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Capturing patterns of argumentation elements, encountered challenges, and social regulation in collaborative argumentation: an epistemic network analysis study

Ziqi Mao [a], Xiaoran Li[b], Yanyan Li [a], Jingjing Shao[a] and Haogang Bao[c]

[a]School of Educational Technology, Faculty of Education, Beijing Normal University, Beijing, People's Republic of China; [b]School of Linguistics and Language Resources, Institute of Linguistic Sciences, Beijing Language and Culture University, Beijing, China; [c]Research Center for Basic Education, the China National Academy of Educational Sciences, Beijing, People's Republic of China

ABSTRACT

Collaborative argumentation is a crucial learning activity affected by various factors, including the use of argumentation elements, encountered challenges, and social regulation. Few studies examined how these factors collectively impact argumentation outcomes based on fine-grained process data. This research employed Chi-squared tests and epistemic network analysis (ENA) to reveal the different frequencies and patterns of these factors in 4 high- and 4 low-performing groups. The data were derived from a 90-minute argumentation task involving 55 undergraduates. The Chi-squared test revealed the frequency differences, indicating that high-performing groups tended to use strong claims, whereas low-performing groups typically used weak counterclaims/rebuttals and encountered more socioemotional challenges. The ENA results further illustrated the differences in the co-occurrences of these factors. In low-performing groups, weak counterclaims/rebuttals intertwined with socioemotional and cognitive challenges. Although students attempted to use socioemotional regulations to address challenges, their efforts were ineffective due to the tense atmosphere. Conversely, high-performing groups successfully alternated between cognitive and socioemotional regulations to formulate strong claims and overcome challenges. These findings highlight the advantages of using ENA to analyze and compare patterns of factors and suggest the need to design educational tools to support effective social regulations.

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Collaborative argumentation; argumentation elements; challenges; social regulation strategies; epistemic network analysis

1. Introduction

Collaborative argumentation is crucial for scientific practice as it helps students evaluate multiple perspectives and deepen their understanding (Asterhan & Resnick, 2020). Some studies have focused on improving the quality of argumentation outcomes (e.g. argumentative essay or diagram) (Lobczowski et al., 2020). However, achieving high-quality collaborative argumentation outcomes is challenging and may be affected by several factors. Given that an argument comprises several interconnected elements (e.g. claim, data, rebuttal), the use of argumentation elements could affect argumentation outcomes (Lund et al., 2007). For instance, groups that put forward

CONTACT Yanyan Li liyy@bnu.edu.cn Yanbo Building, Beijing Normal University, No. 19 Xinjiekou Street, Beijing 100875, People's Republic of China

stronger claims supported by reasonable evidence were more likely to produce better argumentation outcomes (Chuang & Yan, 2022).

However, the improper use of argumentation elements might lead to various challenges, subsequently affecting argumentation outcomes (Asterhan & Resnick, 2020). For example, improperly linking claims to data might result in insufficient argumentation (cognitive challenges), while continuous rebuttals might create a tense atmosphere (socioemotional challenges) (Zschocke et al., 2016). Consequently, researchers have suggested that students need social regulation skills to use argumentation elements appropriately and manage challenges effectively (Järvelä et al., 2015). Some studies have analyzed the impact of the use of argumentation elements, encountered challenges, and social regulation on collaborative argumentation outcomes separately (Lobczowski et al., 2020). However, these studies often rely on coding-and-counting strategy or frequency analysis, which may overlook temporal patterns and reduce the explanatory power of analysis (Vogel & Weinberger, 2018).

The emergence of epistemic network analysis (ENA) provides opportunities to investigate collaborative argumentation from a novel perspective. ENA explores the connections between various factors by measuring co-occurrences in dynamic networks, providing a nuanced perspective to analyze factors collectively (Shaffer et al., 2016). Additionally, ENA enables the comparison of co-occurrences of elements across different groups (Shaffer & Ruis, 2017). Therefore, this study aimed to compare differences in the intertwined patterns of argumentation elements, encountered challenges, and social regulation between high- and low-performing groups through ENA.

2. Literature review

2.1. Factors that may affect the quality of collaborative argumentations

Collaborative argumentation is a social activity that requires students to engage in mutual discussion to solve problems (Asterhan & Resnick, 2020). Numerous studies have explored factors influencing the quality of collaborative argumentation outcomes. On one hand, the argumentation process involves a complex structure of argumentation elements (Lobczowski et al., 2020). The effective use of argumentation elements is linked to the quality of collaborative argumentation (Chuang & Yan, 2022). On the other hand, multiple cognitive and socioemotional challenges often arise when individuals use argumentation elements to challenge each other and express disagreements (Asterhan & Resnick, 2020). This requires students to actively and adeptly regulate these challenges to enhance the quality of collaborative argumentations (Lobczowski et al., 2020). However, previous research only examined how the use of argumentation elements, encountered challenges, and social regulation affected the quality of collaborative argumentation outcomes separately (Lobczowski et al., 2020). The intertwined patterns of these factors and their combined contribution to the quality of collaborative argumentations remain to be further explored.

2.2. Use of argumentation elements

Numerous studies have categorized argumentation elements, with Toulmin's TAP model identifying six interconnected elements: claim, data, warrant, backings, qualifiers, and rebuttals (See Figure 1) (Toulmin, 1958). This model has been effectively applied to assess collaborative argumentation outputs like essays or diagrams. However, Erduran et al. (2004) noted that Toulmin's model was restricted in analyzing short argumentative discourse and proposed a framework to analyze argumentative discourse, including weak claims, strong claims, weak counterclaims/rebuttals, strong counterclaims, and strong rebuttals.

With the in-depth understanding of argumentation elements, some studies began to explore their correlation with the quality of argumentation outcomes. Lund et al. (2007) found that students

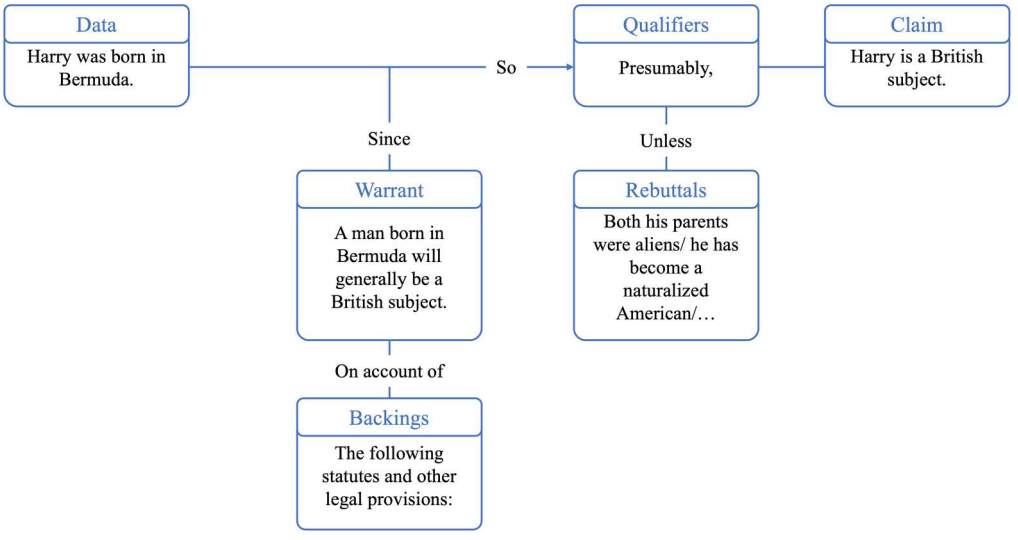

Figure 1. Argumentation elements of TAP model.

using claims supported by adequate data, warrants, and backings via argumentation diagrams outperformed others in individual graphs. Chuang and Yan (2022) examined 150 argumentative essays and found the structure of argumentation elements was associated with the quality of argumentative essays. However, previous studies primarily focused on analyzing written argumentation essays or diagrams, providing limited insight into oral argumentative discourses.

2.3. Encountered challenges and social regulation in collaborative argumentation

When individuals improperly use argumentation elements to express disagreements, various challenges may arise (Asterhan & Resnick, 2020). Challenges are events impacting learning processes, such as difficulties in achieving a shared understanding or avoiding a deadlock (cognitive challenges), as well as disruptive affective expressions and disrespectful communications (socioemotional challenges) (Zschocke et al., 2016). These challenges might affect collaborative argumentation outcomes, such as insufficient argumentation due to inappropriate linking of claims and data, and a tense atmosphere caused by the expression of negative emotions or disrespectful communication (Lobczowski et al., 2020). Consequently, researchers argued that students require skills not only to appropriately use argumentation elements but also to effectively and efficiently cope with challenges to achieve high-quality collaborative argumentation (Malmberg et al., 2015).

Some researchers proposed that social regulation could effectively handle challenges. Social regulation involves collectively managing cognition, motivation, emotions, and behaviors to facilitate successful collaborative learning (Järvelä et al., 2015). By socially regulating cognition aspects, students could make plans, monitor disagreements, and evaluate their performance. By regulating socioemotional aspects, students could productively manage negative socioemotional interactions productively and engage more deeply in collaboration (Hadwin et al., 2018). To explore how social regulation contributes to effective collaborative argumentation, Lobczowski et al. (2020) examined cognitive regulation processes in scientific argumentation activities and found that groups with higher-quality argumentation tended to engage in purposeful planning. Zheng et al. (2023) compared the effects of different argumentation scaffolds and found that TAP scaffolds activated more cognitive self-regulation and enhanced argumentation skills. However,

previous studies primarily focused on cognitive regulation in collaborative argumentations. Some researchers called for further studies to explore socioemotional regulation during argumentation (Gao et al., 2023).

2.4. Using ENA to allow for an integrated view on the use of argumentation elements, encountered challenges and social regulation

While the use of argumentation elements, encountered challenges, and social regulation may influence the quality of argumentation outcomes, most studies examined each of these aspects respectively through statistical analysis. Few studies have explored how these three factors collectively impacted collaborative argumentation outcomes using fine-grained process data. To address these research gaps, ENA provides an innovative approach to investigate the co-occurrences of variables and the patterns they exhibit over time (Vogel & Weinberger, 2018).

ENA provides insights into the connection of different factors through co-occurrence measurement in dynamic network models (Shaffer et al., 2016). ENA encompasses three core concepts: codes, unit of analysis, and stanza (Shaffer & Ruis, 2017). Codes represent a set of conceptual or behavioral factors. ENA can analyze and model the co-occurrence of codes within a unit, which could be an individual participant, a group, or a specific time segment within the interaction. The stanza consists of several lines of codes, representing the scope of recent temporal context (Shaffer et al., 2016). For instance, if the stanza is set to six, ENA calculates the co-occurrence of codes in every six adjacent episodes. In the ENA network, node size indicates the importance of node for the group, and line thickness represents the frequency of co-occurrence (Shaffer & Ruis, 2017). Consequently, ENA can depict the structure and strength of the connection between different processes, making it suitable for modeling the patterns of argumentation elements, encountered challenges, and social regulation. ENA can also compare networks under different conditions using the subtracted network (Shaffer & Ruis, 2017), enabling comparisons between the high- and low-performing groups.

Therefore, this study aimed to identify patterns that may promote or constrain high-quality collaborative argumentation outcomes. The research questions were as follows.

(1) In what way do high- and low-performing groups differ with respect to the frequencies of the use of argumentation elements, encountered challenges, and social regulation?
(2) What are the fine-grained different co-occurrences in the use of argumentation elements, encountered challenges, and social regulation between high- and low-performing groups?

3. Method

3.1. Participants and context

This study recruited 55 undergraduates (mean age 20.33 ± 1.06 years; 51 females) from a normal university in Beijing. Participants joined a collaborative argumentation entitled "Is the Fast Diet a healthy way to lose weight?" This topic was selected due to its complexity and broad relevance among undergraduates, which was sufficient to provoke collaborative argumentation. Before the activity, participants' views on the Fast Diet were investigated using an online questionnaire, and they were randomly arranged to 14 groups with contrasting views (i.e. 13 four-member groups with two supporters and two opponents, 1 three-member group with one opponent and two supporters). All students participated in a 90-minute face-to-face collaborative argumentation in a research space with individual cameras and microphones. Informed consent was obtained from all students after they were briefed on the research purpose, confidentiality, and right to withdraw at any time.

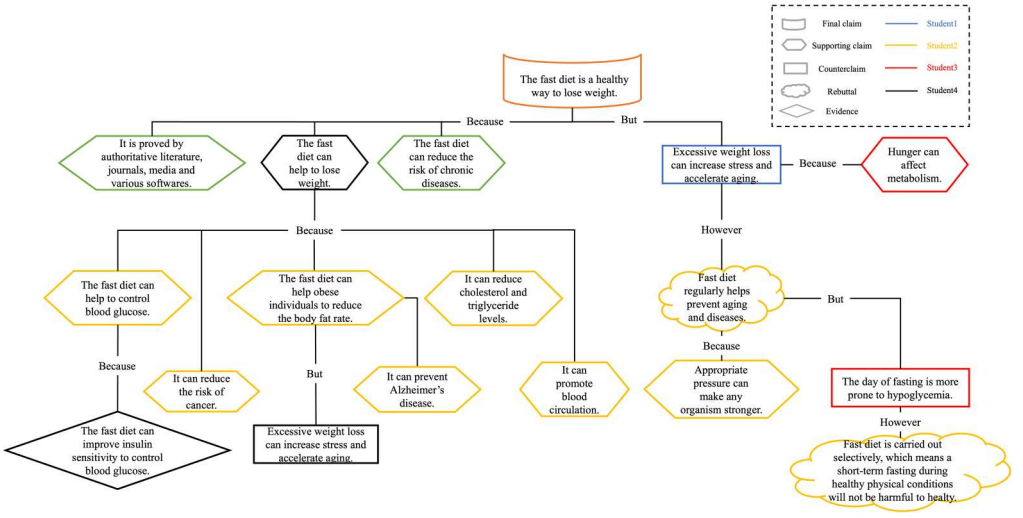

Figure 2. Group argument diagram.

3.2. Procedure

Before the collaborative argumentation, participants received training on using the platform (ProcessOn: https://www.processon.com) to draw argumentation diagrams. Subsequently, students were provided with reading materials containing scientific knowledge about the Fast Diet. They were also encouraged to search for additional evidence on the Internet.

When the activity began, students logged onto the platform and spent 15 min drawing individual argument diagram based on their existing view. Next, they engaged in a 45-minute collaborative argumentation, attempting to convince each other of their viewpoints. After reaching a consensus, they worked together to complete a group argument diagram that included one final claim and four fundamental argumentation elements (supporting claim, counterclaim, rebuttal, and evidence) (see Figure 2).

3.3. Data collection and analysis

3.3.1. Collaborative argument diagram analysis

Group argument diagrams were used to evaluate argumentation outcomes and distinguish between high- and low-performing groups. Two trained coders scored argument diagrams based on the criteria (H. T. Chen et al., 2016) (see Table 1). The inter-rater reliability was satisfactory (Cohen's kappa = 0.81). After the independent coding, the coders discussed any discrepancies face-to-face until consensus was achieved. The coding for argumentation elements, encountered challenges, and social regulation followed the same procedures.

To identify high- and low-performing groups, all groups were ranked by average scores for argument diagrams. Following Su et al. (2018), groups in the top 27% were categorized as high-performing (Groups 3, 6, 8, and 14, 15 participants in total), while groups in the bottom 27% as low-performing (Groups 4, 5, 9, and 12, 16 participants in total).

3.3.2. Argumentation elements

To analyze the use of argumentation elements, encountered challenges, and social regulation, this study utilized eight videos of high- and low-performing groups (48.3 ± 3.2 min). All videos were transcribed into text. The unit of analysis was a meaningful episode, which included several utterances reflecting a specific argumentation element, an encountered challenge, a social regulation, or was

Table 1. The assessment criteria for the argument diagram.

Category	Description	Level	Score
Claim	Final claim: conclusion of the topic (in a sector shape).	Irrelevant/not applicable/unclear.	0
	Supporting claim: A sub-claim that supports the final claim (in hexagon shapes).	Partial claim/not provide evidence/provide irrelevant evidence.	1
	Counterclaim: A claim that refutes a supporting claim or the final claim (in rectangle shapes).	Clear and complete claim with at least one reliable evidence.	2
Evidence	Data or research findings that support a claim or rebuttal (in diamond shapes).	Irrelevant/not applicable/unclear.	0
		Partial or weak (e.g. no indication of the source).	1
		Clear and reliable.	2
Rebuttal	A claim that refutes a counterclaim but always supports the final claim (in cloud shapes).	Irrelevant/not applicable/unclear	0
		Partial or weak.	1
		Strong and reliable.	2

Table 2. Coding scheme for argumentation elements.

Argumentation elements	Definition	Example
Weak claim (Level 1)	A simple claim with insufficient or irrelevant data, warrants, or backings.	"I think the Fast Diet is a healthy way to lose weight."
Strong claim (Level 2)	A claim with complete data, warrants, or backings but that did not contain any counterclaims or rebuttals.	"I think the Fast Diet is a healthy way to lose weight because it can help to regulate the metabolism."
Weak counterclaim/ rebuttal (Level 3)	A simple counterclaim or rebuttal with insufficient or irrelevant data, warrants, or backings.	"I think your point of view is limited."
Strong counterclaim (Level 4)	A counterclaim with complete data, warrants, or backings.	"I think your point of view is limited. Research shows that the Fast Diet may bring psychological pressure, thus accelerating the aging process."
Strong rebuttal (Level 5)	A rebuttal or series of rebuttals with complete data, warrants, or backings.	"Although you countered that the Fast Diet would accelerate the aging process, some studies pointed out that the human body had other mechanisms to prevent aging."

unrelated to these factors (Lobczowski et al., 2020). Two coders independently divided all episodes, achieving reliable analysis (kappa = 0.890). Three mutually exclusive coding schemes were used to code the episodes.

To code the use of argumentation elements, this study adapted the five levels of argumentation outcomes proposed by Erduran et al. (2004) (see Table 2). The inter-rater reliability of the coded variables was satisfactory (kappa = 0.801).

3.3.3. Encountered challenges

To code encountered challenges, this study referred to the coding of challenges presented by Hadwin et al. (2018) (see Table 3). The kappa value was 0.864.

3.3.4. Social regulation

To code social regulation, this study modified schemes used in previous studies by Järvenoja et al. (2019). The scheme is shown in Table 4 and the kappa value was 0.917.

3.4. Epistemic network analysis

To identify the patterns of argumentation elements, encountered challenges, and social regulation in high- and low-performing groups, this study drew the subtracted network using ENA. The codes included in the model were detailed in Section 3.3. Each code had two levels: 0 (absence) and 1

Table 3. Coding scheme for challenges.

Challenges	Definition	Example
Cognitive challenges (CC)	Cognitive challenges refer to difficulties in achieving shared understanding of the domain, choosing effective methods and strategies to solve the problems (e.g. lacking prior knowledge, could not find credible evidence or encountering a deadlock in reaching consensus)	"I don't know much about biology, so I'm not sure whether my understanding is right."
Socioemotional challenges (SC)	Socioemotional challenges are challenges in creating and maintaining a positive climate, including relational problems associated with psychological health, communicating harmoniously, and navigating power relationships (e.g. tense atmosphere manifested as expressing negative emotions, disrespectful communication, or too competitive)	"You must admit Fast Diet is healthy because your claim is too awful! You can't find any reliable evidence at all! I'm so annoyed!"

Table 4. Coding scheme for social regulation strategies.

Regulation	Categories	Definition of behavior	Example
Socioemotional regulation (SR)	SR.AE: Adjust emotions	Used humor, praise, or apology to potentially ease tension, maintain a pleasant atmosphere, or express disagreement	"Oh, sorry! I misunderstood your point of view."
	SR.PM: Promote motivation	Encouraged or facilitated others' participation by recognizing contributions, promoting openness, providing positive feedback, or making a polite request	"I'm still listening. Is there anything you want to explain further?"
Metacognitive regulation (MR)	MR.P: Planning	Asked or decided how to proceed with the task	"Let us take turns to express our claims and then draw the diagram, ok?"
	MR.M: Monitoring	Made an assessment or judgement of the time consumed, the understanding of the task, or if any learning goal was achieved	"Time is running out. Let us sort out the existing claims."
	MR.TS: Use of task-specific strategies	Reread the provided material or found further evidence to support or rebut a claim, or proposed new angles for discussion	"I found articles online saying that the Fast Diet can regulate the metabolism."
	MR.E: Evaluation	Evaluation involved students' judgement, attributions, and emotional reactions to their performance and the effectiveness of the strategies	"It would be great if my future collaboration could be as harmonious as today."

(presence). This study examines units from high- and low-performing groups, with the stanza set to six, a value reported as optimal which made the model stability (Shaffer & Ruis, 2017).

4. Results

4.1. Frequency-based differences in the use of argumentation elements and encountered challenges between the high- and low-performing groups

A Chi-squared test revealed significant differences in the use of argumentation elements between high- and low-performance groups ($\chi^2 = 23.806$, $df = 4$, $p < 0.001$). Low-performing groups utilized more argumentation elements ($H = 174$, $L = 265$). Notably, high-performing groups exhibited a higher percentage of strong claims ($H = 45.4\%$, $L = 29.4\%$), whereas low-performing groups demonstrated more weak counterclaims/rebuttals ($H = 4.6\%$, $L = 18.5\%$). Post hoc comparison indicated significant differences between weak counterclaims/rebuttals and strong claims, weak counterclaims/rebuttals and strong counterclaims, as well as weak counterclaims/rebuttals and strong rebuttals in high- and low-performing groups (Table 5). These results indicated that students in high-performing groups often presented high-quality claims with complete evidence, whereas low-performing groups more frequently proposed weak opposing views with insufficient evidence.

Table 5. Differences in the use of argumentation elements between the high- and low-performing groups.

	W.C		S.C		W.CT/R		S.CT		S.R				
Group	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	Total	χ^2	*p*
High	$6_{a,b,c}$	3.5	79_{c}	45.4	8_{b}	4.6	$27_{a,c}$	15.5	$54_{a,c}$	31.0	174	23.806	0.000**
Low	$7_{a,b,c}$	2.6	78_{c}	29.4	49_{b}	18.5	$39_{a,c}$	14.7	$92_{a,c}$	34.7	265		

Note: W.C, weak claim; S.C, strong claim; W.CT/R, weak counterclaim/rebuttal; S.CT, strong counterclaim; S.R, strong rebuttal; **$p < 0.001$. Each subscript letter in the "Total" line denotes a subset of intervention categories whose column proportions do not differ significantly from each other at the 0.001 level.

Table 6. Differences in encountered challenges between the high- and low-performing groups.

	CC		SEC				
Group	*n*	%	*n*	%	Total	χ^2	*p*
High	20	76.9	6	23.1	26	6.006	0.021*
Low	38	49.4	39	50.7	77		

Note: CC, cognitive challenge; SEC, socioemotional challenge; *$p < 0.05$.

The Chi-squared test showed significant differences in cognitive and socioemotional challenges between different performing groups ($\chi^2 = 6.006$, $df = 1$, $p < 0.05$). Table 6 showed that low-performing groups encountered more challenges ($H = 26$, $L = 77$). Cognitive challenges predominated in high-performing groups ($n = 20$, 76.92%), while low-performing groups encountered both socioemotional challenges ($n = 39$, 50.65%) and cognitive challenges ($n = 38$, 49.4%). This indicated that both high- and low-performing groups faced cognitive challenges, such as having difficulties in achieving a shared understanding. However, the low-performing groups encountered more socioemotional challenges, such as negative emotions or lack of respect. Besides, since the number of social regulations in a few codings (evaluation in low-performing groups) was too small to judge the statistical significance of the difference, differences in social regulations were not reported.

4.2. Differences in ENA patterns between the high- and low-performing groups

This study used ENA to explore the patterns of argumentation elements, encountered challenges, and social regulation during collaborative argumentation. The subtracted networks were shown in Figure 3. The co-registration correlations between the centroids and the projected points indicated a good model fit (dimension 1: $r = 1.00$, $r_s = 1.00$; dimension 2: $r = 1.00$, $r_s = 1.00$). Some meaningful conclusions were drawn from this credible model.

First, socioemotional challenges co-occurred more frequently with weak counterclaim/rebuttal and strong rebuttal in low-performing groups. As shown in Table 7, group members expressed views without providing corresponding evidence. Student 3 complained that Student 1 always used subjective factors. The tone of argumentation became rude, leading to a tense atmosphere.

Second, cognitive challenges often co-occurred with weak counterclaims/rebuttals in low-performing groups, whereas they co-occurred more with strong claims in high-performing groups. As demonstrated by the excerpt from a low-performing group in Table 8, after facing the cognitive challenge of failing to reach a consensus, students rebutted each other without strong evidence, resulting in an unresolved deadlock.

Another example from a high-performing group (Table 9) demonstrated that despite Student 1's difficulty in evaluating the credibility of evidence due to insufficient prior knowledge, the argumentation proceeded smoothly. This was achieved by students proposing strong claims and counterclaims with supporting evidence, effectively overcoming the cognitive challenge.

Third, there was a higher co-occurrence of socioemotional challenges and regulations (SR.AE) in low-performing groups, suggesting that these students used socioemotional regulation when facing

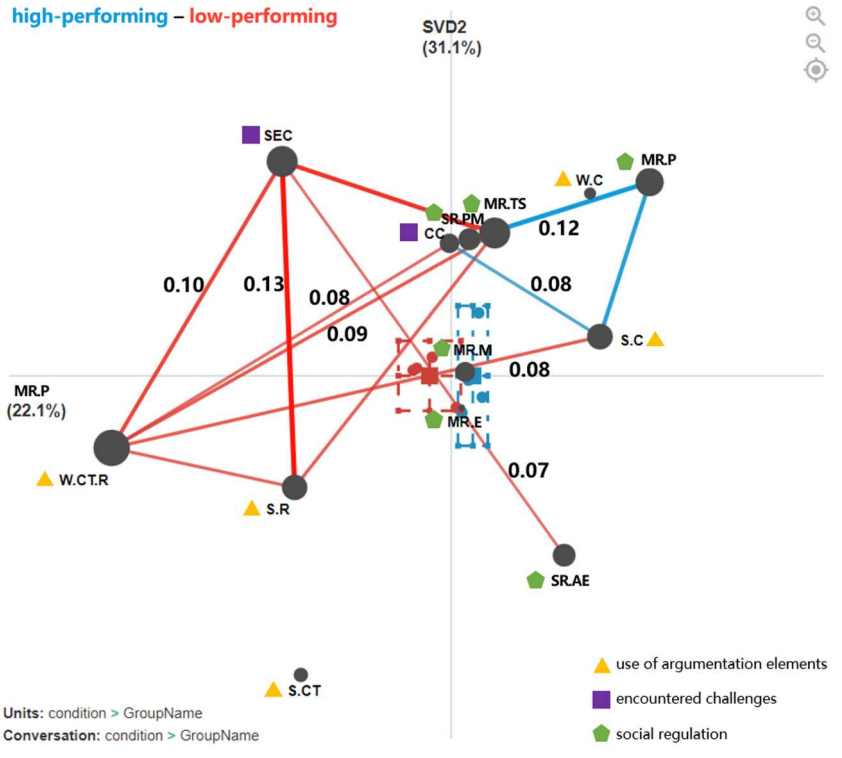

Figure 3. A subtracted network showing differences in the patterns of the use of argumentation elements, encountered challenges, and social regulation in the high-performing groups (blue) and the low-performing groups (red).
Note: S.C, strong claim; W.CT/R, weak counterclaim/rebuttal; S.R, strong rebuttal; MR.P, planning; MR.TS, use of task-specific strategies; SR.AE, adjust emotions; SR.PM, promote motivation; SEC, socioemotional challenge; CC, cognitive challenge.

Table 7. Example from a low-performing group (Group 5).

Episodes	Transcript
1	Student 2: I am fat when I eat normally, so I think it is meaningless to eat as usual in those 5 days. (W.C)
2	Student 3: I think a person used to eat a lot but eat less during the 2 days in the Fast Diet will feel better. (W.CT/R)
3	Student 1: But I think I will want to eat more in that two days. (W.CT/R)
4	Student 3: Goodness me! Here we go again! We have said that subjective factors are not considered for many times. Why are you still mentioning that? (SEC)

Note: W.C, weak claim; W.CT/R, weak counterclaim/rebuttal; SEC, socioemotional challenge.

Table 8. Example from a low-performing group (Group 4),

Episodes	Transcript
1	Student 1: I still think it is very healthy. I do not think you can convince me. (CC)
2	Student 2: I think the biggest problem is that your stomach will be damaged. (W.CT/R)
3	Student 1: So, what is the healthy way to lose weight?
4	Student 2: I think the way to lose weight healthily is to eat regularly and healthily. (W.CT/R)

Note: CC, cognitive challenge; W.CT/R, weak counterclaim/rebuttal.

such challenges. However, the increased tension from frequent socioemotional challenges rendered these regulation strategies ineffective. For example, in Group 9 (Table 10), Student 4 rudely criticized other students' rebuttals as unreasonable. After recognizing their rudeness, Student 4 attempted to alleviate the tension with humor, but it was unsuccessful.

Finally, the co-occurrence of promoting motivation (SR.PM) and planning (MR.P) in high-performing groups indicated that alternating cognitive and socioemotional regulation strategies was

Table 9. Example from a high-performing group (Group 6).

Episodes	Transcript
1	Student 2: Research shows that the Fast Diet may advance the aging process because of the pressure. (S.C)
2	Student 1: I am not sure whether it is right because I do not know much about biology. (CC)
3	Student 1: However, material 6 mentioned that it is inconsistent with the previous materials, which indicated that the Fast Diet can prevent aging. (MR.TS)
4	For example, the pressure caused by the Fast Diet may accelerate the aging process, but our body also has other prevention mechanisms. So, I think it may depend on what changes you focus on. (S.CT)

Note: S.C, strong claim; CC, cognitive challenge; MR.TS, use of task-specific strategies; S.CT, strong counterclaim.

Table 10. Example from a low-performing group (Group 9).

Episodes	Transcript
1	Student 4: I'm sick of your rebuttals. They were totally unreasonable! (SEC)
2	Student 2: Why?
3	Student 4: Because long-term changes are caused by the accumulation of short-term problems. Damage accumulated by frequent fast dieting will break out some days. Just like occasional drinking will not cause harm to the body, but long-term excessive drinking will. (S.R)
4	Student 2: My goodness! Can you tell me your claims directly? (SEC)

Note: SEC, socioemotional challenges; S.R, strong rebuttal; SR.AE, adjust emotions.

Table 11. Example from a high-performing group (Group 8).

Episodes	Transcript
1	Student 3: You can write about induced stress here, and later about accelerated aging. Then I add the social impact. (MR.P)
2	Student 1: OK.
3	Student 3: Do you have any additional suggestions? (SR.PM)
4	Student 2: Don't be nervous. Just think about it. (SR.PM)
5	Student 4: Actually, I don't know the unit of energy.
6	Student 3: Calories. I saw it when I searched for information online. (MR.TS)

Note: MR.P, planning; SR.PM, promote motivation; MR.TS, use of task-specific strategies.

beneficial for argumentation. For example, in Group 8 (Table 11), during the collaborative drawing of argumentation diagrams, Student 3 planned the task by assigning work, while Students 2 and 3 encouraged Student 4, who was nervous about expressing an opinion.

5. Discussion

This study used descriptive statistic, chi-squared test, and ENA to identify the differences in the frequency and intertwined patterns of the use of argumentation elements, encountered challenges, and social regulation between high- and low-performing groups. Several important findings were obtained.

5.1. Differences in the frequency of the use of argumentation elements and encountered challenges

Significant differences were observed in the frequency of the use of argumentation elements and encountered challenges between the high- and low-performing groups. Overall, low-performing groups used more argumentation elements. High-performing groups tended to use strong claims, while low-performing groups were more likely to use weak counterclaims/rebuttals. This finding supported the notion that the structure of argumentation elements was more crucial to the quality of argumentation outcomes than their quantity (Chuang & Yan, 2022). Using sufficient evidence to support claims was more conducive to improving argumentation quality

(Lund et al., 2007). However, most previous studies focused on the argumentation elements in essays or diagrams. This study extended previous research by suggesting that the use of argumentation elements in argumentative discourse might also affect argumentation outcomes. Moreover, it highlighted the importance of developing the ability to present strong claims with sufficient supporting details.

In terms of encountered challenges, low-performing groups encountered more socioemotional challenges. This finding extended previous studies (Lobczowski et al., 2020) by suggesting that socioemotional challenges might contribute to lower performance in collaborative argumentation with empirical evidence. The frequent negative socioemotional interactions might lead to disruptive socioemotional conflicts and hinder effective collaboration (Gao et al., 2023). Hence, greater emphasis on regulating socioemotional challenges might be beneficial in collaborative argumentation.

5.2. Differences in the patterns of the use of argumentation elements, encountered challenges, and social regulation

The ENA results *revealed distinct* patterns in the use of argumentation elements, encountered challenges, and social regulation between the high- and low-performing groups. Firstly, the use of argumentation elements and encountered challenges co-occurred differently. Socioemotional challenges co-occurred more with weak counterclaims/rebuttals or strong rebuttals in low-performing groups. These findings could be explained by previous research. On one hand, the results supported studies indicating that counterclaims or rebuttals lacking sufficient evidence, as well as persistent strong rebuttals, might lead to cause rude communication and trigger socioemotional challenges (Zschocke et al., 2016). On the other hand, it suggested that socioemotional challenges might also result in multiple weak counterclaims or rebuttals in turns. Socioemotional challenges often manifested in dysfunctional interaction behaviors, such as undermining others' opinions and showing little patience to listen carefully (Gao et al., 2023), which were likely to provoke counterclaims or rebuttals. However, intense socioemotional conflicts made students overly eager to refute each other without sufficient evidence, leading to fewer cognitive interactions and lower argumentation quality (Felton et al., 2019).

Secondly, the co-occurrence of argumentation elements and cognitive challenges differed between high- and low-performing groups. Cognitive challenges always appeared together with weak counterclaims/rebuttals in low-performing groups, but with strong claims in high-performing groups. These findings aligned with existing research, which suggested that cognitive challenges did not necessarily impede collaborative argumentation (Malmberg et al., 2015), and they further complemented empirical evidence on the patterns of cognitive challenges in different performing groups. In low-performing groups, cognitive challenges often arose from or triggered counterclaims and rebuttals lacking sufficient evidence. This might be due to students' inability to develop appropriate regulation strategies to address cognitive challenges, resulting in low-quality counterclaims (Järvelä et al., 2015). Conversely, in high-performing groups, students sought to provide credible evidence to support their arguments. This approach helped them avoid or effectively manage cognitive challenges, which facilitated deeper engagement in cognitive constructions (Zheng et al., 2023). Therefore, it is essential to design intervention tools to help students better handle and learn from cognitive challenges.

Thirdly, social regulation strategies and socioemotional challenges co-occurred differently in high- and low-performing groups. The more co-occurrences of socioemotional regulation and socioemotional challenges in low-performing groups indicated that students attempted to use socioemotional strategies to address socioemotional challenges. However, these attempts in that situation were not particularly effective. Previous research had established that frequent socioemotional challenges constrained shared adaptation and reduced the effectiveness of social regulation (Li et al., 2023). The tense atmosphere in low-performing groups made their regulation strategies less

effective in managing socioemotional challenges. The findings underscored the importance of implementing effective measures to help students choose appropriate regulation strategies for socioemotional challenges.

Finally, the co-occurrences of cognitive and socioemotional regulations in high-performing groups indicated their proficiency in alternately applying cognitive and socioemotional regulations. This result was in accordance with previous findings that high-performing groups could flexibly adjust regulation strategies in collaborative learning (Su et al., 2018). This study further verified that view in the context of collaborative argumentation, suggesting that alternating between cognitive and socioemotional regulations might enhance argumentation outcomes. Observed cases of high-performing groups revealed that flexible and alternate use of cognitive and socioemotional regulations enabled them to plan complex tasks and adjust socioemotional experiences during the argumentation, which might create a more harmonious environment for cognitive interactions (Bakhtiar et al., 2017). This approach allowed students to fully develop their ideas without socioemotional conflicts, which was crucial for high-quality argumentation (W. Chen et al., 2024). These results highlighted the importance of guiding students to flexibly use cognitive and socioemotional regulations.

6. Application and further research

6.1. Limitations and further research

The research context, short duration, and sample limited the generalizability of the findings. This study was conducted in a carefully designed argumentation context with all participants from one normal university. The sample size was relatively small and the gender ratio was uneven. Therefore, caution is needed in applying the conclusions to other contexts. In further studies, argumentation activities with longer duration and richer contexts could be designed and more students could be recruited. Additionally, future studies could use more innovative methods to explore the patterns of argumentation elements, challenges, and social regulation. For example, using data mining to analyze the patterns of argumentation elements, encountered challenges and social regulation, since it could provide some information about the sequence of these factors.

6.2. Educational application

This study found that students with high-quality argumentation outcomes mainly used strong claims, whereas low-performing groups had more weak counterclaims and rebuttals which might be related to socioemotional challenges. Therefore, teachers could guide students to provide credible evidence while making claims or counterclaims by designing scaffolds. Early warning tools could also be designed to monitor the potential risks for socioemotional challenges. Additionally, this study showed the importance of mastering social regulation strategies. The alternative use of cognitive and socioemotional regulation helped improve the quality of argumentation outcomes. Teachers could provide more training and guidance to help students better regulate the collaborative process.

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Ethics declarations

The research involved human participants and was approved by the Education Faculty's Ethics Committee. Informed consent was obtained for all participants.

Authors' contributions

Ziqi Mao led the research project, analyzed the data and wrote the manuscript. Xiaoran Li collected the data and revised the manuscript. Yanyan Li supervised the research and revised the manuscript. Jingjing Shao conducted the data analysis. Haogang Bao revised the manuscript. All authors read and approved the final manuscript.

Data availability statement

The data that support the findings of this study are available on request from the first author.

ORCID

Ziqi Mao http://orcid.org/0000-0001-6809-2245
Yanyan Li http://orcid.org/0000-0002-8558-5911

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