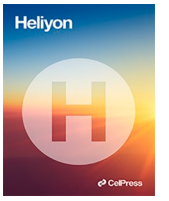
Heliyon 9 (2023) e16237

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Research article

Effects of gender diversity on college students' collaborative learning: From individual gender to gender pairing

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ARTICLE INFO

Keywords:
Gender differences
Gender pairing
Collaborative learning
Quasi-experiment
University

ABSTRACT

This study investigated the effects of gender and gender pairing on behaviors and social interaction during collaborative learning in a blended learning environment. Three types of pairing (all-female, all-male, and mixed) were considered in an empirical study with 44 undergraduate students. The results revealed that, first, female students were more likely to perform well in listening, talking, and integrating during class, and in the quality of posts after class, whereas male students tended to engage more in irrelevant behavior in collaboration. Second, same-gender groups were more active in collaborative discussion, but all-male groups performed worst in quality of posts after class. Third, both male and female students were more active in same-gender groups than in mixed groups. Finally, same-gender groups tended to have greater interpersonal connectedness than mixed-gender groups. The paper ends with a list of practical implications for facilitating effective collaborative learning in co-educational college classrooms.

1. Introduction

Collaborative learning, as a social-constructive instructional strategy, has become increasingly popular in higher education to promote students' learning engagement [1,2], social interaction [3,4], and academic performance [5,6]. The key to excellent group performance and individual gains in collaborative learning is the quality of interpersonal interaction among participants [7], which is influenced by group composition [8,9]. Gender, as a key demographic attribute, has been regularly used to compose collaborative learning groups [10–13], and gender diversity induced a wide range of factors highly relevant for group functioning, such as behavioral patterns [14], peer interaction [15], and emotional expression [16,17], which determine the overall efficacy and experience of collaborative learning. However, there is a lack of research studies investigating the effect of gender and gender diversity on social interaction and learning behavior in the context of higher education. By using the search strings "gender + social interaction", "gender + learning engagement", and "gender + learning behavior", our literature search in the Web of Science Core Collections revealed only 15 relevant empirical studies published from 2002 to 2022 in the field of education, out of the 8703 entries of gender studies.

Gender differences not only are found in biological characteristics but also appear in disciplinary performance, higher-order thinking, conversational style, and emotional expression. For example, several researchers found that male students were more skilled in math courses, while the female advantage was largest for language courses [18–20]. Additionally, differences in higher-order thinking skills appear to exist between boys and girls, as boys tend to demonstrate higher computational thinking [21], and girls have

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https://doi.org/10.1016/j.heliyon.2023.e16237
Received 21 November 2022; Received in revised form 8 May 2023; Accepted 10 May 2023
Available online 19 May 2023
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been associated with superior creative thinking [22] and information and communication technology (ICT) literacy [23]. Moreover, gender differences also exist in collaboration competencies, such as communication style, management skills, and emotional expression. The literature has indicated that male students tend to adopt a more confrontational and assertive communication style, while females are more socially sensitive [24], prefer relationship-building and collaboration [16,25], and shy away from competition and conflict in their learning activities [26,27]. A possible reason is that women have been found to acquire more emotional intelligence than men as measured by emotion perception, expression, regulation, and stress adaption [17,28–30]. However, most of these studies only examined gender differences during collaborative processes and lacked systematic analysis of learners' collaborative behaviors and social interactions before, during, and after class, which are known to affect collaborative learning performance and process synergically [31,32].

Additionally, few studies have explored gender pairing on collaborative learning, with mixed findings reported regarding the effect of gender pairing on group performance. Several researchers found that same-gender groups were more dedicated [15,33], and the proportion of women members was highly correlated with the group's academic achievement [13,34]. Other researchers favored mixed-gender groups or found no significant difference between gender pairings. For instance, Willoughby et al. [35] associated mixed-gender groups with greater behavioral engagement, while Xie [36] revealed that gender grouping had no significant impact on collaborative learning performance. Moreover, male and female students may behave differently in different gender pairing conditions. For example, male students were found to be more commanding and deliberate when working with female counterparts [37], and female students in all-women groups yielded better learning performance than those in mixed-gender groups [38,39]. Moreover, the empirical data reported in the literature were largely limited to traditional approaches, such as tests, questionnaires, and interviews, lacking novel approaches to analyze group dynamics in collaborative learning with enhanced accuracy and depth.

To address these research gaps, this study investigated how gender and gender pairing differences affect behaviors and social interaction during collaborative learning in a blended learning environment, and further conducted social network analysis (SNA) to uncover group interactions in various gender group compositions. The results of this study can provide teachers with specific suggestions and references for creating and facilitating collaborative learning groups in co-ed classrooms. In particular, we sought to answer the following research questions:

(1) Do gender differences affect students' learning behavior and social interaction during collaborative learning?
(2) Do gender pairing differences affect students' learning behavior and social interaction during collaborative learning?
(3) Do female and male students perform differently in same- and mixed-gender groups during collaborative learning?

2. Literature review

2.1. Gender differences in performance and interaction

Gender is a distinct and fixed characteristic that has been verified to be one of the factors influencing academic performance and social interaction patterns [40]. In terms of academic performance, Kuhn and Holling [41] conducted a multilevel mediation analysis revealing that girls outperformed boys in languages, while boys excelled in sciences and reasoning. Similarly, Halpern et al. [19] also found that male students were more skilled in math courses, while female students' advantage was in language courses. Possible reasons for this are that male students prefer using inductive reasoning, theory, and concepts [42]; thinking logically and rationally; and working with symbols and structure [43]. However, female students typically feel more comfortable with ambiguity and prefer hands-on experiences to learn and make intuitive or feeling-based judgments [43].

Existing studies have also explored the effect of gender on students' social interaction, including verbal and non-verbal interactions [44]. In terms of verbal interaction, West and Zimmerman [45] found that male students tended to communicate about different events and exhibited diverse styles of routine social interaction. Specifically, female students were seen to have a supportive communication style that builds relationships, whereas male students were seen to have a dominant style marked by interruptions and dominance [45,46]. The literature suggests that the cause of such gender difference in social interaction is likely due to variance in social expectations rather than biological attributes [46,47].

As for non-verbal interaction, Kring and Gordon [48] employed a systematic observation tool to measure facial expressiveness and found that female undergraduates' faces were more expressive than male undergraduates. Similarly, Ali et al. [15] found that female students were more inclined to make eye contact when talking, while male students preferred not to look at each other. Other gender differences in non-verbal interaction include: male students engage in more movements such as fidgeting, leg movements, leaning, and feet on table, while female students prefer nodding, forward-leaning, making hand movements during speech, gazing at partners, gesturing, and smiling [48,49].

2.2. Impact of gender pairing on collaborative learning

Gender pairing is an easy and widely used grouping strategy in collaborative learning [11,13]. Several researchers have examined the impact of gender grouping on group interaction and learning atmosphere, and mixed findings have been reported in the literature. Several studies favored mixed-gender groups over same-gender groups for enhanced collaboration and equitable contribution [35,44], while other studies revealed that mixed-gender pairs showed lower levels of verbal interaction and peer cooperation [24,33]. Interestingly, the proportion of women in groups was positively correlated with the affective atmosphere within the groups [50], possibly due to women's conflict aversion tendency and sensitivity to criticism [51].

Similarly, the effects of gender pairing on learning outcomes varied in the literature. For example, Underwood et al. [33] compared the performance of all-girl, all-boy, and mixed groups in a computer-based language problem-solving assignment and discovered that same-gender groups, particularly the all-girl groups, achieved higher results. A possible explanation is that same-gender groups function more purposefully than mixed-gender groups and lacked the risk of gender domination [52]. In contrast, a few researchers considered mixed-gender groups to be a better option, citing benefits such as divergent perspectives and increased learning performance [53,54]. Additionally, several studies have examined the impact of different types of gender pairing on collaborative learning outcomes yet revealed no statistically significant findings [36,55,56].

2.3. Gender diversity and its influence on individual learning during collaboration

At the individual level, male and female students may behave differently in same-gender versus mixed-gender groups. Female students perform more affiliative conversation in all-women groups than in mixed groups [57]. Similarly, Light et al. [58] found that elementary school girls in the U.S. participated more actively in a digital environment when playing in same-gender groups than in mixed-gender groups. The advantage of female students in same-gender groupings over those in mixed-gender groups is also found in academic performance, such as knowledge elaboration [53], physics scores [59], and problem-solving in science education [60]. A possible reason may be that as noted by Willoughby et al. [35], girls were submissive and more likely to be critiqued in mixed-gender groups than when working alone or in all-girl groups. In contrast, other findings have shown that girls performed better at ICT literacy in mixed-gender groups than working together in same-gender groups [52]. Hsu et al. [39] also drew parallel results that U.S. female students' counterargument and rebuttal skills in mixed-gender groups significantly exceeded those in same-gender groups.

Similarly, previous studies have offered various perspectives on differences in male students' performance in same-versus mixed-gender groups. Several studies have found elementary school boys in mixed-gender groups monopolized the computer and performed better on a problem-solving task in computer-based collaborative tasks [58]; they also tended to dominate discussions and had many more disagreements than those in same-gender groups [61]. Nevertheless, Leaper and Ayres [57] found male students were significantly more task-oriented and assertive in same-gender groups. Other studies, however, have found no difference in performance between same-gender and mixed groups. For example, Kessels and Hannover [59] randomly assigned students to same and mixed-gender physics classes, and found that male students achieved equally well in both kinds of classes.

In summary, our review of the literature reveals that there are significant differences between girls and boys in behavior, social interactions, and academic performance, and gender pairing also affects group collaborative and individual learning. However, there is no consensus in previous studies about these differences. One reason may be related to the various regions in which the studies were conducted. For example, in Asia and the Pacific, female students seemed to give less importance to same-gender group formation, while in Latin America and the Caribbean region, women emphasized the importance of same-gender groups [10]. Another reason may be that the evaluations in previous studies have mostly been in terms of learning performance, lacking the revelation of the dynamic interaction. Additionally, most of the existing studies have used paper tests or projects to reveal differences among learners. In addition to focusing on these, this paper focused more on revealing students' behaviors, emotions, and interactions during collaboration through formal observations.

3. Method

3.1. Participants

Participants were 44 undergraduate students (11 males and 33 females) recruited from an Introduction to Educational Technology course offered in the 2022 Spring semester. They all majored in Educational Technology, and their ages ranged from 18 to 20 years old ($M = 18.39$, $SD = 0.57$). They have scholastic aptitude, because they all received high scores on the National College Entrance Exam and entered a top-tier research university in central China.

This study was conducted in accordance with the ethical standards of the Helsinki Declaration. The research protocol and instruments of the present study were reviewed and approved by the Institutional Review Board of Central China Normal University (CCNU-IRB-202103019, approved on 2021/03/16). The participants were made aware that their participation in the research study was completely voluntary and all their personal identifiable information would remain confidential in any publications or presentations. The participants provided their written informed consent to participate in this study.

3.2. Research design and procedure

We conducted a quasi-experiment to investigate the effects of gender and gender pairing on behaviors and social interaction during collaborative learning in blended learning. The independent variables were gender and gender pairing: the former refers to participants' birth sex and the latter was based on the collaboration groups randomly formulated during the study, thusly neither of the independent variables were manipulated in the research design. According to Cook and Campbell [62], such research design is considered quasi-experiment. The quasi-experimental design was selected over true experiment in the present study for its higher external validity [63] because it involved a natural educational context and research findings reflected the authenticity and complexity of real-world teaching practice. The quasi-experimental study was implemented in an undergraduate introductory course named Introduction to Educational Technology during the 2022 spring semester, which was designed for students majoring in Educational Technology. Before the course started, participants were randomly assigned into one of the three conditions (all-female, all-male, and

mixed), and formed one male-male group, three female-female groups, and three mixed groups, as shown in Table 1.

The lesson for the fourth week employed the flipped classroom approach, which included asynchronous online discussion before class, group collaboration in class, and asynchronous online discussion after class, as shown in Fig. 1. Before class, participants studied two video clips (12 min in total) and five relevant papers uploaded by the instructor and were required to post their reflective comments and questions regarding the instructional materials in a discussion forum. All pre-class learning activities occurred on the Xiaoya online learning platform (https://ai-augmented.com), which can support a variety of instructional activities. The self-study materials on the Xiaoya platform can also be accessed at https://doi.org/10.17632/fwsdssbnsm.1.

Then, in the face-to-face class, the instructor listed 45 key terms related to educational technology, which were classified into four categories: representative scholars (12 items), instructional theories (9 items), instructional media (15 items), and landmark events (9 items). Participants were then voluntarily divided into seven groups, and each group selected a category and discussed how to present these keywords in chronological order. Meanwhile, a camera and microphone recorded their collaboration behavior, talk, facial expressions, and interactions. Finally, four groups were invited to present their chronicles in front of the whole class.

After class, students had one week to review the content from the face-to-face instruction and submitted their gains and thoughts to the Xiaoya platform. After all of the instructional activities, as an assignment, all participants had to draw a mind map about the relevant content from this lesson. We then invited participants from the seven groups and conducted semi-structured interviews to collect their feelings about this collaboration.

3.3. Data collection and analysis

3.3.1. Data collection

We mainly collected data about participants' online forum behaviors before and after class through the logfile, while data on face-to-face collaboration in class were collected through video recording, as shown in Table 2. Participant behaviors online included the number of words per post and the score of the posts, which were evaluated in terms of accuracy and reflection. Accuracy was rated on participants' comprehension of the history of educational technology development, and reflection was rated on the content of the posts' critical thinking about existing educational and technological developments. The total score for the post was 100 points, with 50 points for each dimension. In addition, we scored the participants' mind map assignments and divided the scores into three levels (level 1: [0, Mean – SD]; level 2: [Mean – SD, Mean]; level 3: [Mean, Mean + SD]). The grading rubric for evaluating the quality of discussion post can be seen in Appendix A.

For the video data, we conducted three brainstorming meetings to identify the analytical units and dimensions. During the meetings, two authors (first and second authors) freely coded three videos, and then these were discussed, validated, and revised with all researchers. Finally, we identified the coding schema based on learning engagement proposed by Fredricks et al. [64], which consists of three categories: behavior, emotion, and interaction, as shown in Table 2. Behavior coding recorded the participant's discussion behavior, such as observing, listening, talking, and exploring. Emotions were recorded based on participants' facial expressions and their conversation, following the proposal of Watson and Tellegen [65], including smile (delighted), frown (confused), asking (interested), and sitting around (uneasy). Interaction consists of verbal and non-verbal interactions; the former means conversational interaction between participants, and the latter refers to interactions such as physical gestures or eye contact.

In addition, we set 15 s as the unit of analysis, and split the 30-min video into 120 encoded units, allowing the learning event to be captured and coded in the segments. When a participant demonstrated a specific behavior, we observed the duration (T) of this instance and calculated its values (n) according to the following equation:

$$n = T \,/\, 15\ \text{s}\ (\text{remainder} = 0), \tag{1}$$

$$n = T \,/\, 15\ \text{s} + 1\ (\text{remainder} \neq 0). \tag{2}$$

For example, if a student continuously laughed for 17 s, the values for "delighted" were coded as 2 according to equation (2), while if a student continued to talk for 15 s, the values for "talking" were coded as 1 according to equation (1). The coding was executed by 14 volunteers divided into seven groups, and all of them accepted a rigorous 2-h training session before formal coding until their evaluation standards were consistent. Any controversial issues during the coding were resolved through weekly discussion meetings by all researchers. Finally, the interrater reliability as measured by Kendall's Tau for each of the seven groups was 0.865, 0.970, 0.870, 0.858, 0.796, 0.941, 0.866, respectively, suggesting a good credibility of the coding results. The detailed video coding rubric can be seen in Appendix B.

Additionally, we invited 35 participants (10 male and 25 female students) from the male group, female groups, and mixed groups and conducted semi-structured interviews to collect their feelings about this collaboration through questions such as, "How do you feel about this group work? Why? Can you talk about it?" and "How did you get involved in the collaboration?"

Table 1
The distribution of male and female students in groups.

	male groups (n = 1)	female groups (n = 3)	mixed groups (n = 3)	total
male	7	–	4	11
female	–	19	14	33
total	7	19	18	44

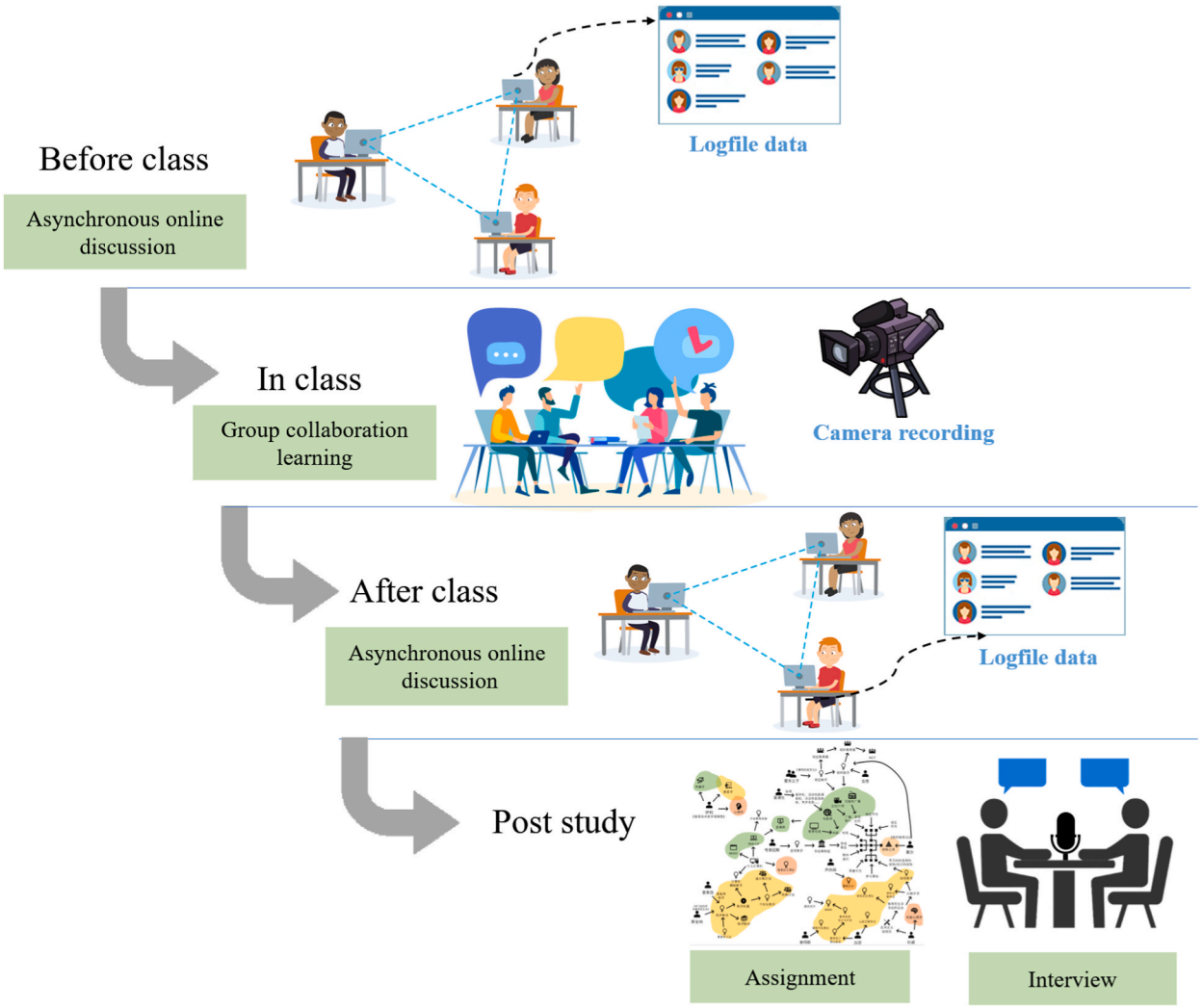

Fig. 1. Flow chart of instructional activities.

Table 2
Measurement of posts before class; behaviors, emotion, and interaction in class; and posts after class.

Construct	Variables	Definition	Source
Pre-class behaviors	Post length	Number of words posted	Logfile
	Post score	Rating posts for the accuracy and reflection	
In-class	Behavior	Observation, listening, talking, exploring, leading, irrelevant discussion, irrelevant behavior, absent-mindedness, interference behavior	Video recording
	Emotion	Delighted, interested, confused, uneasy, anxious, indifferent	
	Interaction	Verbal interaction, non-verbal interaction	
Post-class behaviors	Post length	Number of words posted	Logfile
	Post score	Rating posts for the accuracy and reflection	

3.3.2. Data analysis

The independent variables in this study were gender and gender pairing. The dependent variables were participation behaviors in the online forums and behavior, emotion, and interaction in the face-to-face collaboration learning. Consequently, the main data analysis method was the *t*-test, and when the data were heterogeneous with skewed distribution, the non-parametric tests were used to compute the differences between the genders (Mann-Whitney *U* Test) and the three gender pairing conditions (Kruskal-Wallis Test). Data analysis was conducted using IBM SPSS (version 26). To further understand how group collaboration unfolded in class and how it might differ among different gender pairing groups, we conducted social network analysis using Ucinet software. More specifically, the interactions among students during the in-class collaboration were visually illustrated by NetDraw Plug-in. We used various coding

techniques (e.g., Structural, In Vivo, and Evaluation coding) described by Saldana [66] to qualitatively analyze the interview transcripts, aiming to assist the meaningful interpretation of participants.

4. Results

4.1. Gender difference in students' learning behavior and social interaction

We performed *t*-tests to analyze the gender differences. As shown in Table 3, in terms of online learning, the results showed that there was no significant difference in discussion behavior before class (all p values $> .05$) between male students and female students, while behaviors in class were partly different. Compared with male students' behavior in class collaboration, female students were more likely to perform well in listening ($p < .001$), talking ($p = .002$), and integrating ($p < .001$); however, male students engaged in more irrelevant behavior, such as fidgeting, joking around, and singing. Moreover, female students were more likely to engage in verbal interaction ($MD = 11.53$, $p = .03$), while male students tended to use non-verbal interaction ($MD = 2.88$, $p = .024$). There was no significant difference apparent in participants' emotions (all p values $> .05$).

For the discussion behavior after class, female students significantly outperformed male students, including in the number of words posted ($MD = 240.21$, $p < .001$) and the quality of their posts. As shown in Table 3, female students acquired higher scores than male students, including in the accuracy ($MD = 18.47$, $p = .010$), reflection ($MD = 17.77$, $p = .012$), and total score for the posts ($MD = 36.24$, $p = .011$). A possible explanation for this might be that female students further engage in organization of and reflection on the instructional materials after studying in class. Additionally, we also evaluated and analyzed participants' mind map assignments, and the *t*-test results showed that there was no significant difference by gender ($p = .073$).

4.2. Gender pairing difference in students' learning behavior and social interaction

Due to heterogeneous variance, the Kruskal–Wallis test was used to analyze the differences between the three types of gender-pairing groups. As shown in Table 4, the results revealed that there were no significant differences in online forum discussion before class among the different groups (all p values $> .05$). However, there were significant differences during the face-to-face collaboration. The analyses showed that students in the all-female groups behaved significantly more actively than the other two gender-pairing groups, especially in listening ($p = .010$), talking ($p = .020$), and integrating ($p = .006$). The male group was more skilled in observing, exploring, and leading during collaborative learning, and sometimes engaged in irrelevant discussion, yet these did not differ significantly from the other gender-pairings. However, in the mixed-gender groups (Mean = 15.03), participants appeared to engage in significantly more irrelevant behavior ($p = .010$) than the female groups (Mean = 3.11) and male groups (Mean = 11.21). In terms of interaction, female groups performed significantly more verbal interaction ($p = .006$), while male groups engaged in significantly more non-verbal interaction ($p < .001$).

There existed differences between the three gender pairing groups for the online discussion after class, including in the number of posted words, accuracy, reflection, and total post scores (all p values $< .001$), as shown in Table 4. Compared to the other two gender-pairing groups, the female group performed the best, followed by the mixed-gender group, and the male group. No significant differences were found between the three types of groups for the mind mapping assignment ($p = .112$).

Table 3
Learning behavior and social interaction between female and male students.

		Male (n = 11)	Female (n = 33)	*p*
Discussion behavior before class	Number of words posted	621.91 (320.30)	714.03 (366.35)	.461
	Accuracy	39.182 (4.65)	37.333 (7.48)	.447
	Reflection	34.318 (5.82)	36.121 (7.79)	.486
	Total score of posts	73.500 (7.88)	73.455 (14.80)	.992
Behavior in class	Observation	6.77 (6.30)	8.08 (8.09)	.638
	Listening	6.05 (5.35)	17.05 (13.62)	.000
	Talking	8.09 (6.70)	19.56 (15.57)	.002
	Exploring	66.73 (24.55)	70.88 (20.21)	.579
	Integrating	5.91 (5.68)	19.41 (13.56)	.000
	leading	1.14 (1.76)	0.27 (0.72)	.142
	Irrelevant discussion	3.02 (3.308)	2.80 (4.28)	.878
	Irrelevant behavior	20.86 (26.924)	5.41 (14.02)	.018
	Absent-mindedness	1.36 (2.314)	0.17 (0.32)	.118
	Interference behavior	0.09 (0.302)	0.14 (0.34)	.693
Interaction in class	Verbal interaction	11.27 (9.11)	22.80 (16.01)	.030
	Non-verbal interaction	4.02 (3.55)	1.14 (1.702)	.024
Discussion behavior after class	Number of words posted	162.00 (195.18)	402.21 (163.67)	.000
	Accuracy	19.68 (19.09)	38.15 (7.13)	.010
	Reflection	19.73 (19.10)	37.50 (6.94)	.012
	Total score of posts	39.41 (38.18)	75.65 (14.01)	.011

Table 4
Learning behaviors and social interaction among different group students.

		Male group (n = 7)	Female group (n = 19)	Mixed group (n = 18)	*p*
Discussion behavior before class	Number of words posted	591.57 (342.85)	783.89 (324.20)	631.61 (383.25)	.273
	Accuracy	39.071 (5.84)	39.658 (2.77)	35.333 (9.41)	.193
	Reflection	34.571 (5.80)	37.737 (4.21)	33.917 (9.83)	.092
	Total score of posts	73.643 (8.90)	77.395 (6.56)	69.250 (18.42)	.028
Behavior in class	Observation	7.21 (7.41)	8.58 (8.89)	7.08 (6.56)	.920
	Listening	7.79 (4.88)	21.87 (15.18)	8.83 (7.71)	.010
	Talking	8.71 (6.58)	24.32 (17.83)	11.75 (8.82)	.020
	Exploring	76.93 (8.42)	70.63 (21.12)	66.25 (24.47)	.632
	Integrating	6.93 (6.17)	23.47 (14.13)	11.72 (10.63)	.006
	leading	1.00 (1.15)	0.16 (0.50)	0.64 (1.47)	.052
	Irrelevant discussion	3.96 (3.41)	2.95 (4.25)	2.33 (4.12)	.085
	Irrelevant behavior	11.21 (7.43)	3.11 (5.51)	15.03 (27.95)	.010
	Absent-mindedness	1.71 (2.80)	0.24 (0.39)	0.22 (0.60)	.325
	Interference behavior	0.14 (0.38)	0.24 (0.42)	0.00 (0.00)	.072
Interaction in class	Verbal interaction	15.57 (8.12)	29.21 (17.34)	11.79 (9.20)	.006
	Non-verbal interaction	5.79 (3.20)	0.66 (1.36)	1.60 (1.80)	.000
Discussion behavior after class	Number of words posted	85.29 (114.73)	465.05 (151.64)	312.33 (163.87)	.000
	Total score of posts	28.214 (35.27)	79.211 (2.91)	68.194 (25.08)	.000
	Accuracy	14.071 (17.590)	40.158 (1.81)	34.111 (12.55)	.000
	Reflection	14.143 (17.690)	39.053 (1.43)	34.083 (12.55)	.000

4.3. Individual difference in different gender pairing groups

To explore the differences between males and females in same-gender versus mixed-gender groups, we conducted ANOVA to compare the interactions of male and female students in the different gender-pairing groups, as shown in Fig. 2. The results showed that male students in the male group engaged in significantly more verbal ($MD = 11.84$, $p = .030$) and non-verbal interaction ($MD = 4.87$, $p = .018$) than male students in the mixed groups. Similarly, female students in the female group engaged in significantly more verbal interaction ($MD = 15.14$, $p = .003$) than in the mixed groups. However, female students used less non-verbal interaction ($MD = 1.14$, $p = .056$) than in the mixed groups, although there were no significant findings.

4.4. In-depth analysis of group dynamics in different gender groups

To further explore the group dynamics in the different gender-pairing groups, we conducted social network analysis of the seven groups. Each group's interaction patterns are visually presented in Fig. 3. Learners each are displayed as individual nodes using triangle, square, and box shapes which symbolized the level of their mind mapping score. The color of the nodes represents male and female students. The size of the nodes varied based on the value obtained from the network of connections to which a particular student belonged. The thickness of the lines represents the degree of interaction.

The results showed that the interaction networks in the all-males and all-females groups demonstrated high density and high connectedness, as indicated by a single cluster, while mixed groups appeared to show high centralization and high marginalization. The density of the all-male and all-female groups (groups 2, 6, and 7) were 0.548, 0.7, and 0.7, respectively, which suggested that

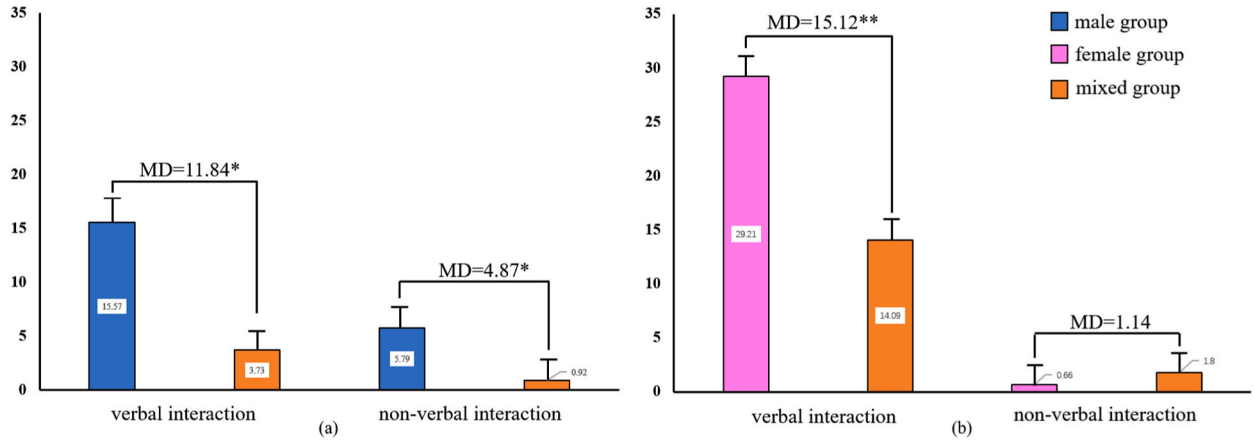

Fig. 2. Interaction of male and female students in different groups; (a) male students' interaction in the male group and mixed groups; (b) female students' interaction in female groups and mixed groups.

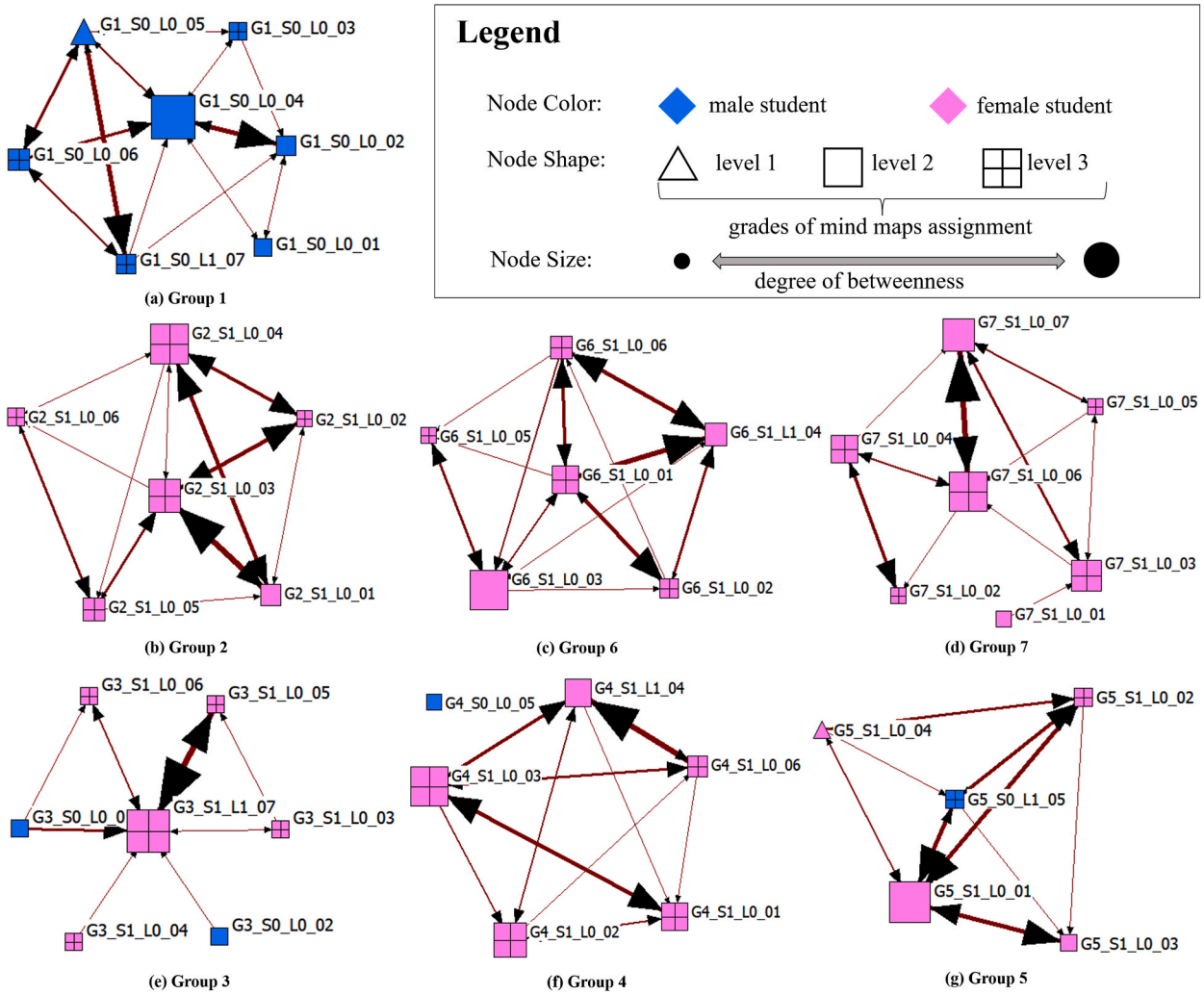

Fig. 3. Participant–participant interaction networks in the seven groups; (a) Group 1 with seven male students; (b) Group 2 with six female students; (c) Group 6 with six female students; (d) Group 7 with seven female students; (e) Group 3 with two male students and five female students; (f) Group 4 with one male student and five female students; (g) Group 5 with one male student and five female students.

participants in same-gender groups have many interpersonal connections within the group and can easily access each other [67]. However, in the mixed groups, the interaction patterns showed lower density and lower connectedness. For example, one student in the third group (G3_S1_L1_07) was the central focal point for interaction, which indicated that the group members had to communicate with this central student to achieve communication with the others. Additionally, a male student in the fourth group (G4_S0_L0_05) was at the edge of the group interaction and failed to participate in the group collaboration. The possible reason for this phenomenon in the mixed groups might be that students were more reserved when facing students of the other gender. As one male student explained, "my communication with the boys tends to be more open, but when talking to girls, I will be more polite" (G3_S0_L0_02).

Compared to female students, male students were generally less proactive and less involved in collaborative learning. However, if the male students were in the center of the physical location or elected as the group representative to make the presentation, they might also be actively involved in the collaboration. For example, the student at the network center of the all-male group was physically located in the center and was responsible for the group presentation, as he said, "I was elected to present by drawing lots, and had to communicate with someone else" (G1_S0_L0_04). Similarly, a male student in the fourth group (G4_S0_L0_05) had no interaction with others because he was seated in the corner of the group, while a male student in the fifth group (G5_S0_L1_05) had an important role in the group collaboration because he was sitting in the central position.

Additionally, we found a possible association between the level of engagement and learning performance in collaborative learning. Generally, female students obtained higher scores with higher levels of collaborative participation, while male students achieved lower scores when interacting actively with others. As shown in Fig. 3, most of the girls scored higher on the mind map assignment when they had more connections with others in the group collaboration. However, a boy (G1_S0_L0_04) in the first group who was also located in the center of the collaborative network diagram only obtained an average score. The possible reason is that female students care more

about academic performance and capacity in collaboration, while male students prefer to present their leadership and dominance.

Regarding gender composition, participants mostly believed that combining the strengths of male and female students could lead to the accomplishment of collaborative tasks more effectively. For example, one male student (G1_S0_L0_05) confessed that he did not read the literature carefully before class and failed to provide useful information in the group collaboration, unlike the female students, who were thoughtful while reading the paper. Another male student (G3_S0_L0_02) also agreed that girls were considered more meticulous and comprehensive, while boys' direct expression in collaboration could enhance the efficiency of the collaboration. As one female student summarized the gender grouping for collaborative learning,

> *Boys may be more straightforward, and girls may be too polite, their manner of speaking being too euphemistic, (group collaboration) needs straightforward expression, without beating around the bush, so as to make the collaboration more effective.* (G3_S1_L1_07)

5. Discussion

This study addressed three research questions, and empirical analysis was conducted to explore the differences created by gender and gender pairings on collaborative behavior and social interaction, as well as to determine whether female and male students perform differently in same-versus mixed-gender groups. Our findings for each of the three research questions can be summarized as follows.

5.1. Discussion on research question 1: do gender differences affect students' learning behavior and social interaction during collaborative learning?

Male and female students engaged in significantly different behaviors and interactions during the collaboration learning. Female students engaged in more verbal interaction and were better at communicating with peers to share their opinions while also preferring to listen and integrate their groupmates' opinions. These results corroborate the findings of other researchers, who have found that female students tended to exhibit more social behavior to maintain collaboration, such as listening and responding to group members' questions, as well as giving more supportive feedback [14,68,69]. As Thompson and Voyer [70] found in their study, women outperformed men on decoding nonverbal communications, especially in the recognition of others' facial expressions. However, male students favored more non-verbal than verbal interactions, and, in particular, more irrelevant behaviors emerged during their collaboration. These results were consistent with the findings of other researchers, who found that male students are weak in verbal performance but skilled in behavioral expression [71]. Additionally, male students are prone to disconnecting from group collaboration and exhibiting irrelevant behavior, such as fidgeting, joking around, and singing, which is often a form of spontaneous and unconscious communication [72].

5.2. Discussion on research question 2: do gender pairing differences affect students' learning behavior and social interaction during collaborative learning?

The all-female groups exhibited more relevant collaborative behavior, such as listening, talking, and integrating, while the all-male groups were the least active in communicating with peers and participating in learning tasks. This is in line with the findings of several studies that have reported that groups with a high proportion of girls had more collaborative discussions [13,34] and group success [73], because female students are more "talkative" and tend to share whatever they think might be relevant to their tasks or groupmates [69]. However, students in mixed-gender groups had the fewest conversations and demonstrated more irrelevant behaviors. This contradicts the previous findings in Jiang et al. [14] and Ma et al. [9], who reported that mixed-gender groups had a more relaxed atmosphere and more conversations occurred. One possible reason for their findings is that the participants of these studies were elementary school students (fourth- and sixth-grade students, respectively), who are more expressive of their emotions and viewpoints when confronted with opposite-gender group members. According to Chaplin and Aldao [74], boys showed decreasing levels of externalizing emotions from pre-school to adolescence due to the effects of socialization. Therefore, compared to children, undergraduate students tended to be more restrained in expressing their opinions in mixed groups. Another reason may be the small number of boys in the mixed group (only 1 or 2 boys in each group) due to the unbalanced gender distribution in this study, which makes it difficult for them to find the other boys to interact with.

5.3. Discussion on research question 3: do female and male students perform differently in same- and mixed-gender groups during collaborative learning?

Additionally, both male and female students engage in more verbal and nonverbal interactions in same-gender groups than in mixed-gender groups. These results supported previous finding that most of the participants have longer talk time in same-gender groups compared to mixed-gender group interactions [75]; female students especially appear to do better in all-female groups than in mixed-gender groups when collaborating to solve a problem [38,53]. As previous research has indicated that more positive social interaction occurs in same-gender pairing over mixed pairings [58], this might be due to the similarity of expression between same gender peers, which allows them to have more empathy and a more comfortable interaction [75]. In contrast to earlier findings showing that male students were more involved in verbal interaction in mixed-gender groups [38], this paper found that male students were generally less proactive and more disconnected in mixed-gender groups during collaborative learning. One possible reason for

this is that each mixed-gender group had only a small proportion of male students, who thus exerted insufficient peer pressure to trigger and sustain conversation led by male members.

Interestingly, gender differences for in-class behavior and interaction also transcended into differences in post-class learning performance measured by the post quality of online discussion. Female students were better at listening and discussing during the in-class collaboration, and this learning pattern continued in post-class online discussion behaviors, such as reading, replying to, and integrating other members' viewpoints. Furthermore, the quality of the after-class posting was much higher for a high proportion of female students (in all-female and mixed-gender groups), as previous studies stated that the proportion of female members was highly correlated with group success [13,34]. Male students, however, exhibited more irrelevant behaviors during the classroom discussions, suggesting poor self-regulation of their learning abilities [76]. It is thus not surprising that the cohort of male students did not perform as well in the independent online learning session after class.

6. Practical implications

Based on the research findings, we propose several suggestions for teachers to facilitate effective collaborative learning in co-educational college classrooms. First, male students tend to be less skilled in communication than their female counterparts during collaborative learning. Consequently, all-male groups merit a teacher's special attention and might benefit from additional facilitation. Second, in cases involving an unbalanced number of male and female students in the class, it is recommended prioritizing same-gender groupings instead of mixed-gender groupings to enhance social interaction and dialogue. Third, this study revealed a correlation between students' in-class and post-class learning behaviors during collaborative learning, so the learning performance of social loafers needs to be closely monitored by teachers. Finally, if the mixed gender groups are unbalanced, we recommend electing the group leader from the less prevalent gender to promote social inclusion and participatory equity.

7. Limitations and future research

There are several limitations to this study. First, the participants were students from a single course, which affected the representativeness of the conclusions. Different instructional activities and learning tasks might lead to different interaction patterns and group dynamics in collaborative learning in other courses. Future studies could consider a wider range of disciplinary domains and educational contexts to examine the effect of gender diversity on collaborative learning. Second, the mixed groups in this study all contained a high proportion of female students, and the threat of gender bias on research findings cannot be eliminated. Future research could further explore the learning behaviors and interactions of mixed groups with more balanced gender proportions. Third, the present study focused on participant's learning behaviors and social interactions, with little attention paid to their learning experience. Future research could use validated questionnaires to measure students' perception in terms of group cohesion, motivation, and engagement. Finally, the measurement of learning achievement could be further improved. This study assessed learning outcomes solely based on the subjective evaluation of assignment quality while lacking more rigorous evidence from objective measurement. We recommend using multimodal data from diverse sources in future research to further boost the construct validity of the research findings.

Funding statement

This work was supported by the Hubei Provincial Teaching and Research Project for Higher Education, Hubei, China, grant number 2021085; Teacher Education Specialized Grant of Central China Normal University, grant number CCNUTEIII 2021–10; and Fundamental Research Funds for the Central Universities, grant number CCNU22QN011.

Author contribution statement

Qinna Feng: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Heng Luo: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Wenhao Li: Conceived and designed the experiments; Analyzed and interpreted the data.

Tianjiao Chen: Performed the experiments.

Ningning Song: Analyzed and interpreted the data.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e16237.

Appendix A. Post Quality Grading Rubric

Dimension	Description	Score range
Accuracy	The answers are accurate, with no conceptual or logical errors.	41–50
	The answers are relatively accurate, with only some conceptual and logical errors	21–40
	The answers are unreasonable, with more conceptual and logical errors	1–20
Reflection	Consider actively about the content of what they have learned and understand and reflect on it in relation to their own experiences, and to construct and internalize knowledge.	41–50
	Attempt to analyze and think about the content of what they have learned and be able to ask their own unanswered questions or queries, but they do not think deeply enough, nor do they combine their own experiences.	21–40
	Only retell or simply quote the content of the course or textbook without developing their own understanding and thinking.	1–20

Appendix B. Video Coding Rubric

Behavior	Observing	Observing peers, works, etc
	Discussing	Listening: listening to others during the discussion
		Talking: talking to others during discussion
	Exploring	Conscientiously complete tasks related to group assignments
	Integrating	Consulting with other members of the group
	leading	Assigning tasks, making decisions, etc.
	Irrelevant discussion	Discussing irrelevant content
	Irrelevant behavior	Irrelevant actions, such as fidgeting, playing, singing, etc.
	Absent-mindedness	Inattentiveness, such as looking around, dull eyes, etc.
	Irrelevant behavior	Interrupting other people's discussions
Emotion	Delighted	Happy, laughing, with a happy face
	Interested	Curious, inquiring
	confused	Frowning, asking questions, looking at each other questioningly
	Uneasy	Nervous and anxious about what to do
	Anxious	Concerned about mission accomplishment
	indifferent	Expressionless, indifferent
Interaction	Verbal interaction	Conducting verbal discussions
	Non-verbal interaction	Perform interaction with body, gestures, eyes, etc.

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