Research Article

Received: 18 February 2023 / Accepted: 21 April 2023 / Published: 5 May 2023

Sequential Analysis of Online Scholarly Discussions of University Students using a Cognitive Subset of Critical Thinking

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DOI: https://doi.org/10.36941/jesr-2023-0053

Abstract

Following the COVID-19 pandemic, online technologies have been introduced to facilitate students' engagement in education. Online discussion has been used to provide them a communal learning environment. This investigation examined online scholarly discussions conducted by university students with a view to ascertaining how they demonstrated critical thinking (CT). Course participants were tasked with submitting research reports related to assignments to the Moodle discussion forum. These were subsequently shared with their student peers. After the ensuing discussions were recorded, the statements made by the students were coded using subskill indicators of CT. A code sequence analysis was subsequently conducted, with CT and altruism serving as dependent variables. In total, 121 students contributed 310 messages to the Moodle forum. In cases involving CT, lower-level skills were found to be predominant among the code sequences. In contrast, cases involving altruism displayed sequences that transitioned from higher to lower skills. When both dependent variables were active, the highest count of sequences was recorded for self-regulation skill, indicating higher-order cognitive skill activities. The students recognized their cognitive limitations, actively sought additional information, and re-evaluated the topic. This study establishes a novel analytical methodology for evaluating critical thinking skills.

Keywords: *Altruism, Critical thinking, Online learning, Sequential analysis*

1. Introduction

With the widespread dissemination of the internet and the advancement of information and communication technologies, online learning has emerged as a crucially important tool for higher education. In recent times, and especially during the COVID-19 pandemic, online learning has continued to expand and develop as a means of communication (Ayu, 2020). Online learning can emphasize student-centered learning and can provide an expanded learning environment beyond the classroom, thereby allowing students to drive the learning process with their proper choices for self-

regulated learning strategies and with emphasis on knowledge-sharing in the discussion forum (Zheng, 2016). Fundamentally, students have the freedom of choice to respond to messages and to post and view comments (Sivanandan et al., 2014). This online scholarly communication encourages students to share ideas and perspectives, thereby fostering participation in discussion and increasing their involvement in learning (Balaji & Chakrabarti, 2010). Moreover, online discussions have the potential to develop and enhance critical thinking (CT), a cognitive skill that earlier theorists have argued is the most important skill for online learning (Gilster, 1997). Actually, CT is structured by cognitive skills that encourage an informed, conscious, systematic, deliberate, and logical approach to decision-making, leading to arguments and conclusions that are valid, well-founded, and resistant to criticism. The effectiveness of CT extends to students' responsiveness to the information explosion in online learning (Onions, 2009). Additionally, students' altruism in communicating in online discussions is known to foster a learning community to develop CT (Hussin et al., 2019). When online messages incorporate expressions of gratitude, a heightened level of propensity exists for forming mutual connections among students (Yoshida, 2022a). Furthermore, students changed and increasingly expressed gratitude for being both benefactors and beneficiaries. They were able to cultivate their prosocial behavior. The primary aim of this study was to identify CT characteristics by analyzing messages posted in online discussion forums and by ascertaining the effects of altruistic behavior.

2. Methodological Framework

This study employs cognitive skills for CT provided by the Delphi research project, which has received financial support from the American Philosophical Association (Facione, 1990) (Table 1). These subskills were used in educational assessments to evaluate the core competencies of CT at the college level.

Table 1: Codes and Subskills involved in CT (Facione, 1990)

Code	Subskills for critical thinking
IT	Interpretation
A	Analysis
EL	Evaluation
IF	Inference
EX	Explanation
SR	Self-regulation

Note. Codes of the first column were used for analyses

As a remarkable characteristic of CT, self-regulation skill is placed as the final subskill. Research has indicated that students who can self-regulate their learning are more likely to seek help when needed, which is regarded as an important part of self-regulated learning (Martín-Arbós et al., 2021). This subset for CT was selected based on communal aspects of self-regulation skill and other skills. It has been deemed most appropriate to identify the process.

With respect to the influence on communication that arose from the online discussion, Hussin et al. (2019) demonstrated that interaction plays a crucially important role in online learning and that it can enhance CT with respect to knowledge sharing. Altruism, as an important factor in promoting trust within a community, is positively related to knowledge sharing (Chen et al., 2014). Figure 1 presents the criteria employed for this study.

Figure 1: Analytical criteria

This study explores effects of online academic discussions on the development of CT. The following research questions were put forth.

RQ1: Scrutinize the code sequences in which subskill codes manifest in online discussions and explicate the connotations of significant code sequences.

RQ2: Differentiate discussion threads using dissimilarities in code sequences.

RQ3: Determine the influence of communication on online discussions, with particular emphasis on the altruistic conduct of peers, which cultivates the acquisition of CT.

3. Method

The target course was implemented using an online approach reported earlier, which was online discussion activated by the submission of an academic report. It was aimed at promoting student discussion through the comparative analysis of indexed information that was made available online (Yoshida, 2022b).

3.1 Subject students and a course

A total of 121 first-year undergraduate students, enrolled in either engineering or nursing at a Japanese university, were recruited as participants. The target course was wholly managed online using the Moodle learning management system during the COVID-19 pandemic. Following an introductory lecture, students were assigned to one of four groups of assignments (Table 2), which asked them to compare the Sustainable Development Goal indicators. This process exposed students to a range of diverse perspectives and facilitated in-depth discussions of global issues (Yoshida, 2022c).

Table 2: Questions used for the assignment (translated by the authors)

Number	Assignment
1	Select one emerging country and evaluate the changes over time between GDP per capita and the unemployment rate. Investigate and explain some characteristics of the economic situation of that country.
2	Select one emerging country and evaluate the changes over time between GDP per capita and proportion of people below the national poverty line. Investigate and explain the characteristics of the economic situation of that country.
3	Select one emerging country with GDP per capita < GNI and evaluate the changes over time. Investigate and explain the characteristics of the economic situation of that country.
4	Select one emerging country with GDP per capita > GNI and evaluate the changes over time. Investigate and explain the characteristics of the economic situation of that country.

Note. GDP, Gross Domestic Product; GNI, Gross National Income

Figure 2 depicts the online learning process. After identifying an unexpected pattern between the indicators, students proceeded to acquire supplementary information pertaining to a specific country to address the answers which were submitted. Following this, they submitted a report to a Moodle forum designated for discussion, and accorded the opportunity to provide feedback about the submissions of their student peers.

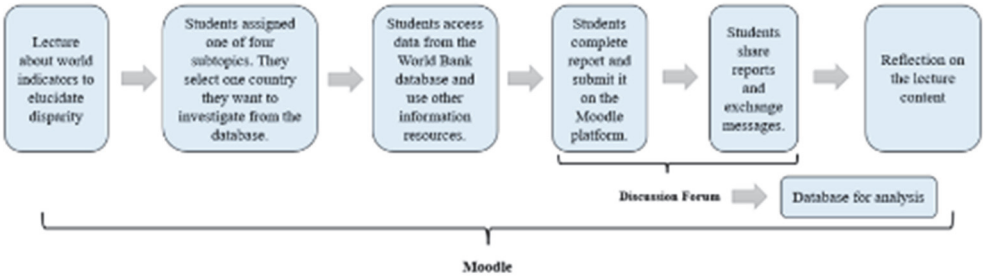

Figure 2: Course process flow

Datasets used for analysis comprised both the responses and comments. Subsequently, a process of data coding was applied to the data using a subset of cognitive skills.

3.2 Sequential analysis

In instances of overlapping codes, we have opted to select the dominant feature of the sentence which forms the encoding basis because the data to be encoded must comply with the rules of mutual exclusivity and exhaustiveness (ME&E) for continuous analysis. This compliance implies that, for every coded entity, one code from a sentence is applicable (exhaustive), although only one (mutually exclusive) code can be assigned.

The current study uses sequential analysis, a systemic observational method that is employed predominantly for qualitative data analysis. Specifically, sequential analysis based on two continuous codes is used to investigate whether a specific type of behavior triggers a rise or fall in the probability of another type of behavior within a specified number of coded behaviors or time units (Yoder & Tapp, 2004).

The transition probability differs from the underlying occurrence rate of an event in that a high transition probability does not necessarily imply a higher frequency of transitions than chance. To conduct statistical evaluation, Gottman et al. (1977) recommended use of the Z-statistic. This procedure entails calculation of the adjusted residuals (Z-scores) to identify sequences with significant differences, as shown in (1) (Bakeman & Quera, 2011):

$$Z_{rc} = \frac{x_{rc} - e_{rc}}{\sqrt{e_{rc}(1-b_c)(1-b_r)}}. \qquad (1)$$

In that equation, Z_{rc} represents the adjusted residuals, in which r represents the number of rows (*givens*), c denotes the number of columns (*targets*), x_{rc} is the observed joint frequency for cells in the r-th row and c-th column of an $r \times c$ table, and e_{rc} is the expected frequency, by chance $= b_{+c} \times X_{r+}$. In addition, b_c represents the probability for the c-th column $= X_{+c}/N$ and b_r is the probability for the r-th row $= X_{r+}/N$. Among them, X_{+c} represents the sum of the counts in the c-th column, X_{r+} represents the sum of the counts in the r-th row and $N = X_{++}$ represents the number of counts total for the $r \times c$ table.

The occurrence of behavioral continuity was found to be significant when a Z-score of 1.96 or higher ($p < .05$) was attained. These highly dominant sequences play a crucially important role in identifying meaningful and continuous behavioral patterns (Gottman et al., 1977). In other words, $p <$

.05 for adjusted residual probabilities denotes an association between two codes (Bakeman & Quera, 2011). The generalized sequential querier (GSEQ), which is a computer program used for general sequence analysis, is used frequently in the education sector to analyze interaction sequences. The results of statistical tests can be transformed into behavior-transfer diagrams (Bakeman & Quera, 2001). For our analysis, we applied GSEQ to detect subskill patterns associated with the dependent variables of CT and altruism.

4. Results and Discussion

In all, 310 messages that were deemed valid were identified within the dataset, with 189 of those messages specifically pertaining to comments and replies. Consequently, a total of 358 code sequence data of subskills for CT were introduced into analysis using GSEQ software. The analysis specifically examined whether the dependent variables CT and altruism were present in the thread. Table 3 presents a summary of the dataset.

Table 3: Summary of Code Analysis Quantities

			Altruism		
CT	Y	Sequence	62 (17)	20 (6)	82 (23)
		Thread	9 (7)	6 (5)	15 (12)
		Rate	6.9	3.3	5.4
	N	Sequence	61 (17)	215 (60)	276 (77)
		Thread	18 (15)	88 (73)	106 (88)
		Rate	3.4	2.4	2.6
	Total	Sequence	123 (34)	235 (66)	358 (100)
		Thread	27 (22)	94 (78)	121 (100)
		Rate	4.6	2.7	3.0

Notes. Upper, numbers of code sequences in a dataset (percentages in parentheses); Middle, numbers of threads in a dataset (percentages in parentheses); Lower, numbers of code sequences per thread.

In that table, upper rows provide a summary of the subskill code sequence quantities present, which are categorized based on the two dependent variables of CT and altruism. Middle rows exhibit a summary of thread quantities featured in the dataset. By combining these findings, lower rows manifest a compendium of code sequence quantities per thread. Whereas CT constituted 23% of all code sequences (in upper cells), related threads encompassed a lesser proportion (12%) of the entire threads (in middle cells). The results are explainable by the lower rows. Emergence of active students' cognitive skills was observed in the learning environments with both CT and altruism. As described in the following sections, sequences of codes from four cases were analyzed based on differences in the dependent variables.

4.1 Code sequence analysis of threads with no CT and no Altruism

In Table 4, the rows denote the scores of previous codes, whereas the columns signify the subsequent codes. This case had the highest count of sequences among the four analyzed cases, and occupied 60% of all code sequences and 73% of all threads. Figure 3 displays the result of the sequential analysis of the data, revealing five sets of sequences and one self-loop of skills. Sequences to A (count 107) displayed 50% and sequences to the IF (count 77) occupied 36% of all sequences. Sequences to both codes made up most sequences in this case. Apparently, the distribution of their subskills is non-uniform and skewed toward lower skill levels, particularly for situations in which neither CT nor altruism is involved.

Table 4: Counts of code sequences and Z-scores (in parentheses) of threads with no CT and no altruism

	IT	A	EL	IF	EX	SR
IT	2 (-1.07)	65 (8.6*)	0 (-2.39)	3 (-6.78)	1 (-0.34)	0 (-1.59)
A	6 (1.01)	7 (-9.97)	4 (-0.25)	67 (10.51*)	1 (-0.62)	1 (-0.92)
EL	0 (-1.53)	22 (1.49)	6 (3.45*)	6 (-2.63)	0 (-0.91)	2 (1.41)
IF	2 (1.61)	10 (1.68)	0 (-0.9)	0 (-2.89)	1 (1.51)	1 (1.24)
EX	1 (1.3)	2 (-0.82)	1 (1.3)	1 (-0.99)	0 (-0.34)	1 (2.36*)
SR	0 (-0.33)	1 (0.01)	0 (-0.33)	0 (-1.06)	1 (5.06*)	0 (-0.22)
Totals	11	107	11	77	4	5

* $p < .05$

Note. IT, Interpretation; A, Analysis; EL, Evaluation; IF, Inference; EX, Explanation; SR, Self-regulation

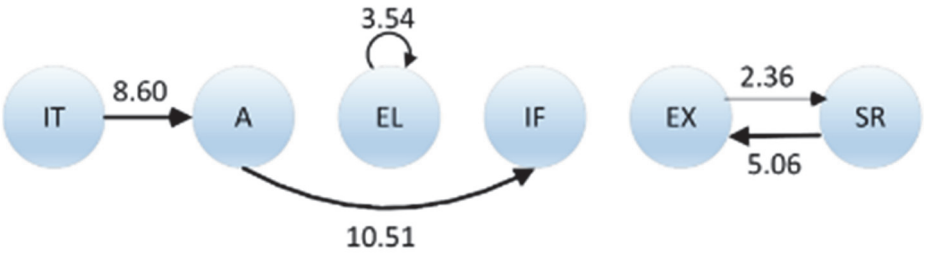

Figure 3: Significant code sequences of threads with no CT and no altruism.

Three important sequences illustrate the progression of skills to higher levels: IT→A, A→IF, and EX→SR. Of those, IT→A denotes an improvement in the transformation of skills, as students engaged in a discussion based on the information they had shared. The A→IF sequence reached its maximum in this case, indicating that students used information to articulate their opinions with inferences. The self-referential loop of EL demonstrates the emergence of recurrent evaluation activities and elucidates situations in which problem-solving was challenging. A chasm in subskills exists between lower-level and higher-level skills, as presented in Figure 3. The following recording of messages from students is an example of the dominant code sequence: A→IF.

> *Message from S117, 27 April 2021*
> *Since the 1980s, India has implemented economic liberalization policies. In the 1990s, drastic economic system reform and liberalization began. As a result, labor productivity improved. The economic growth rate increased. It continues to grow and is expected to continue growing in the future.*
> *I can give you some examples, such as rising unemployment since 2000. In addition to the continuous increase in the employed population every year, the reason is that the industry is shifting from the conventional primary industry to the secondary and tertiary industries. Job skills do not match.*
> *In addition to the IT service industry, finance, communications, commerce, medical care, and transportation are expanding rapidly. This trend is expected to continue in the future. However, the employment situation is expected to continue to be difficult because the corona virus has restricted many economic activities and has led to a larger number of unemployed people.*

Note. A, analytical skill (sky blue); IF, inference skill (gray). The original messages were written in Japanese and were translated by the authors.

The sequences of both EX→SR and SR→EX appeared once as a reciprocal message exchange. Although engaging in online discussions with peers can aid in refining self-regulated learning skills through feedback and support (Barnard-Brak et al., 2010), unfortunately, a student failed to attain CT

despite great efforts. Considering the inertness of both CT and altruism, it appears that the nature of messages apparently shows remarkable sway. Two directions were discerned in the messages: comments on the content and impressions of the discussion. However, most of the comments expressed agreement, which made it simple to deduce the discussion. It also hindered continuation of the discussion. This trend was also evident from earlier research. Results show that when the online discussion concluded with an agreement, it was not easy to advance further discussion (Zhang et al., 2017).

4.2 Code sequence analysis of threads with CT and no Altruism

Table 5 presents the outcome obtained in this case. The result presented an analysis that concentrated on threads with CT and no altruism. In all, 20 sequences (6% of all sequences) were observed. They accounted for the lowest number of threads (count 6) among the four cases. An absence of explanation skill was found in summative behavior and interpretation skill for information-based behavior, but the learning community was facilitated by the inquiry activity of students in this case.

Table 5: Counts of code sequences and Z-scores (in parentheses) of threads with CT and no altruism

	IT	A	EL	IF	EX	SR
IT	0 (0)	6 (1.78)	0 (-0.54)	0 (-1.45)	0 (0)	0 (-1.48)
A	0 (0)	0 (0)	1 (0.37)	6 (1.57)	0 (0)	2 (-1.72)
EL	0 (0)	0 (-2.21)	0 (0)	0 (-1.13)	0 (0)	4 (5.06*)
IF	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
EX	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
SR	0 (0)	1 (0.37)	0 (-0.21)	0 (-0.56)	0 (0)	0 (0)
Totals	0	7	1	6	0	6

* $p < .05$

Notes. IT, Interpretation; A, Analysis; EL, Evaluation; IF, Inference; EX, Explanation; SR, Self-regulation

Based on Figure 4, the code transitions on threads are characterized by a singular significant sequence: EL→SR. The count for such cases amounts to merely four. Actually, EL→SR refers to received evaluation that led to individual deep understanding. Furthermore, our result highlights this sequence, in which a student can jump to a conclusion without a sequential cognitive process, which also occurred in an earlier study (Hou et al., 2008).

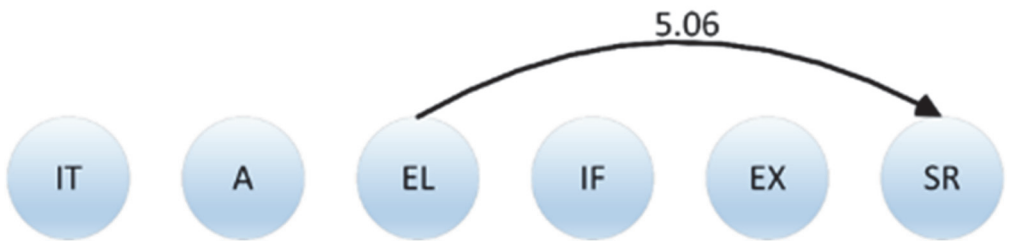

Figure 4: Significant code sequences of threads with CT and no altruism.

One conclusion that can be drawn from this observation is that no predetermined trajectory for CT has been identified.

4.2 Code sequence analysis of threads with no CT and with Altruism

Table 6 presents the outcome of this case. The results indicate that the number of messages in a thread observed was only half that of the case in which both CT and altruism were present. Additionally, the target skills which are counted in sequences are not evenly emergent when juxtaposed with the assortment of variety of subskills. Nonetheless, this case exemplifies that all significant transitions engender an elevated tier of subskills and that they appear to yield beneficial outcomes in terms of altruism.

Table 6: Counts of code sequences and Z-scores (in parentheses) of threads with no CT and with Altruism

	IT	A	EL	IF	EX	SR
IT	0 (-0.63)	16 (4.7*)	0 (-1.29)	1 (-3.33)	0 (-0.63)	0 (-1.1)
A	1 (0.96)	4 (-5.5)	4 (1.97*)	20 (3.89*)	1 (0.96)	2 (0.51)
EL	0 (-0.33)	4 (1.07)	0 (-0.68)	2 (-0.32)	0 (-0.33)	0 (-0.59)
IF	0 (-0.19)	2 (1.56)	0 (-0.38)	0 (-1.16)	0 (-0.19)	0 (-0.33)
EX	0 (-0.13)	0 (-0.93)	0 (-0.27)	0 (-0.81)	0 (-0.13)	1 (4.43*)
SR	0 (-0.23)	2 (0.74)	0 (-0.47)	1 (-0.22)	0 (-0.23)	0 (-0.4)
Totals	1	28	4	24	1	3

* $p < .05$

Notes. IT, Interpretation; A, Analysis; EL, Evaluation; IF, Inference; EX, Explanation; SR, Self-regulation

Figure 5: Significant code sequences of threads with no CT and with Altruism.

The observed patterns of significant sequences (Fig. 5) exhibit similarity with the cases of both no CT and no altruism. It is noteworthy that a particular sequence of A→IF also manifests the highest count in this context. Furthermore, the sequence EX→SR is identified as a significant sequence, albeit with only one count. The chasm of subskills between lower and higher levels of expertise remains evident. Results suggest that a lack of successful integration of recognition exists in higher level skills. Results indicate that the sequences in the thread were fewer than in the case which demonstrated both CT and altruism (lower rows in Table 3). Conversely, a noteworthy phenomenon observed is the absence of a significant sequence from higher to lower skill levels. That lack of sequence might be attributable to the students' lack of motivation to question their own understanding.

4.3 Code sequence analysis of threads with both CT and Altruism

Table 7 presents the outcome of this case. The prominent characteristic of this case involves the reverse transitions from higher to lower skill levels (Fig. 6).

Table 7: Counts of code sequences and Z-scores (in parentheses) of threads with both CT and Altruism

	IT	A	EL	IF	EX	SR
IT	0 (-0.42)	7 (3.01*)	0 (-1.16)	1 (-0.56)	1 (1.45)	0 (-2.24)
A	1 (1.31)	1 (-3.77)	3 (0.33)	7 (2.01*)	1 (0.38)	10 (1.45)
EL	0 (-0.64)	9 (1.72)	1 (-0.91)	1 (-1.61)	0 (-0.92)	7 (0.71)
IF	0 (-0.18)	1 (0.49)	0 (-0.51)	0 (-0.67)	0 (-0.26)	1 (0.55)
EX	0 (-0.18)	0 (-1.03)	0 (-0.51)	2 (3.1*)	0 (-0.26)	0 (-0.99)
SR	0 (-0.39)	3 (0.23)	3 (2.51*)	0 (-1.41)	0 (-0.55)	2 (-0.47)
Totals	1	21	7	11	2	20

* $p < .05$

Notes. IT, Interpretation; A, Analysis; EL, Evaluation; IF, Inference; EX, Explanation; SR, Self-regulation

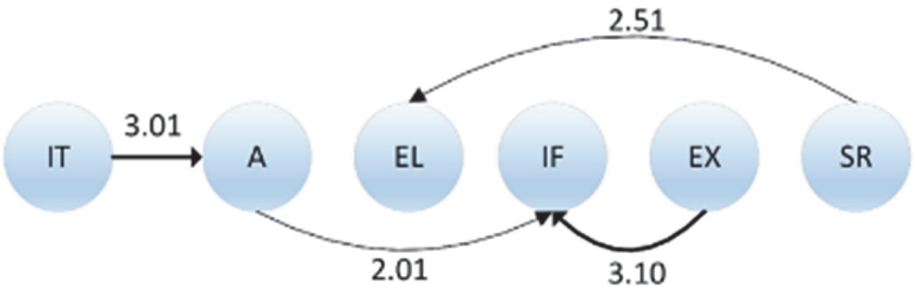

Figure 6: Significant code sequences of threads with both CT and Altruism.

It is noteworthy that the learning environment exhibited significant reverse sequence patterns of SR→EL and EX→IF, and that it appeared infrequently (a total of 5). Results show that SR→EL is endemic to the communal environment in which students expressed their own recognition to others. EX→IF refers to extended learning derived from information provided underlying by peers to deepen information recognition. Earlier studies have elucidated the reasons behind a student's presentation of a conclusion during the discussion. This might be attributed to their underlying strategy to achieve deeper insights or novel perspectives in various dimensions (Hou et al., 2008). In other words, proactive participants were more prone to employing thorough and reflective strategies when evaluating and comparing ideas or arguments and modifying their cognitive models (Lucas et al., 2014). The following is an example of this reverse transition.

> *Message from S90, 26 April 2021*
> *"I saw S5's post. I researched Egypt, which is said to be the following country to achieve economic development after the BRICs. Seeing that S5 predicted the country's future trends from the population pyramid's shape, I also investigated the Egyptian population pyramid. It certainly matches the background of a country with a large labor force, and I realized that the population pyramid is closely related to the country's economic situation and future trends."*

Notes. SR, self-regulation skill (yellow); EL, Evaluation skill (green). The original messages were written in Japanese and were translated by the authors.

The significant occurrence of sequences to SR, numbering 20 in all, warrant attention because the sequences constitute 32% of the observed sequences in this case. Although the A→SR sequence is not a significant sequence, it is noteworthy that it garnered the highest frequency count of ten among all other sequences transforming to SR. As such, the students had attained a satisfactory level of

recognition of the subject matter under discussion, particularly in instances where the discussion was of a straightforward nature. The sequences IT→A and A→IF were observed to be the predominant sequences not only in this case but also in other cases. Nonetheless, the sequences established interconnections among all the sub-skills in this case, which suggests the emergence of dynamic cognitive activity.

As a synthesis of all the cases examined, it was observed in the case where neither CT nor altruism was present (section 4.1) that there were reverse sequences of skills toward A, such as EL→A (count 22) and IF→A (count 10). This finding suggests that students had some difficulty demonstrating their higher-level skills. Conversely, in the case where CT was present but altruism was not (section 4.2), there was a scarcity of reverse transitions. However, in the cases where altruism was present (sections 4.3 and 4.4), a diverse range of significant sequences was identified, which is also evidenced by comparison to the cases presented in section 4.2. When CT could not be achieved (section 4.3) in the threads, the sequences were generally completed with A or IF. In contrast, when CT was achieved (section 4.4), not only did the number of sequences that could reach SR increase; reverse sequences also occurred, as did instances of rethinking processes for deeper inquiry. The findings pertaining to the primary research questions are presented succinctly below.

RQ1: Scrutinize the code sequences in which subskill codes manifest in online discussions and explicate the connotations of significant code sequences.

The significant sequences of subskills accounted for the effect on the two dependent variables in the online discussion environment. In the case involving CT, sequences among lower-level skills were predominant among the sequences. Conversely, in cases involving active altruism, significant sequences between skills were increased. Threads involving active CT but no altruism were few. When both dependent variables were active, the highest count of sequences was recorded for SR, indicating a higher order of cognitive skill activities. Additionally, sequences between codes leading from higher to lower appeared. The students were aware of their cognitive limitations, actively sought additional information, and re-evaluated the topic.

RQ2: Differentiate discussion threads using dissimilarities in code sequences.

Our research findings are applicable to identify discussion threads in which both CT and altruism are operational. The presence of these dependent variables results in a rise in the number of code sequences and patterns associated with the thread, which in turn facilitates knowledge exchange. Moreover, an increase in sequences pertaining to higher skill levels was observed under the active conditions of both independent variables. It is worth noting that the inclusion of CT and altruism in online discussions can aid in achieving a code of profound comprehension, commonly known as SR. However, the effect is not so strong. The number of codes in the thread remains low. Nevertheless, we were able to use this method sufficiently to evaluate the characteristics of the threads.

RQ3: Determine the influence of communication on online discussions, with particular emphasis on the altruistic conduct of peers, which cultivates the acquisition of CT.

Altruistic behavior was manifested effectively in the learning process of students, as evidenced by the significant sequences which emerged when they engaged in scholarly discussions through online threads. Lower-order cognitive subskills were used for focusing, explaining, and inferring the subject issues that were being discussed. Altruistic tendencies have the capacity to extend the domain of communication. Furthermore, altruism enhanced skill sequences of the reverse direction, in which a student can reconsider their recognition because of the influence of a peer. This process is analogous to the process of double-loop learning (Argyris, 1976).

5. Conclusion

This study delineated the distinctive features and implications of disparate sequences via the identification of cogitative subskills associated with CT during online scholarly discussions. Online

learning endows students with copious amounts of knowledge and information as well as a generous amount of time to think. As students demonstrate greater commitment to their respective fields of study and adopt altruistic ways of communication, diverse skills are stimulated, leading them to process information based on communal learning. In other words, students themselves influence the succession of skills, and accordingly, influence critical thinking via the exchange of information. Altruism influences the maturation of CT through its effects on communication. Furthermore, this research establishes a novel analytical methodology for the evaluation of CT skills.

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