous work in the emerging field of MMLA, we used established motion capture tools to collect and analyse the data, which may help provide standards, validity and repeatability for future work (Shankar et al., 2018). Our qualitative analysis has shown that closeness is an indicator of on-task behaviour for both elementary school students and university students. This finding implies that the distance between learners, an indicator used in multimodal learning analytics research, could be more informative if observed in relation to on-task versus off-task actions. Moreover, the study suggests that movement is not necessarily a key indicator of collaboration. Finally, the study shows the relevance of considering mixed methods, in which qualitative analysis can explain and confirm the validity of the trends revealed by quantitative analysis.

In summary, our findings suggest supporting collaboration researchers, learning designers and other stakeholders in their need to understand how the physical space and table shape can be used to support learning in relation to age and the skills of the students. In terms of MMLA systems, the physical interaction between learners (motion) alone is not strong enough to support an understanding of collaboration without the context of on-task and off-task actions and other human modes of communication and collaboration. Lastly, there is a need for richer frameworks, like AL4LD, for research, analysis and visualisation and for learners and teachers, that are able to scale both human and machine data in understanding and supporting education.

Limitations of the study

Experimenting in laboratory conditions provided the possibility to administer control over features of the collaborative activity (same space, same light, same instructors, etc.). However, the evident age differences between elementary school students and university students imposed unavoidable limitations on the study. In both cases, the collaborative activity followed a Jigsaw pattern, but tasks were adjusted to the age of the participants. However, their design was kept as similar as possible (both were design tasks that combined the use of laptops and tangibles). Also, within one level of education, age differences could affect the “maturity” of the students. Elementary school students also had occasional help from the instructors. However, the help was kept to a minimum. Also, concerning the removed outliers, it would have been desirable to have a higher number of participants. Although this did not seem to influence the interpretation of the main results, it reduced the number of samples for the range of movement analysis. The university students came from engineering bachelor’s degree programmes, so the generalisability of the findings is not clear and could have been improved by collecting more qualitative data via focus groups and interviews to gain deeper insights into participants’ preferences for table shapes.

Conclusions and future work

This paper examined how table shape (round vs rectangular) has different effects on physical interactions and patterns of participation of students where variables related to learners’ profiles (level of education) and elements of the pedagogical method (group size) were analysed. The statistical analysis has shown significant differences between the levels of independent variables related to table shape and how the effect differs between two different levels of education, and this was further supported by a qualitative analysis of the observations obtained from the video recording of the activities.

This study adds evidence, with implications for practice, about the relevance of including the physical space as an important facet of collaborative learning design. The evidence provided is for two different table shapes, a design task and a learning design involving group sizes of two and three students. Further research should tackle similar studies and consider different characteristics of physical space, educational contexts, tasks and learning designs. A variety of methods in multimodal learning analytics should help study these settings. In our future work, we will further investigate the influence of table shape by expanding the data set, analysing potential gender differences and introducing new modalities (electrodermal activity analysis and voice analysis) to study more dimensions of students’ behaviour.

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Statements on open data, ethics and conflict of interest

The study was approved by the ethics committee of University of Barcelona, supporting the INPhINIT program.Consent was obtained from participants. Anonymized data are available in Zenodo (https://doi.org/10.5281/zenodo.3843436). There are no potential conflicts of interest in the work.

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