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PAPER

Critical Thinking Process in Online Collaborative Learning Based on Different Group Metacognitive Regulation Levels

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ABSTRACT

Critical thinking (CT) is acknowledged as one of the core skills to survive in the future. Learner's critical thinking skills (CTS) could be cultivated in online learning through collaborations, which are promoted by group metacognitive regulation (GMR). The existing studies on CTS mainly focus on improving students' CTS levels but ignore the CT process. In this study, students collaborated online in small groups with the intervention of GMR for four tasks. GMR prompts were applied to guide students in regulating their collaboration. Facione's CTS model was adopted to code students' CTS for content analysis. Lag sequential analysis was conducted to reveal students' CT processes based on different GMR levels. The result shows that GMR is positively significantly correlated with CTS. Students' CT process differs upon at different GMR levels. High-GMR groups possess the highest frequency and balanced CT process, medium-GMR groups have the most sophisticated CT process, and low-GMR groups have the lowest frequency and simplest CT pattern, which reveals the usefulness of GMR in promoting students' CTS.

KEYWORDS

critical thinking process, group metacognitive regulation, lag sequential analysis, online collaborative learning

1 INTRODUCTION

Critical thinking (CT) is essentially a process of analyzing and evaluating information based on factual evidence to make reasonable inferences and judgments [1]. Critical thinking skills (CTS) are regarded as one of the essential competence of 21st-century citizens and help students succeed in school performance, workplace and personal life [1, 2]. Meanwhile, online learning provides more opportunities

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for fostering students' CTS. For example, the online live discussion boards, interactive feedback and structured questioning are employed to improve students' CTS [3, 4].

However, online collaborative learning also faces challenges, such as a lack of effective guidance, feedback and social-emotional support [5]. In online collaborative learning, group members should jointly construct the shared task understanding, goals and strategies and regulate the learning process, which means that group metacognitive regulation (GMR) is required [6]. GMR is an important element in developing CTS in online learning [7], yet the CT process based on GMR is rarely explored in previous studies. Therefore, this paper aims to investigate the distribution and patterns of CT process in online collaboration based on different GMR levels.

2 PROBLEM BACKGROUND

2.1 Fostering critical thinking through online collaborative learning

Online collaborative learning is advantageous in fostering students' CT as it gives learners more time to think and allows them to comment on discussion topics after careful consideration [8]. Online discussion is one typical form of online learning to help students foster CT [9]. However, some factors hinder students from actively participating in online collaborative learning, including students' cognition level, discussion topic, learning task, the necessity of discussion, peer influence, instruction design, teachers' feedback, and technical support [10].

Based on the constructivist theory of the Zone of Proximal Development [11], researchers have applied different prompts in online collaborative learning to improve students' CT [12], for example, Mahtari, Wati [13], Bellaera, Weinstein-Jones [14] applied question prompts; Ramirez and Monterola [15], Bernstein and Isaac [16] applied script prompts; and Giacumo and Savenye [17], Cheong and Cheung [18] utilized procedure prompts to foster students' CT. Although technology-enhanced prompt consists of four types, namely, procedural, conceptual, strategic and metacognitive prompts [19], the previous studies on CT in online collaborative learning mainly focused on the intervention of procedural, conceptual, and strategic prompts. As to the metacognitive prompt, recent research mostly concerns the effect of self-regulation or individual metacognition on CT [20, 21], and few studies have been found on applying group metacognitive prompts to explore students' CT.

2.2 Group metacognitive regulation and critical thinking in online collaborative learning

Group metacognitive regulation (GMR) refers to the skills and strategies used by learners to control and coordinate their group learning processes. It involves key regulation skills such as learners' shared task planning, shared task monitoring and shared task evaluation [22]. GMR is important in promoting learners' cognitive performance [23] in online collaborative learning because it stimulates learners to participate in active and meaningful discussions. Hence, GMR is used as a method to improve students' knowledge construction [24], group performance [25], problem-solving [26], and social interaction [27].

Giacumo and Savenye [17] set the metacognitive scaffolding in online learning to develop CTS. Kitsantas, Baylor [28] explored the correlation between self-regulated learning and critical thinking skills and found that the development of self-regulated learning leads to the enhancement of students' CTS, such as analyzing data, drawing inferences and making decisions. However, the mentioned studies focus on individual metacognitive regulation rather than GMR.

Even though metacognitive regulation has many advantages in promoting CT, little research has been conducted on GMR and CT. Zuhairah, Ismail [29] designed research to investigate how GMR in problem-based learning affect students' CTS. However, this study only proposed a research design without giving the research result. Cortázar, Nussbaum [7] proposed that GMR significantly impacted students' CT in online project-based learning. Yet this study did not explore students' CT processes during learning, which serves as the gap for this study.

The research questions are as follows:

1. What is the distribution of students' CT process in online collaborative learning based on different GMR levels?
2. What are the patterns of students' CT process in online collaborative learning based on different GMR levels?

3 METHODS

This study uses the quantitative research design (see Figure 1).

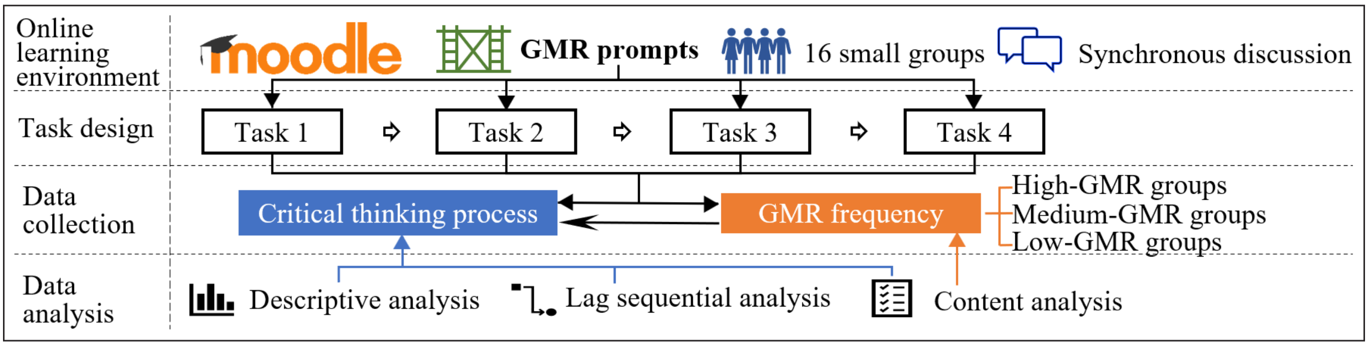

Fig. 1. Research design

3.1 Online learning task design

This study involved 62 second-year English major undergraduate students who took the translation subject and randomly formed 14 quartet groups and 2 triad groups. Participants used Moodle LMS and were required to discuss synchronously four translation proofreading tasks collaboratively with the treatment of GMR prompts.

Each task went through four steps based on GMR prompts which were provided to the participants when they began the collaboration. Figure 2 illustrates the GMR prompts.

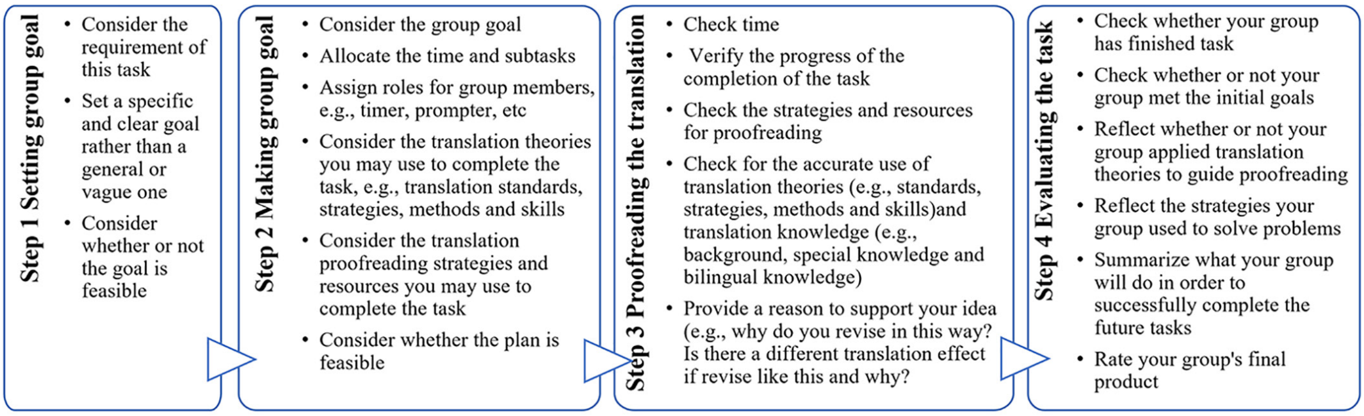

Fig. 2. GMR prompts

3.2 Data collection and analysis method

All the data were collected from the online discussion scripts for the four tasks. The discussion scripts were analyzed using content analysis to determine participants' CT processes and GMR levels.

Coding for CT process. The coding scheme for CT process was adapted from [1]. There are six CT processes by [1], which are (1) Interpretation (codes as "IP"), (2) Analysis ("AL"), (3) Inference ("IF"), (4) Evaluation ("EV"), (5) Explanation ("EX") and (6) Self-regulation ("SR"), see Table 1. Two raters first coded CT process independently. The inter-rater agreement was 0.934. Then the two raters discussed and resolved all the discrepancies.

Table 1. Coding scheme for critical thinking process

Critical Thinking	Description (Based on the Tasks)	Code
Interpretation	• Propose a translation issue for discussion	IP
Analysis	• Clarity the source text • Analyze the error from the translated text	AL
Inference	• Propose a revised translation • Query evidence to support the solution	IF
Evaluation	• Judge the revised translation	EV
Explanation	• Provide evidence to support the revised translation	EX
Self-regulation	• Self-correction • Self-examine whether the solution is appropriate	SR

Coding for GMR. The GMR coding scheme was adapted from [30] and [31]. There are six GMR strategies: (1) Task planning (coded as "TP"), (2) Content planning ("CP"),

(3) Task monitoring ("TM"), (4) Content monitoring ("CM"), (5) Task evaluation ("TE") and (6) Content evaluation ("CE"), see Table 2.

Table 2. Coding scheme for group metacognitive regulation

GMR Strategy	Description (Based on the Tasks)	Code
Task planning	• Discuss the shared task plans, such as role assignments and how to go about answering the task questions	TP
Content planning	• Discuss shared understanding goals related • Evoke task-relevant content knowledge	CP
Task monitoring	• Verify the progress toward or completion of each task prompt	TM
Content monitoring	• Monitor content contribution or check the accuracy of task responses	CM
Task evaluation	• Check the completion of all the task prompts, evaluating having met task directions	TE
Content evaluation	• Check whether the group met the initially set goals • Evaluate the accuracy of the final task solution	CE

Students' discussion scripts were divided into several "episodes" as the analysis unit, which began when one student triggered the GMR strategy and ended when one student started another GMR process. Two raters first decided the division of episodes, which were then coded independently. The inter-rater agreement was 0.920. The two raters discussed and resolved all the discrepancies. The collaborative groups were then categorized into high-, medium- and low-GMR levels.

Sequential analysis. To explore students' CT process, lag sequential analysis (LSA) [32] was conducted with GSEQ 5.1. Six CT processes are the variables for the LSA. Sequential analysis calculates the transitional probability from one CT process to another. The sequence is significant only when the Z-value exceeds 1.96 [32], indicating that the previous action triggers the subsequent.

This study performed the LSA based on the high-, medium- and low GMR levels. The significant sequences in each GMR level were illustrated in the state transition diagrams where the arrow (→) joins two sequential critical thinking skills, and the arrow thickness represents the probability of transition (a thicker arrow indicates a higher probability of transition).

4 RESULTS AND DISCUSSION

4.1 Levels of group metacognitive regulation

Table 3 presents the total GMR frequency during four tasks based on which the 16 collaborative groups were categorized into low-, medium- and high-GMR levels. Five groups, Group 2, 3, 5, 8 and 12, were categorized as high in GMR level; six groups, Group 4, 7, 9, 10, 13 and 14, were categorized as medium in GMR level; and the other five groups, Group 1, 6, 11, 15 and 16, were categorized as low in GMR level.

Table 3. GMR frequency and levels for each group during four tasks

Group	TP	CP	TM	CM	TE	CE	Total GMR	GMR Level
Group 1	1	0	4	10	0	1	16	L
Group 2	9	3	46	44	5	4	111	H
Group 3	6	0	28	45	9	12	100	H
Group 4	12	0	30	33	1	5	81	M
Group 5	7	3	22	49	1	7	89	H
Group 6	5	2	19	32	0	4	62	L
Group 7	5	4	24	40	3	2	78	M
Group 8	4	2	41	49	1	4	101	H
Group 9	5	0	31	45	1	2	84	M
Group 10	13	1	22	34	4	2	76	M
Group 11	5	4	12	37	0	2	60	L
Group 12	4	4	42	38	4	4	96	H
Group 13	4	4	34	38	2	1	83	M
Group 14	8	0	28	32	2	4	74	M
Group 15	4	1	19	17	0	1	42	L
Group 16	4	5	24	10	3	3	49	L

Note: GMR = Group metacognitive regulation, TP = task planning, CP = content planning, TM = task monitoring, CM = content monitoring, TE = task evaluating, CE = content evaluating, H = high-GMR level, M = medium-GMR level, L = low-GMR level.

4.2 Distribution of critical thinking process during online collaborative learning based on different levels of group metacognitive regulation

The distribution and percentage of each CT process during the online discussion is shown in Table 4, which is arranged according to high-, medium-, and low-GMR levels. From an overall viewpoint, Inference (IF) ranked first (32.87%), showing that students could propose many solutions. Evaluation (EV) ranked second (26.42%), showing that students could assess the solutions timely. The result indicates that reasoning skills were the most prominent in the CT process for translation practice, which underscores the findings from [33, 34].

In this study, Interpretation ranked third (15.11%), indicating that students could identify translation errors. The result differs from the research of [33] that assumption identification was the least used critical thinking skill. This is because under GMR treatment, students could better understand the task, and thus identify more translation errors.

The percentage of Explanation (EX) (11.84%) and Analysis (AL) (10.18%) were small, indicating that although students could identify translation errors and propose solutions, they were not able to engage in a deep discussion, compared with the percentages of Inference and Interpretation. Self-regulation (SR) has the smallest distribution (3.58%), showing that personal-level reflection was rare under the GMR treatment.

Table 4. Distribution of critical thinking process for each group during four tasks

GMR Levels	Group	IP	AL	IF	EV	EX	SR	Total CT
High-GMR Level	Group 2	36	28	101	72	25	10	272
	Group 3	41	27	87	96	37	11	299
	Group 5	51	28	104	83	30	13	309
	Group 8	61	53	89	109	48	13	373
	Group 12	38	29	64	40	21	2	194
	Total	227	165	445	400	161	49	1447
	Percentage	15.69%	11.40%	30.75%	27.64%	11.13%	3.39%	–
Medium-GMR Level	Group 4	29	25	118	78	33	14	297
	Group 7	49	23	68	59	26	12	237
	Group 9	42	27	91	63	42	7	272
	Group 10	31	27	86	75	48	14	281
	Group 13	36	21	68	51	20	7	203
	Group 14	24	15	70	68	26	14	217
	Total	211	138	501	394	195	68	1507
	Percentage	14.00%	9.16%	33.24%	26.14%	12.94%	4.51%	–
Low-GMR Level	Group 1	5	3	16	13	2	0	39
	Group 6	31	26	58	66	32	7	220
	Group 11	26	17	102	48	15	1	209
	Group 15	22	10	27	12	14	0	85
	Group 16	14	2	17	4	1	2	40
	Total	98	58	220	143	64	10	593
	Percentage	16.53%	9.78%	37.10%	24.11%	10.79%	1.69%	–
Overall	Total	536	361	1166	937	420	127	3547
	Percentage	15.11%	10.18%	32.87%	26.42%	11.84%	3.58%	–

Note: CT = critical thinking, IP = interpretation, AL = analysis, IF = inference, EV = evaluation, EX = explanation, SR = self-regulation.

Translation proofreading consists of two steps, identifying errors in the original text (IP and AL are included) and correcting the translation errors (IF, EV, EX and SR are included). Figure 3 shows that groups with different GMR levels had different distributions for each CT process, reflecting the difference in the two translation proofreading steps.

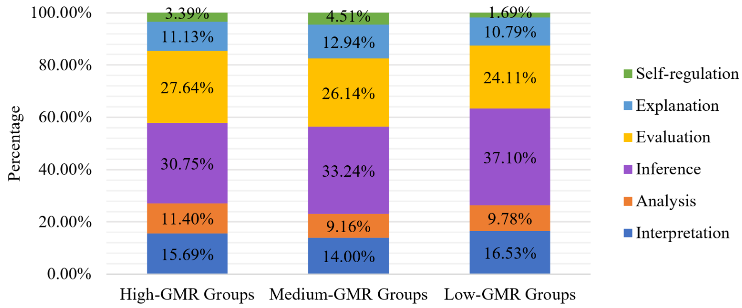

Fig. 3. Distribution of each critical thinking process for groups with different GMR levels

The percentage difference between IP and AL in high-GMR groups (4.29%) and medium-GMR groups (4.84%) was almost the same, but the former had more IP, indicating that high-GMR groups could identify more errors and make more analysis. Low-GMR groups had the most IP (16.53) and the largest percentage difference between IP and AL (6.75%), showing there were more chances for low-GMR groups to revise the translation directly after identifying the errors without analysis.

High-GMR groups had the smallest percentage difference between IF and EV (3.11%) as well as IF and EX (19.62%), and the percentage difference was 7.1% and 20.3% in medium-GMR groups, 12.99% and 26.31% in low-GMR groups. The results reflect that high-GMR groups could judge the solution and engage in in-depth discussions, while low-GMR groups contributed the most correction but without much careful evaluation. Interestingly, medium-GMR groups had the most percentage of SR, indicating that more mistakes were made and more self-reflection and self-correction were needed.

4.3 Correlation between group metacognitive regulation and critical thinking process

To investigate the relationship between GMR and CT process, a Pearson correlation was conducted since total GMR and CT frequency among 16 collaborative groups were normally distributed.

Table 5 reports that total GMR and total CT had a significant positive correlation, with a value of 0.883 at a significant level of 0.01, indicating that when GMR increased, CTS increased during the four collaborative learning tasks.

Table 5. Correlation between total GMR and total CTS among 16 collaborative groups

Pearson Correlation (N = 16)	Total CT	
	r	p
Total SSRL	0.833**	<0.001

*Note:***Correlation is significant at the 0.01 level (2-tailed).

4.4 Patterns of critical thinking process during online collaborative learning based on different levels of group metacognitive regulation

To get the patterns of CT process during online collaborative learning, threes LSAs were carried out based on high-, medium-, and low-GMR groups. In Table 6, a positive value ≥ 1.96 suggests a significant sequence, meaning the CT process in the column is followed by the other CT processes in the row. As such, 10 significant sequences are identified for high-GMR groups, 11 significant sequences for medium-SSSL groups, and 9 significant sequences for low-SSSL groups, see Table 7. Then, the significant sequences are transferred to diagrams, as shown in Figure 4.

Table 6. Z-score matrix of critical thinking skills in high-, medium- and low-GMR groups

		IP	AL	IF	EV	EX	SR
High-GMR groups	**IP**	−2.51	**19.42***	**2.27***	−10.4	−5.11	−2.48
	AL	−0.55	−3.32	**9.92***	−4.39	−3.12	−1.4
	IF	0.68	−6.82	−8.57	**7.84***	**7.76***	−0.83
	EV	**2.24***	−4.89	−2.02	**2.34***	**2.14***	1.58
	EX	0.09	−3.52	1.13	**2.57***	−4.08	**4.27***
	SR	−0.49	−0.31	1.37	0.16	−0.84	−1.19
		IP	AL	IF	EV	EX	SR
Medium-GMR groups	**IP**	−2.51	**19.42***	**2.27***	−10.4	−5.11	−2.48
	AL	−0.55	−3.32	**9.92***	−4.39	−3.12	−1.4
	IF	0.68	−6.82	−8.57	**7.84***	**7.76***	−0.83
	EV	**2.24***	−4.89	−2.02	**2.34***	**2.14***	1.58
	EX	0.09	−3.52	1.13	**2.57***	−4.08	**4.27***
	SR	−0.49	−0.31	1.37	0.16	−0.84	−1.19
		IP	AL	IF	EV	EX	SR
Low-GMR groups	**IP**	−2.51	**19.42***	**2.27***	−10.4	−5.11	−2.48
	AL	−0.55	−3.32	**9.92***	−4.39	−3.12	−1.4
	IF	0.68	−6.82	−8.57	**7.84***	**7.76***	−0.83
	EV	**2.24***	−4.89	−2.02	**2.34***	**2.14***	1.58
	EX	0.09	−3.52	1.13	**2.57***	−4.08	**4.27***
	SR	−0.49	−0.31	1.37	0.16	−0.84	−1.19

Note: IP = interpretation, AL = analysis, IF = inference, EV = evaluation, EX = explanation, SR = self-regulation,*Significant value selected to create state transition diagram, z ≥ +1.96.

Table 7. Significant sequences for high-, medium- and low-GMR groups

High-GMR Groups		Medium-GMR Groups		Low-GMR Groups	
Significant Sequences	Z-Score	Significant Sequences	Z-Score	Significant Sequences	Z-Score
IP→AL	19.42	IP→AL	19.49	IP→AL	8.55
IP→IF	2.27	IP→IF	2.56	IP→IF	4.26
AL→IF	9.92	AL→IF	7.98	AL→IF	6.05
IF→EV	7.84	IF→EV	7.37	IF→IP	2.97
IF→EX	7.76	IF→EX	6.47	IF→EV	2.54
EV→IP	2.24	EV→EX	4.31	IF→EX	3.59
EV→EV	2.34	EV→SR	2.17	EV→EV	4.67
EV→EX	2.14	EX→IF	2.28	EX→EV	2.11
EX→EV	2.57	EX→EV	4.68	EX→SR	2.86
EX→SR	4.27	EX→SR	2.17		
		SR→IF	2.05		

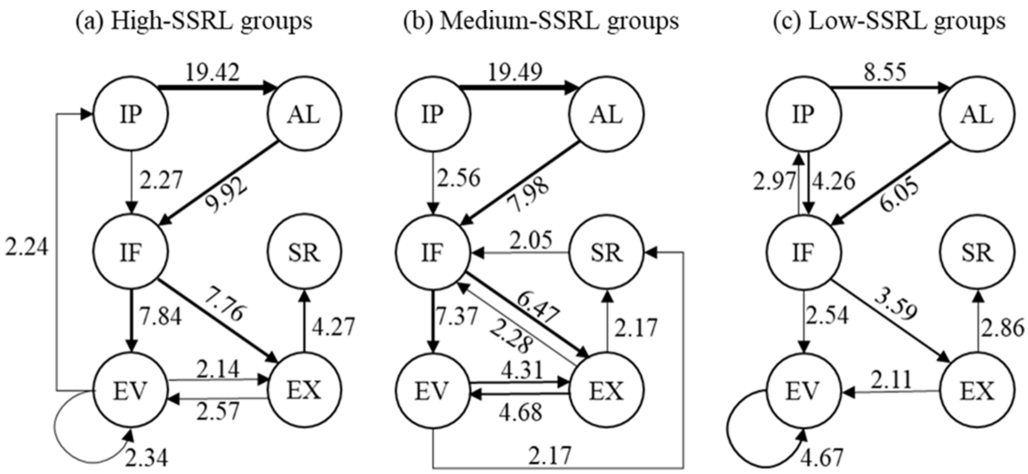

Fig. 4. State transition diagram of CT process in high-, medium- and low-GMR groups

To further analyze the patterns of CT process, the significant sequences are joined based on the two steps of the translation proofreading task – Identifying errors in the original text and Correcting the translation errors. According to the coding scheme for CT process, "IF", as proposing a possible solution, marks the division of the two steps.

Pattern of high-GMR groups. Two paths were revealed in the step of identifying errors in the original text: (1) IP→AL→IF; (2) IP→IF. Four paths were summarized in the step of correcting the translation errors (3) IF→EX→…→SR; (4) IF→EX→…→EV; (5) IF→EX→…→IP; (6) IF→EV→…→SR; (7) IF→EV→…→EV; and (8) IF→EV→…→IP. "…" means different CT processes in the path. The paths are explained in detail in Table 8.

Table 8. Paths for critical thinking process and explanations for high-GMR groups

Step	Path	Explanation
Identifying errors in the original text	**1.** IP→AL→IF **2.** IP→IF	The task began, and the students first pointed out the errors (IP). Then, they followed Path (1): analyzing the errors (AL) and proposing a new translation (IF); or Path (2), correcting the error directly. AL was the most behaviour following IP, indicating that in most cases, students could analyze the errors in the original text, which is the basis for revising the translation effectively. There were also some occasions when students presented a revised translation directly. It was appropriate to make direct revisions when the errors were explicit.
Correcting the translation errors	**3.** IF→EV→…→SR **4.** IF→EV→…→EV **5.** IF→EV→…→IP **6.** IF→EX→…→SR **7.** IF→EX→…→EV **8.** IF→EX→…→IP	After proposing the corrected translation (IF), students evaluated the correction (EV) as in Path (3), (4), (5); or discuss and justify the corrected version and the translation procedures (EX) as in Path (6), (7), (8). In proportion, EV (7.86) and EX (7.76) were approximately equal, showing that GMR led to meaningful discussion. Next, students had several discussions, manifested by the significant looped sequence of "EV↔EX", meaning that students assessed the translation, gave justifications, and stated further issues regarding the task. The discussion episode ended with three critical thinking skills trends: SR, EV and IP. SR followed EX, indicating that students' self-reflection mostly focused on the discussion content rather than the quality of the correction. In other words, students gained from the groupwork with GMR prompts. EV was in a looping process (EV→EV), indicating students gave several assessments on the correction, which shows that students discussed to reach the shared solution. IP followed EV, meaning that the students checked the original version and made further analysis when they experienced disagreement in evaluating the revised version.

Pattern of medium-GMR groups. Two paths were revealed in the step of identifying errors in the original text: (1) IP→AL→IF; (2) IP→IF. Six paths were summarized in the step of correcting the translation errors: (3) IF→EV→SR→IF; (4) IF→EX→SR→IF; (5) IF→EV→…→IF; (6) IF→EX→…→IF. "…" means different critical thinking skills in the path. The paths are explained in Table 9.

Table 9. Paths for critical thinking process and explanations for Medium-GMR groups

Step	Path	Explanation
Identifying errors in the original text	**1.** IP→AL→IF **2.** IP→IF	The task began, and the students first pointed out the errors (IP). Then, they followed Path (1): analyzing the errors (AL) and proposing a new translation (IF); or Path (2), correcting the error directly. The same with high-GMR groups, AL was the most behavior following IP, indicating that students, triggered by GMR prompts, could analyze the errors in the original text. There were also some occasions when students presented a revised translation directly when the errors were explicit.
Correcting the translation errors	**3.** IF→EV→SR→IF **4.** IF→EX→SR→IF **5.** IF→EV→…→IF **6.** IF→EX→…→IF	After proposing the corrected translation (IF), students slightly preferred EV behavior (7.37) to EX (6.47). Path (3) and (4) are typical critical thinking paths for a simple issue where the reviewer could reflect on his own problem (SR) immediately upon others' evaluation (EV) or justification (EX) and make a further modification (IF). Path (5) and (6) show the CT processes when dealing with complex issues. During the discussion, the significant looped sequence of "IF↔EX" and "EV↔EX" occurred, indicating that students assessed the translation, justified the solution, and came out of different revisions to complete the task. It means that under the treatment of GMR prompts, students were involved in a deep group discussion. The discussion episode all ended with IF, meaning that students finally reached a shared solution, which reached the aim of GMR.

Pattern of low-GMR groups. Three paths were revealed in the step of Identifying errors in the original text: (1) IP→AL→IF; (2) IP→IF; (3) IP→…→IF→IP. Three paths were found in the step of correcting the translation errors: (4) IF→EX→SR; (5) IF→EX→EV→EV; (6) IF→EV→EV. The paths are explained in Table 10.

Table 10. Paths for critical thinking process and explanations for low-GMR groups

Step	Path	Explanation
Identifying errors in the original text	**1.** IP→AL→IF **2.** IP→IF **3.** IP→…→IF→IP	The task began, and the students first pointed out the errors (IP). Then, they followed Path (1): analyzing the errors (AL) and proposing a new translation (IF); or path (2), correcting the error directly. In low-GMR groups, students had more Path (2) frequency, indicating that their analyses were much less than the high-, and medium-GMR groups. Path (3) is unique in low-GMR groups. IF→IP indicates that students did nohgt have further discussion in this error but directly continued with a new one, indicating that their discussions were relatively less in-depth.
Correcting the translation errors	**4.** IF→EX→SR **5.** IF→EX→EV→EV **6.** IF→EV→EV	Low-GMR groups generally had simple paths where some critical thinking skills were absent. Path (4) revealed that although students justified the translation process (EX) and made self-reflection (SR), they sometimes did not assess the corrected translation, which was not conducive to getting the agreed solution. In path (5), students give some explanation for the correction (EX), followed by the looping process of EV (EV→EV); in Path (6), students directly gave several assessments on the correction (EV→EV) without any other discussion, indicating that students in low-GMR groups did not involve in deep discussion on the corrected version.

Comparison of patterns. There are different patterns of students' CT processes based on different SSLR levels. In general, high-GMR groups demonstrated the most balanced CT process with highest CTS. The pattern for the medium-GMR groups was the most sophisticated. The low-GMR groups had the lowest frequency of CT process and the simplest pattern.

In the step of "identifying errors in the original text", high- and medium-GMR groups shared a similar pattern of CT process. "Interpretation→Analysis→Inference" was the most significant sequence, indicating that students analyzed and understood the errors in the source test, which was a prerequisite for high-quality translation proofreading. In contrast, "Interpretation→Inference" sequence was prevalent in low-GMR groups, which indicates that students preferred revising translations directly without much analysis. Besides, the "Inference→Interpretation" sequence in low-GMR groups suggests the superficial learning activities as students repeated the loop of "identify one translation error – correct the error – identify another translation error" without further discussion, which was rarely found in high- and medium-GMR groups.

In the step of "correcting the translation errors", the sequential order of "Inference", "Evaluation", "Explanation" and "Self-regulation" differed among the groups with different GMR levels. Notably, the subsequent behaviour of "Evaluation" was different. The only subsequent behaviour of "Evaluation" in low-GMR groups was "Evaluation" with a large Z-score, indicating that students tended to confirm previous opinions. The paths of CT process for low-GMR groups were mostly unidirectional, showing that the CT processes were simple and students did not engage in deep discussion.

In contrast, high- and medium-GMR groups had more follow-up behaviours after "Evaluation", indicating more complex CT processes. The looped CT process of "Evaluation↔Explanation" indicates that students focused on justifying the proposed solution. "Evaluation→Interpretation" was a unique sequence of high-GMR groups, which means that students looked back to the source text, suggesting that high-GMR groups analyzed the problem in a more comprehensive way.

"Evaluation→Self-regulation" sequence was unique for medium-GMR groups, so students tended to self-reflect on the previous ideas, which led to more "Evaluation↔Explanation" process. This explains why the Z-score of "Evaluation↔Explanation" in medium-GMR groups is twice that in high-GMR groups. Besides, in medium-GMR groups, the paths converged in "Inference", showing that medium-GMR groups paid more attention to the second step in the task. In other words, they emphasized more on the final solution.

In conclusion, the CT process echoes the translation process. Since CT processes predict translation quality [35], the findings aligned with the previous research [26, 36–38] that GMR improves students' learning achievement. The study expanded the previous research that GMR significantly improved students' CTS in online learning [9] because it investigated how students performed their CTS during the learning process. The data on the CT process and GMR also revealed that the groups with higher GMR level had higher quality of CT process, which is in line with the conclusion from [39] that the quality of discussion is crucial for the success of learning.

5 CONCLUSION

This study investigated students' CT process under the intervention of GMR in online collaborative learning. The findings indicate the different distribution and patterns of CT among high-, medium- and low-GMR groups. High- and medium-GMR groups engaged in more rich and complex CT processes in comparison with low-GMR groups. The distribution of each CT process in high-GMR groups was more balanced than in medium- and low-GMR groups, suggesting that GMR is helpful to involve students in critical discussion and deep learning. In this regard, this study provides empirical evidence of the effect of GMR on students' CT process.

The significantly positive correlation between GMR and CT provides instructional insight into fostering critical thinking in online collaborative learning. However, due to the limited sample size, the causal relationship could be revealed in this study. So, future studies could be conducted to form a causal model between GMR and CT.

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