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Multimodal analysis of learners' communications in CSCL of a mathematical proof

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Abstract: In this study, we explore the CSCL of a mathematical proof using HTML-based dynamic geometry content. In addition to the learners' transcribed communication, multimodal log data of their manipulations of the content and utterances are analyzed. First, we use multimodal data to segment the whole learning process into stages and identify the characteristics of those stages. This segmentation is then aligned with the transcribed communication. Our finding is that the participants' choice of words varies according to each stage and is compatible with the characteristics derived from multimodal data. Resultingly, when and how the convergent conceptual change occurred is inferred from the commognitive perspective.

Keywords: Mathematical proof, dynamic geometry, log data of manipulations, log data of utterances, text mining of annotated dialogue

1. Introduction

While mathematicians construct proofs as part of their professional work, students also construct them in mathematics classes. In both situations, some scientific discovery is involved and the convergent conceptual change leading to it is often investigated through ethnomethodological studies (Garfinkel, 2002). One puzzle related to the investigation of scientific discovery lies in how is it that we can talk about the matter being discovered while still engaged in the work of discovering it (Koschmann, & Zemel, 2009). Moreover, especially in the case of the activities in classroom, the account of the discovery tends to become highly complex due to the learners' lack of domain-specific knowledge and related vocabulary. In their previous work (Kaneko, Egi, & Noda, 2022), the authors investigated learners' collaborative activity of proving the addition theorem for trigonometric function while manipulating HTML-based content generated using the dynamic geometry system CindyJS (https://cindyjs.org/). For that investigation, a Moodle plug-in of CindyJS was used to store the log data of learners' manipulations (Kaneko, Nakahara, & Noda, 2020). Moreover, the conversation analysis system Diana-AD was also used to record learners' utterances and measure the loudness of their voices (Ishikawa, Okazawa, & Egi, 2019). One of the main findings was that high-resolution multimodal log data derived from them could serve as well-grounded material for inferring where to "locate a proposal for a possible discovery" in the whole learning process (Koschmann, & Zemel, 2009). Based on that finding, in this study, we explore another group's learning in a similar setting and discuss how to align the multimodal log data with the transcribed communication. In the case of this proof activity, learners can be assumed to experience some commognitive conflict while generalizing their prior knowledge to newly emerging situations. Their participation in some discursive processes (metadiscourse) to handle the relevant commognitive conflict can lead to the reification of those processes through which increasingly sophisticated approximations to the targeted concept are constructed (Sfard, 2009). Since this reification can be assumed to

cause some change in the pattern of both manipulation and discourse, we first segment the whole learning process according to the change in their manipulating pattern and the power balance between each participant's utterances. Then, we examine the difference in each participant's choices of words and their associated meanings among the segmented parts.

2. Research Methods and Results

Figure 1 (left) shows the content used in which the angles α(red) and β(green) can be moved. Two first-grade female students with a pharmaceutical science major in a Japanese university were asked to manipulate the content collaboratively on an iPad. Beforehand, they were asked to fill in the worksheet in Figure 1 (center and right) to prove the theorem for the rudimentary case where $\alpha + \beta$ was acute. The time they needed to do that was measured and one participant (A) was assumed to have higher prior skill than the other (B).

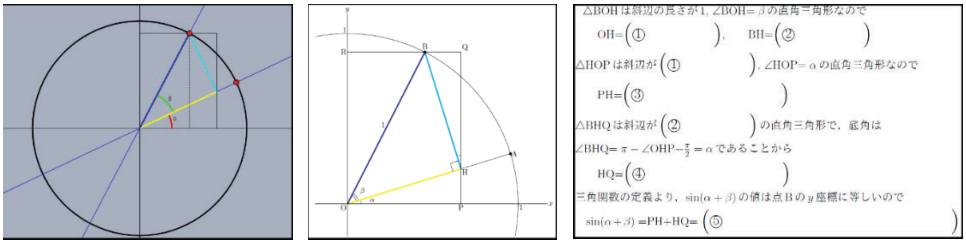

Figure 1. The CindyJS content (left) and the worksheet (right) including the figure (center)

While Figure 2 (left) shows the fluctuations of the three angles α(blue), β(orange), and $\alpha + \beta$(grey), the yellow curve in Figure 2 (right) shows the power balance of utterance between A (lower domain) and B (upper domain). It can be seen from the left figure that, during 2:30-13:00, almost no manipulation was made. In fact, a videotaped image of the participants' activities tells us that almost all of their motions were pointing to the figures in both worksheet and iPad during this time interval. Thus, we divide the whole process into three stages, Stage I (0min00sec - 2min30sec), Stage II (2min30sec – 13min00sec), and Stage III (13min00sec – 17min00sec).

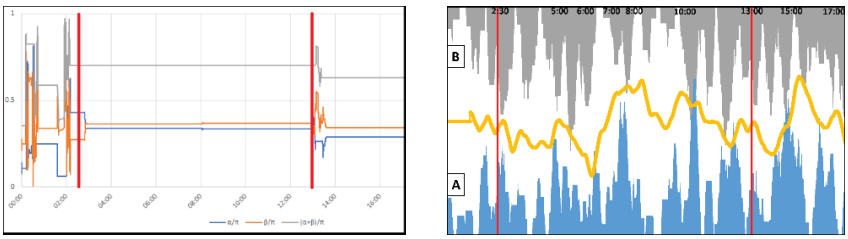

Figure 2. The fluctuation of angles (left) and the power balance of utterance (right)

Aligning these results with the transcribed communication, it can be seen that A played the leading role in the search for a probable positional relationship between angles while manipulating the content at Stage I. Then, at Stage II, B gradually increased her presence while comparing the situation they encountered with the rudimentary case on the worksheet. At this stage, A became dominant only once between 6min00sec and 8min00sec when A presented some assumptions. Finally, at Stage III, A again became dominant when she claimed the orthogonality of ∠BHO, which is one of the key points.

To examine the participants' choice of words, the author used the text mining software KHCoder (https://khcoder.net) which is specialized for the Japanese language. Some previous studies pointed out that a seemingly vague pronoun, which does not refer to any prior antecedent but is a prospective indexical, might leave room for later elaboration leading to a new understanding (Koschmann, & Zemel, 2009). Therefore, we calculated the frequency of the use of demonstrative pronouns (DP) and common nouns (CN) for each participant and stage. Figure 3 visualizes the resulting cross table in which the sizes of the

rectangles represent the incidence of sentences including DP (upper row) and CN (bottom row) among all ones in each category. As is seen, while B used DP throughout the whole process, A gradually replaced the use of DP with the use of CN.

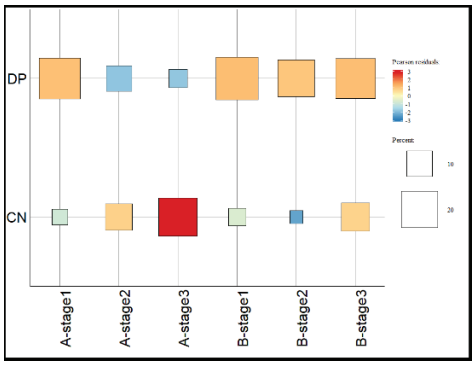

Figure 3. Visualization of each participant's choice of words

3. Discussion and Future Works

While most of the DP referred to some specific antecedents, there do exist some DP without any clear referent. For instance, after B said cautiously at 14min44sec, "The length of OH is, let me see, $cos\ \beta$? I am not sure, but *it* will be the same," A responded at 15min03sec, "Anyway, our task should be to check whether *that* still holds or not when the angles are changed." It can be judged from the context that the pronoun "that" in this utterance of A was used not to refer to some specific fact but to propose the possibility of literally imitating the descriptions in the rudimentary case. Thus, this pronoun use clearly indicates that the preceding discourse had been reified into some newly proposed "discovery".

Because of the limited number of cases examined, the findings in this study cannot be generalized to other cases directly. In fact, in another case study where the prior skill of the participants was fairly higher than that in this study, the utterances and manipulations of one participant were almost always dominant and the other participant only listened to her partner, occasionally throwing in an appropriate word or two. Therefore, many more cases should be explored to search for the possible communication patterns in this proof activity. Moreover, some situations in which "actions speak louder than words" were observed. The fine-grained log data of learners' gestures should be synchronized and analyzed.

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