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ORIGINAL PAPER

A case study of process performances during a small-group activity: comparison between a round-shaped and a crescent-shaped seating arrangements in studio-style learning spaces

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Abstract
This research explored the best shapes and layouts of seating arrangements for fostering process performances of students in studio-style learning spaces, which have emerged in the development of collaborative learning environments in higher education. We conducted a design case study to explore both team and individual process performances during a small-group activity in a round-shaped and a crescent-shaped seating arrangement. Evaluators observed and measured the individual process performance of each group member together with the team process performances of each group. All factor scores of the individual process performance were higher in the crescent-shaped seating arrangement than in the round-shaped seating arrangement, with substantive effect sizes. In the group process performance, the factor scores of 'planning and process' and 'independence and leadership' in the crescent-shaped seating arrangement were substantially higher than those of the round-shaped arrangement, indicating that the crescent-shaped seating arrangement fostered students' ability to collaborate responsibly in their project work. Video analysis revealed that groups in the crescent-shaped layout tended to have more eye-contact and to spend less time planning, which indicates that such sociopetal effects have the potential to promote efficiency in the discussion between people seated in a crescent-shaped arrangement. We discuss the necessity to take students' seating arrangements into consideration regarding the sociopetal, as well as a proximal focal point and less-disparate distance between the leader and other participants to allow them to engage in their own work better.

Keywords Collaborative learning · Group work · Leadership · Seating arrangements · Sociopetal · Studio-style learning spaces

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Introduction

Designing new types of physical learning spaces for both schools and informal learning settings is an issue that has emerged in the last three decades in the area of educational science and technology in elementary, secondary, and higher education (Attai et al., 2021; Brooks, 2011; Cleveland & Fisher, 2014; Ellis & Goodyear, 2016; Hod, 2017; Kariippanon et al., 2018; Ozkan Bekiroglu et al., 2021). Some of the projects involved in the development of new learning spaces have constructed *studio-style classrooms* that encourage collaborative experiments, explanations, and the construction of learning artifacts, as well as developing the curriculum in studio-based activities (Beichner et al., 2007; Dori & Belcher, 2005; Hoellwarth et al., 2005; Little & Cardenas, 2001).

Studio-style classrooms are created in order to foster collaboration among students so that they can achieve deep understanding of subjects that they are learning. Thus, special tables and whiteboards for group work are typically found in such classrooms (Beichner, 2014). However, there is limited research on studio-style learning spaces that focuses on fostering collaboration between students in face-to-face situations, as opposed to students' conceptual understanding which has been the subject of ample research (e.g. Dori & Belcher, 2005). Although most studio-style classrooms use round table settings for fostering collaborative learning, there have not been proper investigations carried out to clarify whether this type of seating arrangement or formation is effective (Taylor, 2009).

The current study explored the possible effectiveness of an alternative seating layout different from the typical round-table layout in order to create an effective collaborative learning environment. In accordance with the knowledge of how students should be seated in a studio-style learning environment in order to have deep interactions in order to create knowledge (Attai et al., 2021; Paavola et al., 2004), we suggest a different seating arrangement called 'crescent-shaped'. Unlike a round-table style seating arrangement, the crescent-shaped arrangement can establish a less-disparate distance between the lead student and the other students, thus improving students' process performances. The process performance mentioned here is conceptualized from performance assessment (e.g. Herman et al., 1992, p. 31), in which assessment of students' learning-process quality should be based on their performance during a learning activity. Because of interpersonal distance and the focal point generated by the crescent shape, we hypothesized that this seating arrangement can enhance students' process performances by enhancing team members' active communication and proactive discussion in their teamwork.

Studio-style classrooms for enhancing collaboration between students in physics and other subjects

In the studio-style classroom literature, North Carolina State University's Student-Centered Active Learning Environment with Upside-down (SCALE-UP; Beichner et al., 2007) and the Massachusetts Institute of Technology's Technology-Enabled Active Learning (TEAL) classrooms (Dori & Belcher, 2005) were highlighted. In these projects, the 'studio' was conceptualized as a flat-floored room with integrated furniture and information and communication technology (ICT) that facilitate group work (Ellis & Goodyear, 2016, p.170). Mainly physics educators have developed similar studio-style classrooms and utilized them in their educational programs (Florman, 2014; Whiteside et al., 2009). In addition, the idea of studio-style classrooms has attracted researchers and practitioners in other disciplines

who, in turn, have developed studio-style classrooms for a variety of subject matters (Hao et al., 2021; Jamieson, 2003; Rook et al., 2015). These classrooms are relatively low-tech, but they have flexible furniture that students can move around for a variety of learning activities in order to foster peer interaction and collaboration in a classroom (Attai, et al., 2021; Hod, 2017) and public displays with which students can share a variety of representations, such as conceptual drawings on whiteboards, pictures, movies, presentation slides, and computer simulations on students' tablet PCs when they collaborate on various subjects (Hod, 2017).

Even though most studio-style classrooms have technology appropriate for enhancing scientific understanding through simulation, virtual experiments, data analysis, and/or presentations, the furniture used is also one of the most important factors in the design of such studio-style classrooms for strengthening collaboration among students (Oblinger, 2006). A flexible furniture layout that allows students to move around in order to tackle different types of activities is essential, not only in classrooms such as those used for science education, but also in content-flexible future learning spaces (FLS) (Hod, 2017).

Layout and furniture affecting students' process performances

There is a need for research in learning environments with a variety of configurations of seating or learning arrangements that can support students' activities in a studio-style classroom, even though previous research evaluated studio-style teaching and learning. For example, Foulds et al. (2003) reported that students' attitudes and interests in the subject matter improved during studio-style teaching. Brooks (2012) conducted a quasi-experimental research on the effectiveness of a traditional classroom and a TEAL-like classroom, particularly focusing on instructor behavior, classroom activities, and levels of on-task student behavior, revealing that different classroom types resulted in different instructor and student behaviors. When Clinton and Wilson (2019) compared students' affective dimensions during collaborative learning in a studio-style classroom setting with a traditional classroom setting, the studio-style classroom setting was perceived to be better for collaborative learning. In addition, a broader focus of research on flexible furniture in learning spaces rather than in a studio-style classroom revealed that the flexibility of seating arrangements based on flexible furniture could improve students' affections and/or motivation (Attai et al., 2021; Kariippanon et al., 2018; Ozkan Bekiroglu et al., 2021).

However, key seating arrangements or formations are still not clear at this stage, because most studio-style classrooms use round tables for fostering collaborative learning performance, and there have been limited investigations of other possible seating or learning arrangements (Taylor, 2009) in the studio-style classrooms. Broadly focused learning-environment research revealed that increasing flexible furniture and the flexibility of students' layout can enhance students' movement and autonomy in a classroom (Attai et al., 2021) as well as student–to–student and teacher–to–student interaction (Ozkan Bekiroglu et al., 2021). Thus, such flexible furniture can be key for fostering collaborative learning performance compared with the fixed layout aligned with furniture such as a round table. However, learning environment research has not yet focused on specific potential forms of students' seating or learning arrangement with flexible furniture that enhance students' process performance in their collaborative learning.

Anyway, classifying different learning space designs in a simple and general way is meaningless; however, all learning spaces should have some key parameters that fulfill the purpose of their design (Ravelli, 2018). For example, initial studio-style classroom designs

such as SCALE-UP and TEAL classrooms have adopted round tables of seven-foot diameter that are intended to allow students to have enough space to collaborate and communicate across the table when speaking at a reasonable volume (Beichner et al., 2007). Such big tables allow students to use laptop computers and conduct hands-on experiments with their peers in order for them to understand the scientific aspects of basic physics. Needless to say, providing only round tables for such studio-style classrooms does not provide a satisfactory solution because we also need to consider creating more content-flexible FLS for students.

Similar to the cluster-type seating arrangement (in which two or four small tables are positioned together so that small groups of students face one another), the round-table seating layout described above is commonly used and considered suitable for teams of students with relationships that are equal or have slight differences in roles, allowing team members to effectively support the behaviors, expressions, and emotions of all members (Sommer, 1969). We also think that a possible drawback of the round-table setting that could prevent students from engaging in deep interactions in a variety of ways with other students is the varied distances among them, particularly between a leader and the other students within a small group. Generally, a leader role in a small group of students is typical and widely used. It is either spontaneously created by the students or assigned by a teacher to maintain the social relationships and performance abilities of the group, although the role is usually assumed without any particular training or instruction (O'Donnell & Dansereau, 1992). When seated around a round table, some students are closer to particular students than to others. Thus, some students are physically closer to the leader, and others are further away from the leader. This is a potential hurdle for communicating as a group because group members need to have equal opportunities to contribute to the workflow so that a variety of members can begin to participate proactively as the group organizes itself in order to achieve its goals (Gloor, 2006). The round-table shape of the seating arrangement seems to facilitate the creation of a homogeneous power center with differentiated relationships among its members.

Crescent-shaped seating arrangement for fostering every member's equal opportunity to participate in collaborative learning

A different line of research involves students' seating preferences in various classroom layouts in order to foster learning. Controlling interpersonal boundaries helps individuals to develop a sense of competence and regulate social contact in the physical environment (Gifford, 2002; Sommer, 2002). For example, Kaya and Burgess (2007) compared a traditional setting, a U-shaped arrangement, and a cluster-type seating arrangement in the context of social interaction. U-shaped and cluster-type arrangements both generated an increased sense of community in the same way in that they eased discussions and promoted social interaction. The cluster-type arrangement, in which four to six students work on various tasks together rather than with the class as a whole, is a common type of seating arrangement. Another study also indicated that the orientation of students' seating can contribute to better interaction and dialog, especially when the seats are close together (Nordquist & Fisher, 2018).

One of the reasons why participants in those settings can experience better interactions and a sense of community is what Hall (1966) called *sociopetal*. He explained that creating an interpersonal formation that allows every person to have eye contact encourages social activity among members. Hall further indicated that interpersonal distance, what he called

proxemics, is also crucial in facilitating communication among members, because appropriate proximity can enhance collaboration and empower participants to be creative and show innovation, because teamwork calls for some sort of territoriality.

Based on the above, we believe that there is great potential in creating a crescent-shaped layout (Fig. 1b) consisting of two U-curbs in order to encourage every member to participate in a group work. Despite the round seating layout (Fig. 1a) having benefits, both the round-shaped and the crescent-shaped layouts provide good personal distance for students to collaborate with each other. Meanwhile, the round table layout means that distances between members are varied, resulting in some members not being able to carry out responsible followership because the interaction between a lead student and some of the members can be decreased because of lack of proxemics. The crescent-shaped layout also provides sociopetal factors similar to the round table in that it generates intense interaction among the members. In addition, the crescent shape's two U-curbs can provide a more proximal focal point to stimulate conversations and more facilitation of discussion among the students (Suner, 2001). If a lead student is located at the focal point of the other students, they can maintain eye contact with the leader, which facilitates active discussion among the members; then, the members will generate mutual support through an increase in eye contact and verbal interactions. As such, the crescent-shaped seating arrangement can elicit members' proactive participation to achieve better collaboration.

Research question

Our research, which was preceded by the above literature review, was developed to answer the following questions:

- Do student groups in the crescent-shaped seating arrangement outperform those in the round-shaped seating arrangement in terms of process performance?

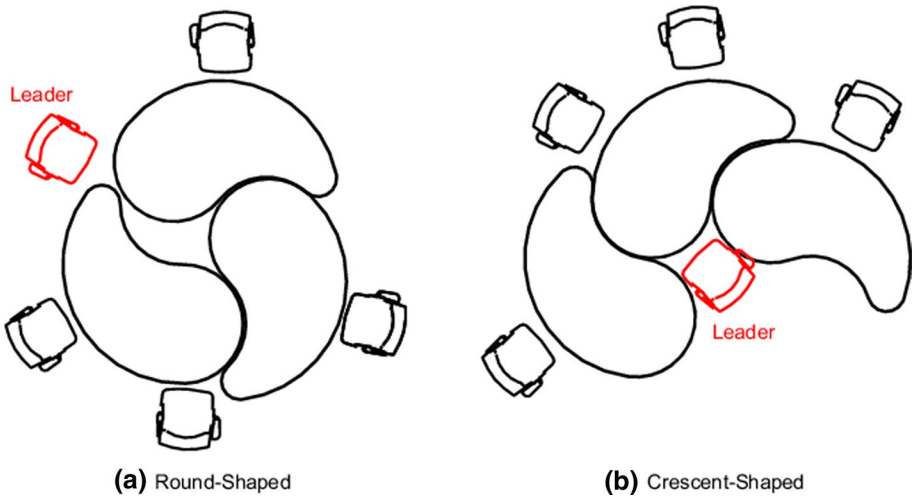

Fig. 1 Two types of seating arrangements

- Based on this pioneering exploration, could a different design perspective for content-flexible FLS be proposed?

Method

Participants, tasks and design

To explore the group process performance in the crescent-shaped seating arrangement, we conducted a design case study in the realm of collaborative learning in a studio-style learning space at a university. The space was designed based on the initial studio-type classrooms described above, but all the furniture was movable to make this learning space content-flexible FLS (Fig. 2). We explored how the process performance in the crescent-shaped seating arrangement worked in comparison with that in the round-shaped seating arrangement which, as described above, is a typical group learning arrangement and can be the baseline for considering process performance in the crescent-shaped seating arrangement. Considering a significant number of students would be required in a group study situation (Cress, 2008; Maas & Hox, 2005), we investigated the process performances through descriptive methods.

A total of 45 undergraduate and postgraduate students, including 25 females and 20 males, were recruited from 17 universities (4 national and 13 private) in the Tokyo metropolitan area through advertisements on campus and social media, and by the snowball sampling technique. Participants and other participants whom they recruited were separated from each other in this study. The participants were studying a variety of disciplines (see Appendix 1 for details). The age range of the participants was 18 to 24 years ($M = 20.00$, $SD = 1.45$). The students could fluently speak Japanese and they communicated only in Japanese during the group projects described below.

As shown in Table 1, the study was designed with two types of order (α and β) for the two discussion sessions in order to offset the order effects of the first and second sessions; the students were randomly assigned to nine groups, and worked on two different tasks in order, on a round-shaped and a crescent-shaped seating arrangement, but the order of the seating arrangement was reversed in four of the nine groups. Type α groups performed Task 1 first then Task 2; Type β performed Task 2 first then Task 1. Each task was

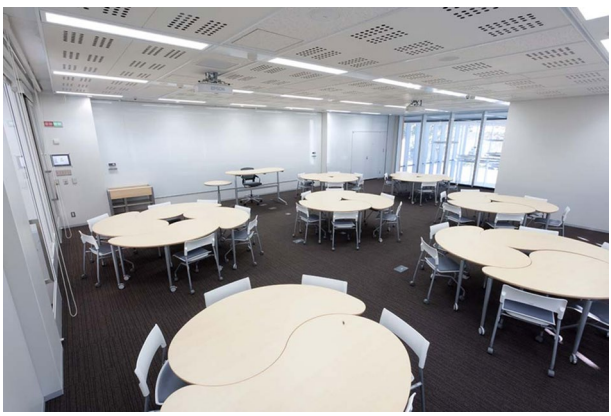

Fig. 2 The learning space where the current study was conducted

Table 1 Design of present study and how each student group worked in each condition

Categories	Type α number of groups		Type β number of groups	
	α1 groups	α2 groups	β1 groups	β2 groups
	3	2	2	2
1st session (55 min)	Task 1 in crescent-shaped setting Presentation (5 min)	Task 1 in round-shaped setting	Task 2 in crescent-shaped setting Presentation (5 min)	Task 2 in round-shaped setting
2nd session (55 min)	Task 2 in round-shaped setting Presentation (5 min)	Task 2 in crescent-shaped setting	Task 1 in round-shaped setting Presentation (5 min)	Task 1 in crescent-shaped setting

Number of participants: 5 students randomly assigned in each group

Fig. 3 Group work (in a round-shaped arrangement and in a crescent-shaped arrangement) followed by a presentation

completed in about 50 min, followed by a five-minute group presentation. In the round seating arrangement, students were asked to have a seat around the table (Fig. 3, upper left). While a lead student in the group was asked to take a seat in the central position of the crescent-shaped seating arrangement, a leader was able to select his or her preferred position in the round seating arrangement (Fig. 3, upper right).

The lead student in each group was chosen through a short discussion among the participants before they took their seats. Those leaders, as well as the other students, did not receive any particular instruction regarding leadership and facilitation because we took ecological validity into account. As O'Donnell (1999) indicated, most implementations of small groups in a learning context are unstructured, and it is well-known that there are no golden rules for leadership in a group work scenario. For example, sometimes unstructured groups could generate better results than structured groups, as Cohen (1994) indicated. It is possible that the round-shaped seating arrangements elicit participation because all members have similar seating positions regardless of who the leader is, whereas it is possible that the crescent-shaped seating arrangements do so because all members are seated in accordance with sociopetal and proxemics that foster communication among the members. We only recommended that the leader work while imagining how a group leader in a small group should/would perform.

Then students were asked to conduct two different tasks that required collaborative construction of products based on their discussion:

(1) Task 1: Development of a desert resort area: students were asked to propose a new resort area based on the characteristics found in a desert.
(2) Task 2: Development of a mobile school: students were asked to propose a new school that could move freely like a car or a ship instead of remaining in a fixed location.

These projects involved students providing some prototypes based on their proposals. LEGO building blocks, some A0 paper, and pens were offered before starting the discussion.

Both project tasks contained contradictory elements in order to foster collaboration through the project work in a short time. For example, deserts are generally considered to be areas with no or few living things and with limited human activity, while resorts are recognized as places with living things and plenty of food and water and where people can find enjoyment in a variety of activities. The task that requires integrating such contradiction usually causes cognitive dissonance, which increases intrinsic motivation to achieve consonance that enhances creative performance (Acar, 2020; Festinger, 1957). As such, task conflict or contradiction in group work can affect the process performances of members in a positive manner, because they need to have a deep understanding of the reasons for the conflict or the contradiction through discussion so that they reach better and satisfactory decisions (Farh et al., 2010).

Figure 3 shows how each group of students worked on their projects. As shown in Table 1 and Fig. 4, two or three groups worked simultaneously during one session. Both groups were separated by whiteboards and at a sufficient distance so that they could not hear voices in other groups.

Assessment of individual or group process performances

To evaluate group process performance in collaborative learning, we developed a rating scale, together with a specific method, procedures, and criteria for individual and group process performance evaluation. Furthermore, we recruited raters who conducted the process performance evaluation using the scale. In each session, two of them observed

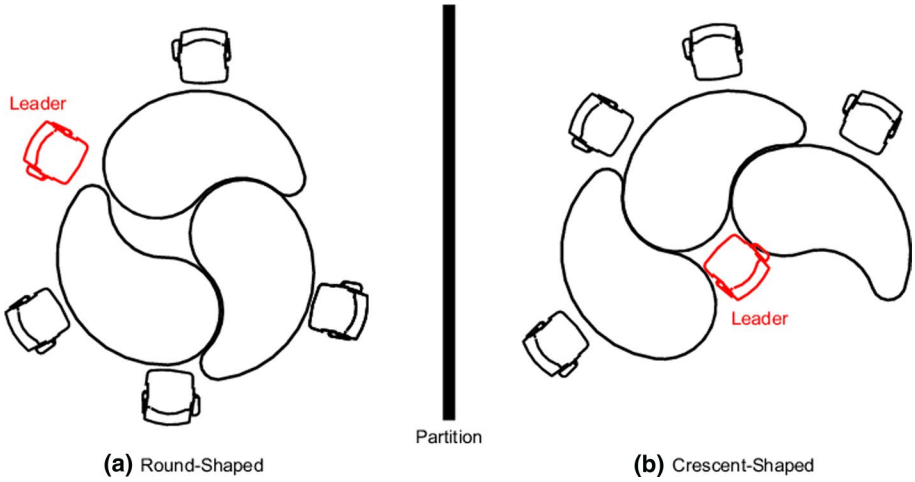

Fig. 4 Two groups simultaneously working in different seating arrangements

and rated the process performance in each student group using the team process performance evaluation scale, which we developed based on Plowman and McDonough's (2013) criteria.

The scale measured each group member's individual process performance and each group process performance. Based on the rating scale of group process performance in collaborative work that was developed by Plowman and McDonough (2013) at Bright Hub, we developed a score sheet as a rating scale for evaluating individual and group process performances in collaborative learning settings. We created two types of score sheets, one of for individual evaluation and the other for the evaluation of group process performance. The evaluators rated both process performances on an 8-point Likert scale (from 1—Definitely inapplicable to 8—Definitely applicable).

Table 2 shows individual evaluation items, whereas Table 3 shows group evaluation items. To establish overall control, the rating scale for individual and group evaluation, terms, sentences, and expressions were translated from English to Japanese with minor modifications for adjusting the context; because the original scale was developed for use in the workplace, we modified expressions used in the workplace such as 'employee' and 'team' to more general expressions such as 'participant' and 'group', respectively. Furthermore, based on a preliminary examination, we merged some items into one item. For example, "can effectively manage one's time and assigned tasks" and "is able to analyze and solve problems timely and effectively" were merged into "effectively analyzes and resolves problems while managing one's time".

Eighteen trained evaluators were recruited. Prerequisites for the evaluators were experience in collaborative learning and evaluation of group work. Therefore, the evaluators, except one, were graduate students with mentoring experience as teaching assistants in collaborative learning. The lone exception managed a nonprofit organization and had already earned a Master's degree with a research study of a small collaborative and creative group work. Before the study, we had an evaluator training session with the following procedure. First, we explained the experiment's purpose and procedure. However, we did not explain our hypothesis or how the score sheets had been constructed to avoid evaluator bias; thus,

Table 2 Items for evaluating individual group members' process performance

Categories	Items
Attitude	1. Participant acts in a positive manner and is involved in the team activity
	2. Participant displays high energy and creates a motivational environment for the group
	3. Participant strictly adheres to the time and rules of the progress of the activities
	4. Participant fully incorporate work to be done by individuals
Behaviors	1. Participant assists group members who experience difficulties
	2. Participant is receptive to group member recommendations for improvement
	3. Participant demonstrates a willingness to forego their individual opinion for that of the group
	4. Participant exhibits the same effort and dedication to the project as other members
Competencies	1. Participant effectively analyzes and resolves problems while managing one's time
	2. Participant respects group members and works cooperatively with them in a proactive manner
	3. Participant can independently and effectively make decisions in a timely manner
	4. Participant accurately completes assigned tasks

Table 3 Items for evaluating individual group members' process performance

Categories	Items
Planning and processes	1. Group effectively plans activities such as assigning tasks, timelines, and steps to achieve the project, in order to ensure a timely delivery
	2. Group makes the project's goal and tasks clear
	3. Group regularly reevaluates processes and adjusts their ways in order to improve productivity
	4. Group processes utilize all members' strengths and compensate for weaknesses
Interdependence and leadership	1. Group embraces members' difficulties and failures and they help each other
	2. Group creates an atmosphere to encourage members to consult and advise each other
	3. Group shares information and progress with each other
	4. Group maintains a close and friendly relationship
	5. Leader successfully distributes tasks and responsibilities equally to members
	6. Leader adopts team members' ideas and reflects this in their products
	7. Leader clearly shows what to do and how to do it
	8. Leader gives attention and consideration to members with problems or doubts
	9. Leader has the power to involve members
Results	1. Group has successfully achieved its goals
	2. Group has met the expectations for the task provided
	3. Group effectively used resources to achieve positive results
	4. Group met its productivity goals according to the estimated timeline

the evaluators had no information about our hypothesis or our expectation of their scoring. Next, we explained how to evaluate both individual and group process performances; we also provided a booklet to allow the evaluators to check the criteria in detail during their evaluation (Appendix 2 contains the booklet's content translated into English). Each evaluator was then asked to assess and rate students' individual and group process performances by observing how they were working in each seating arrangement. Then, we asked each evaluator, as they noticed students' characteristic behaviors, to write an informal memo on the score sheets. Because the evaluators were recruited based on their experience in evaluating group work, we finally held a short question-and-answer session to clarify anything that they were unable to understand fully based on the previous explanation. The training session took approximately 40 min.

Video analysis of eye contact with leaders

Besides the evaluator observations, we video-recorded each group's activity while students discussed and completed their tasks. Next, to examine qualitatively how the students made eye contact with their leaders, we observed video data from five of the nine groups to indicate when students have opportunities to communicate. Videos of these five groups clearly captured eye contact between leaders and the other members, without any unexpected

obstacles or trouble such as students standing in front of the video cameras or the camera recording being interrupted or stopped.

Data analysis

Individual or group process performance

Each evaluator submitted 12 score sheets, 10 for individual evaluations and 2 for group evaluations. In total, the 18 evaluators submitted 216 score sheets. Based on evaluator ratings, we calculated the means and standard deviations of factor scores for individual and group process performances.

To measure the internal consistency of individual process performance factor scores for each rating item, we calculated Cronbach's alpha coefficients: Attitude = 0.834; Behavior = 0.874; Competence = 0.913. For each case, a Cronbach's alpha of greater than 0.8 confirmed sufficient internal consistency and reliability.

Regarding inter-rater agreements, we calculated average intraclass correlation coefficients (ICC) for individual and group process performance scores which were, respectively, 0.65 with a 95% confidence interval (CI) from 0.61 to 0.68 (F (1079, 1079) = 4.681, $p < 0.001$) and 0.61 with a 95% CI from 0.53 to 0.67 (F (322, 322) = 4.081, $p < 0.001$). Coefficients fell within the 0.61–0.80 range which, according to Landis and Koch (1977), confirms 'substantial agreement'. Therefore, inter-rater agreement was deemed sufficient. If two raters' scores differed, we used the average scores for analysis. Based on the foregoing, although we modified the original scale somewhat, reliability did not seem to be adversely affected.

Next, to examine differences of the process performance between the conditions, we compared individual or group process performance factor scores as evaluated in each seating arrangement by computing effect sizes as descriptive instead of as inferential analyses. Because the experimental design was repeated measures (i.e., each group experienced both conditions), we first calculated Student's t-value using the difference of each group process factor score between the two conditions and then computed Pearson's r as the effect size by using the t-value as follows:

$$r = \sqrt{\frac{t^2}{t^2 + df}}$$

To understand the reasons for the differences, we also compared item scores in each individual process performance factor. We considered the necessity to include the factor of whether the student was a group leader or a participant in order for us to examine the exact effect of the seating arrangement. Thus, we computed partial eta squared (η^2_p) as an effect size based on group mean differences according to each factor. Partial eta squared indicates the percentage of variance in each effect (or interaction) and the associated error accounted for by that effect (or interaction).

Video analysis

The videos were observed by two of the authors independently. Before observation, each video's length was adjusted according to the task's beginning and end (i.e., when the experimenter asked the students to start or end the task). Then, every minute, the observers

Table 4 Means and standard deviations of individual process performance factor scores in each layout

Categories	Round-shaped		Crescent-shaped		Range	Effect size
	M	*SD*	*M*	*SD*		*r*
Attitude	19.29	4.95	22.95	5.73	0–32	0.67
Behaviors	19.36	4.56	22.01	5.95	0–32	0.52
Competencies	18.20	5.10	21.84	6.49	0–32	0.58

Table 5 Means and standard deviations of group process performance factor scores in each layout

Categories	Round-shaped		Crescent-shaped		Range	Effect size
	M	*SD*	*M*	*SD*		*r*
Planning & Process	16.5	5.21	22.72	5.76	0–32	−0.86
Independence & Leadership	36.5	11.55	51.56	18.46	0–72	−0.84
Results	21.06	3.03	23.44	5.34	0–72	−0.36

counted the number of students who made eye contact with their leaders. We calculated the average ICC [0.77 with a 95% CI from 0.73 to 0.80 (F (506, 506) = 7.599, $p < 0.001$)], so that the inter-rater agreement could be deemed sufficient. The two researchers then discussed the discrepancies, rechecking the videos if necessary, and determined the final values.

Results

Individual or group process performances

Results of the analyses for the individual or group process performances are shown in Tables 4 and 5. With respect to individual evaluations, all the factor scores (i.e., Attitude, Behavior, and Competence) are higher in the crescent-shaped seating arrangement than in the round seating arrangement with substantial effect sizes of $r = 0.67$, 0.52, and 0.58, respectively. With respect to group evaluation, two factor scores (i.e., Planning and Process and Interdependence and Leadership) are higher in the crescent-shaped seating arrangement than in the round-shaped seating arrangement, with substantial effect sizes of $r = -0.86$ and -0.84, respectively, while *Results* factor scores in the crescent-shaped seating arrangement are higher than that in the round-shaped seating arrangement with medium effect size of $r = -0.36$. In the group process performance, the *Independence and Leadership* score in the crescent-shaped layout was almost 1.4 times score of the round-shaped layout, indicating that the crescent-shaped arrangement fostered students' ability to responsibly collaborate in project work.

Individual or group process performance scores (except the group-level *Results* score) were greater than median scores of the factor scores for each in the round- and crescent-shaped seating arrangements. We can consider that both seating arrangements did not negatively impact the students' collaboration. The *Results* scores were lower than the median

Table 6 Means and standard deviations of item scores according to students' roles in each layout

Categories and items	Round-shaped		Crescent-shaped	
	Leader	Non-leader	Leader	Non-leader
Attitude				
1. Participant acts in a positive manner and is involved in the team activity	6.11	5.22	6.39	5.93
	(−1.41)	(−1.72)	(−1.69)	(−1.50)
2. Participant displays high energy and creates a motivational environment for the group	5.39	4.64	5.94	5.26
	(−1.69)	(−1.82)	(−1.99)	(−1.90)
3. Participant strictly adheres to the time and rules of the progress of the activities	4.17	4.04	5.78	5.36
	(−1.75)	(−1.50)	(−1.62)	(−1.81)
4. Participant fully incorporate work to be done by individuals	4.83	5.08	5.88	6.14
	(−1.17)	(−1.30)	(−1.98)	(−1.37)
Behaviors				
1. Participant assists group members who experience difficulties	4.56	3.92	4.89	4.79
	(−1.59)	(−1.56)	(−2.10)	(−1.92)
2. Participant is receptive to group member recommendations for improvement	5.11	4.93	5.89	5.47
	(−1.43)	(−1.39)	(−2.06)	(−1.83)
3. Participant demonstrates a willingness to forego their individual opinion for that of the group	5	5.28	5.67	5.67
	(−1.50)	(−0.94)	(−2.00)	(−1.56)
4. Participant exhibits the same effort and dedication to the project as other members	5.72	4.97	6.33	5.89
	(−1.46)	(−1.51)	(−1.46)	(−1.39)
Competencies				
1. Participant effectively analyzes and resolves problems while managing their time	4.28	3.74	5.11	4.84
	(−1.60)	(−1.48)	(−1.90)	(−1.87)
2. Participant respects group members and works cooperatively with them in a proactive manner	5.56	5.08	6.39	5.41
	(−1.69)	(−1.65)	(−1.76)	(−1.91)

Table 6 (continued)

Categories and items	Round-shaped		Crescent-shaped	
	Leader	Non-leader	Leader	Non-leader
3. Participant can independently and effectively make decisions in a timely manner	4.5 (−2.09)	3.69 (−1.43)	5.44 (−2.23)	5.1 (−1.93)
4. Participant accurately completes assigned tasks	5.5 (−1.27)	5.28 (−1.11)	6.5 (−1.60)	6.08 (−1.35)

Rating scale is as follows: 1: definitely inapplicable, 2: mostly inapplicable, 3: inapplicable, 4: slightly inapplicable, 5: slightly applicable, 6: applicable, 7: mostly applicable, 8: definitely applicable. Numbers within parenthesis are standard deviations

scores because our observation and the evaluator's informal comments indicated that students had little time to create their learning artifacts together after the discussion.

Table 6 shows the process performance scores in both types of seating arrangements for the lead students and other participants. Accordingly, we observed consistently-higher performance scores in the crescent-shaped seating arrangement. Furthermore, score tendencies of the leader and participants were almost similar in both arrangements. We examined differences by considering both factors (Seating arrangement × Role (i.e., the leader or participants)) for each item score, revealing that the following items scores are higher in the crescent-shaped seating arrangement than in the round-shaped seating arrangement with more than medium effect sizes: following time and rules ($\eta^2_p = 0.391$), fully incorporating work required to be done by the individuals ($\eta^2_p = 0.221$), exhibiting the same effort and dedication to the project as other members ($\eta^2_p = 0.161$), effectively analyzing and resolving problems ($\eta^2_p = 0.215$), making decisions in a timely manner ($\eta^2_p = 0.243$), and accurately completing assigned tasks ($\eta^2_p = 0.203$).

Video analysis

Figure 5 shows the number of students who made eye contact with the leader in each sample group, as well as the duration for which they discussed and created their learning artifacts. We realized that most of the groups in the crescent-shaped seating arrangement

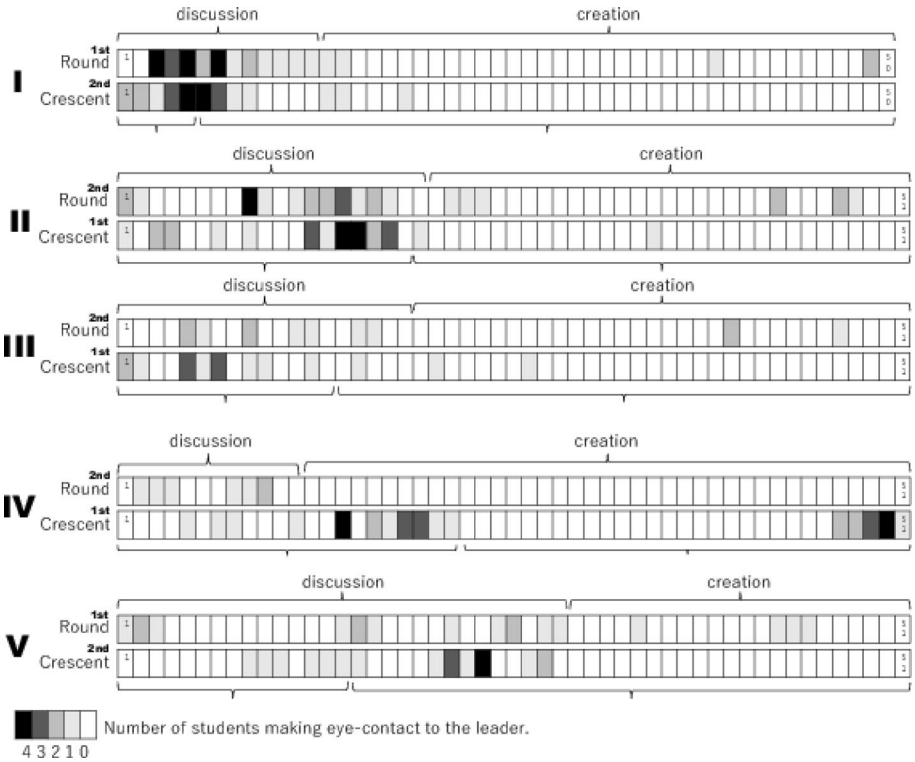

Fig. 5 Number of students making eye-contact with the leader in the sampled groups

tended to conduct their discussions in a shorter amount of time (average of 15.8 min) than those in the round-shaped seating arrangement (average of 18.4 min), regardless of the order of the tasks assigned to them. During the discussion, more students in the crescent-shaped seating arrangement made eye contact with their leaders than those in the round-table seating arrangement; the average numbers (standard deviations) of the students who made eye contact with the leader in every minute during the discussion in the crescent-shaped arrangement were: I: 2.00 (1.41), II: 1.84 (1.38), III: 1.61 (1.20), IV: 1.95 (1.17), and V: 1.25 (0.73). In comparison, those in the round-shaped arrangement were I: 1.31 (1.32), II: 1.40 (1.27), III: 0.89 (0.94), IV: 1.45 (0.82), and V: 1.10 (1.01), respectively. Thus, we observed that all groups could make eye contact with the leader easily in the crescent-shaped seating arrangements so that students could elicit their process performances better than those in the round-shaped seating conditions.

Discussion

Overall, the results suggest that seating arrangements can influence collaboration between students and that practitioners such as learning environment designers and instructors need to pay attention to interpersonal space and students' seating positions in order to achieve ideal interactions when they design studio-style learning spaces or learning activities in such spaces, with regard to the furniture used and the layout of the specific items.

Individual process performance evaluations indicate that students tended to work more efficiently in the crescent-shaped seating arrangement; according to Table 6, they tried to maintain the time limit and follow the rules, engaged with their own work, exhibited the same effort and dedication, effectively made decisions, and completed their tasks. Group evaluation results also indicated that group members in the crescent-shaped seating arrangement showed better process performance in flexibly developing their division of labor (Hutchins, 1990), time management, mutual aid, information sharing, and social relationships. Leaders in this seating formation also showed great process performances in team management, which was enabled by less-disparate distances between the leaders and other members. One possible reason is sociopetal, which is naturally generated in the crescent-shaped arrangement. We argue that the crescent shape guided students to make eye contact with the leader easily by generating the focal point with the U-carbs so that they could perform in an efficient manner, particularly during the discussion. The video analysis of the eye contact revealed that the groups in the crescent-shaped layout tended to have more eye contact and to spend less time planning, which indicates that such sociopetal effects have the potential to promote efficiency in the discussion between the people seated in a crescent-shaped arrangement. Thus, individual and group process performances elicit cooperative behavior (i.e., a better group process performance can prompt each member's cooperative behavior; Slavin, 2014). This implies that a better interactional environment in the crescent-shaped seating layout could elicit a better process performance regarding leadership and task and information sharing. This could lead to members outperforming in managing the social aspect of their collaborative learning (Barron, 2003), particularly for efficiently achieving more idea-centered goals (Hod & Ben-Zvi, 2018), such as collaborative problem solving.

However, the impact of the crescent-shaped seating arrangement on the Results factor score of the group process performance was relatively small. This is consistent with prior studies that revealed that external collaboration scripts (Fischer et al., 2013) that prompted interaction among participants were not significantly effective in terms of their learning outcomes (e.g., Janssen et al., 2007; Raes et al., 2016). Thus, we consider that changing the seating arrangements can cause an effect that is similar to the external collaboration scripts, and that improving individual or group process performances with respect to students' proactive participation does not guarantee an improvement in their group learning outcomes. We need to further investigate factors responsible for this issue.

Usually in everyday learning spaces (not only in studio-style classrooms, but also in classrooms with traditional seating arrangements), the seating layout is already set according to how the furniture is arranged, with students naturally taking their seats according to the formation before starting learning activities. In other words, it is difficult for the students to create their own appropriate seating arrangements, even in flexible learning spaces. According to Gibson's (1977) theory of affordances, the physical properties in a learning space can promote or disturb desired activities. Norman (1999) also noted that "the art of the designer is to ensure that desired, relevant actions are readily perceivable" (p. 41). Therefore, as learning environment designers, we must carefully consider and design layouts of not only furniture but also the students in ways that foster students' collaboration appropriately by taking into account sociopetal considerations, focal points, and proxemics among the leader and other students. We need to have a more-flexible mindset that allows combinations or a variety of furniture arrangements in various ways to enhance the students' potential interactions, if necessary.

Limitations and future directions

Several limitations of our present study should be noted. First, the sample size of the present study was small; therefore, we could not conduct statistical testing for generalizing these results and thus need to consider that different outcomes could be obtained during other learning activities with large sample sizes. If we had larger samples, we could conduct multilevel analyses that would additionally allow us to examine the differences and their emergence in depth. However, we believe that this pioneering study is very useful when framed as a design case.

Second, the duration of the collaborative project work was less than one hour, and longer collaborative projects would require consideration of different aspects of collaborative learning, such as socially shared regulation (Panadero & Järvelä, 2015). We need to consider and pursue the limitation of the environmental factors that learning environment designers and instructors can modify or coordinate.

Third, the tasks assigned for the students' collaborative project were creativity driven because our research aimed to gain insight into design perspectives for FLS regardless of discipline. This also allowed us to decrease confounding associated with differences in students' prior knowledge of specific disciplines. However, we should consider task characteristics that increased students' inquiries and intrinsic motivation to generate their own conclusion (i.e., design). For learning a specific discipline, such as physics in FLS, for

example, we believe that interpersonal distance and eye contact can be important when students address a collaborative and ill-structured inquiry (e.g., Nicol et al., 2018), while students might show similar process performances even in round-shaped seating arrangements if they struggle with structured inquiry tasks (e.g., Dori et al., 2007) that follow the instructor's course structure. Further studies should involve this aspect of the interaction between classroom arrangements and small-group projects.

There is a need to consider the potential for using ICTs in technology-enhanced learning spaces in the near future. The results indicated that sociopetal and proxemics should be considered when designing how students work in the FLS for improving their process performances. This also implies that better varieties of students' layouts can be created when students' collaborations are mediated with some technological artifacts in technology-enhanced learning spaces such as classrooms with multi-touch screen tables. Further investigation is needed because our results indicate that there is possible confounding between the shared technological artifacts and students' layouts in collaborative learning in content-flexible FLS.

Conclusion

The present study provides new insights into better seating arrangements to foster the process performances of students in collaborative learning conducted in studio-style learning spaces by comparing two different seating arrangements: round-shaped and crescent-shaped. This study has illustrated that students' individual and group process performances in the crescent-shaped seating arrangement outperformed the performances in the round-shaped arrangement. Taking the theoretical backgrounds into account, we discussed how every member's participation could be improved in accordance with the interpersonal space of the team members; thus, sociopetal and proxemics must be considered when practitioners design learning spaces and layouts of furniture.

There have been few studies of relationships between students' seating arrangements and process performance, especially in a collaborative learning setting, and no such studies in the design of studio-style classrooms. Thus, this is a pioneering study that focused on students' learning process performance with respect to seating arrangements in collaborative learning. The present study revealed that taking into account sociopetal and proximal focal points is important for fostering students' abilities in group work, and therefore that learning environment designers or instructors should incorporate these ideas when students are learning in a collaborative project.

Appendix 1

See Tables 7 and 8.

Table 7 Majors studied by participants in national or private universities

Major	*N*		
	National	Private	Sum
Applied mathematics		1	1
Basic sciences	1		1
Business		1	1
Economics	3		3
Education	3	1	4
Engineering	1		1
Human sciences		3	3
Information science		6	6
International communication		1	1
Law	1	5	6
Law and politics	1		1
Liberal arts	9		9
Linguistics		1	1
Literature		2	2
Policy studies		1	1
Political science and economics		2	2
Sciences	1		1
Social informatics		1	1
Total	20	25	45

Table 8 Names and types of the universities with which participants were affiliated

No	Type	Name	Participant
1	National	Hitotsubashi University	1
2	National	Shiga University	1
3	National	The University of Tokyo	17
4	National	Tokyo Gakugei University	1
5	Private	Aoyama Gakuin University	1
6	Private	Chuo University	1
7	Private	Kaetsu Women's College	1
8	Private	Kokushikan University	5
9	Private	Meiji University	1
10	Private	Meisei University	1
11	Private	Musashino Gakuin University	1
12	Private	Senshu University	4
13	Private	Soka University	1
14	Private	Takushoku University	2
15	Private	Tokyo City University	2
16	Private	Tokyo University of Science	1
17	Private	Waseda University	4
Total			45

Appendix 2

Observer handbook

OBSERVER HANDBOOK (English translation from Japanese)

For groupwork evaluators

To-do list and evaluation criteria

Evaluation Schedule*

PM 1	Task 1	Task 2	PM 2	Task 2	Task 1
	14:20 – 15:10	15:20 – 16:10		14:20 – 15:10	15:20 – 16:10
	Round-shaped	Crescent-shaped		Round-shaped	Crescent-shaped
	Round-shaped	Crescent-shaped		Round-shaped	Crescent-shaped
	Round-shaped	Crescent-shaped		Crescent-shaped	Round-shaped
	Round-shaped	Crescent-shaped		Crescent-shaped	Round-shaped
	Crescent-shaped	Round-shaped		Crescent-shaped	Round-shaped
	Crescent-shaped	Round-shaped		Crescent-shaped	Round-shaped

Terms Definitions

-Round-Shaped: each set of tables is arranged as a circle.
-Crescent-shaped: each set of tables is arranged as a crescent.
- Task 1: Development of a desert resort area.
- Task 2: Development of a mobile school.

- Please do not let the participants know when your evaluation starts, and when you move to the different group's evaluation.
- Please start observing groups that you are in

Interpretation of score sheet items and evaluation criteria

	Factors	Items	Evaluation Criteria
Dimension 1	Attitude	1. Participant acts in a positive manner and is involved in the team activity.	Positive: Speaks a lot; Actively expresses his/her ideas; tries to get along with other members. Negative: Silent most of the time; only follows what others say.
		2. Participant displays high energy and creates a motivational environment for the group.	Positive: Motivational speech such as "let's do something", or "let's do our best; Encouraging other member to ask such as "what do you think about this?", "that's a good idea," etc.
		3. Participant strictly adheres to the time and rules of the progress of the activities.	
		4. Participant fully incorporate work to be done by individuals.	Positive: Concentrated effort to complete the task at hand. Negative: Not putting in full effort into any task; just helping other members; or chatting with them.
	Behaviors	1. Participant assists group members who experience difficulties.	
		2. Participant is receptive to group member recommendations for improvement.	
		3. Participant demonstrates a willingness to forego their individual opinion for that of the group.	Positive: Not being attached to their own opinions in order for the project to run smoothly, even if he/she has their own personal idea.
		4. Participant exhibits the same effort and dedication to the project as other members.	Please decide this individual evaluation based on their number of utterances during the discussion, valuable opinions suggested, and their individual contribution (ratio and importance) to the group's overall products. Give a 7 (or higher) based on how their performance is better than the others; give a 5 or 6 for relatively similar performance to the others; and give a 4 (or lower) if their performance was not as good.

*Note: The schedule was designed for the maximum capacity of students that can be accepted in the classroom where the experiment was conducted.

	Competencies	1. Participant effectively analyzes and resolves problems while managing own time.	Positive: Spends 10 min or less on each piece of a problem that is necessary to achieve the task. Is aware of and monitors the deadline of the task. Negative: Give a 4 (or lower) if he/she obsesses about a single piece of a problem for more than 15 min without planning how to use time for completing the task.
		2. Participant respects group members and works cooperatively with them in a proactive manner.	Positive: Give a 6 (or higher) if he/she contributes to active discussions and/or helps other members. Negative: Give a 3 (or lower) if he/she does not get involved with any other members, or if their conversation is just a chat.
		3. Participant can independently and effectively make decisions in a timely manner.	Positive: Give a 5 (or higher) if he/she decides on any idea (except for the overall goal of the project) within 10 min. Negative: Give a 4 (or lower) if he/she spends more than 15 min on making one decision.
		4. Participant accurately completes assigned tasks.	
Dimension 2	Planning & Process	1. Group effectively plans activities such as assigning tasks, timelines, and steps to achieve the project in order to ensure a timely delivery.	Positive: Give a 5 (or higher) if the group can decide on their assignment of pieces of the task and on a rough timeline and steps to achieve the project within 10 minutes from the beginning of the task. Negative: Give a 3 or 4 (or less) if the decision takes more than 10 minutes from the beginning of the task.
		2. Group makes the project's goal and tasks clear.	Positive: Give a 5 (or higher) when the following criteria is satisfied: Clarifying the goal and task assignments among members within 10 min from when the project starts; No major changes of the goal and the tasks already decided. Negative: Give a 4 (or lower) if it takes more than 10 min from the beginning of the project to decide their goal and task assignments (or if they cannot decide their goal and task assignments by the end of the project). Or give a 4 (or lower) if the group makes significant change(s) to the goal and the task assignments after the first decision even though the first decision is made within 10 min from when the project begins.
		3. Group regularly reevaluates processes and adjusts their ways in order to improve productivity.	Positive: Give a 5 (or higher) if the group is aware that their plan does not work well before 20 min have passed after the project starts provided that the group makes adjustments to their plans; or if their work goes smoothly without any problem. Negative: Give a 4 (or lower) if the group does not adjust their way of working or thinking even if they have difficulty proceeding with the task or if the group begins to change the ways of working or thinking after 20 min have passed after the beginning of the project.
		4. Group processes utilize all members' strengths and compensate for weaknesses.	Positive: For example, a person who likes architecture is in charge of building, a person who is good at coming up with ideas is in charge of generating ideas, or a person who is good at managing people should be in charge of leading, etc.
	Interdependence & Leadership	1. Group embraces members' difficulties and failures and members help each other.	
		2. Group creates an atmosphere to encourage members to consult and advise each other.	Positive: Give a 6 (or higher) (to everyone) if the members give help or advice about the parts that the other members are in charge of, or if the group members exchange responses such as "It's nice" or "good idea" with each other more than 5 times when someone gives advice. Negative: Give a 4 (or lower) if the members do not respond to the other members' suggestions or advice, or if they usually oppose to others' suggestions.
		3. Group members share information and progress with each other.	Positive: Give a 6 (or higher) if you observe at least 5 times that group communication behaviors or utterances show that the members monitor or share other members' progress with each other, by asking "How are you going?," "How about the part of…?," or making statements such as "We're making progress," "We're pretty much done," "We're ready to go," etc. Negative: Give a 4 (or lower) if the members are in isolation and/or without monitoring or sharing their progress.
		4. Group maintains a close and friendly relationship.	Positive: Members communicate well and complete tasks on time. Negative: Give a 4 (or lower) if some (one or more) members are in isolation; give a 4 (or less) if all members are overexcited and standing or moving around even though they seem to communicate well
		5. Leader successfully distributes tasks and responsibilities to members equally.	Positive: If the leader demonstrates task-sharing behavior within the first 20 min of the start if the project, give a 5 (or higher).
		6. Leader adopts team members' ideas and reflects this in their products.	Positive: Give a 6 (or higher) if the product has more than three aspects that are based on the members' advice or ideas. Neutral: Give a 4 or 5 if the product has one or two aspects that are based on the members' advice or ideas. Negative: Otherwise, give a score of 1 – 3.
		7. Leader clearly shows what to do and how to do it.	Please give an average score for Planning & Process items #1 and #2.
		8. Leader gives attention and consideration to members with problems or doubts.	Positive: Give a 6 (or higher) if the leader takes actions to help those who have questions or/and those who work well on their own piece of the task, or listens to the comments of the team members.
		9. Leader has the power to involve members.	
	Results	1. Group successfully achieves its goals.	Positive: Give a 6 (or higher) if the content of the product is sufficient and consistent with the goal and concept. Negative: Give a 4 (or less) if the content of the product is insufficient, or if the product does not match the original goal and concept
		2. Group has met the expectations of the task provided.	Task 1: The product reflects the characteristics of a desert as a resort. Task 2: The campus can be moved, so new types of learning are likely to occur.
		3. Group effectively uses resources to achieve positive results.	
		4. Group meets its productivity goals according to estimated timeline.	Evaluate whether their project is completed by the set time based on the goal and concept. Positive: Give a 6 (or higher) if the product is substantial, interesting, unique, and aligns with the goal and concept.

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