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Case-based Portraits of Contrasting Micro-Interaction Processes During Online Assessment of Collaborative Problem Solving

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Abstract: This study recognizes the role and the quality of social aspects in collaborative problem solving (CPS) processes and outcomes. The aim of this study, relying on multiple data and phases of analysis, is to explore and visualise, through contrasting case-based portraits, how micro-interaction processes at pair level evolve during CPS assessments in an online environment. The assessment is designed for a student pair in the STEM domain. The results show that in despite students' similar CPS performance scores, variations in micro-interactions occurred across pairs. It is expected that studying these patterns at pair level may provide new insights into CPS processes and so to support acquiring these skills.

Keywords: case-studies, collaborative problem solving, computer-supported collaborative learning, directed content analysis, peer interaction, social aspects of learning and teaching, qualitative research

1. Background of the Study

Collaborative problem solving (hereafter CPS) combining critical thinking, problem solving, communication and collaboration (Care, Scoular and Griffin, 2016; Griffin and Care, 2015) has received increasing interest as a 21st century skill suitable for formative assessment (e.g. ATC21STM, www.atc21s.org; OECD's PISA 2015, <http://www.oecd.org/pisa/>). However, the assessment practices for complex 21st century skills, such as collaboration and CPS have remained relatively vague (Strijbos, 2011; Vista, Care and Awwal, 2017). The tools or approaches used do not always reflect collaborative learning in a way that takes into account the complexity of cognitive, social and motivational factors as they occur over the collaborative process (Kumar, Gress, Hadwin and Winne, 2010). In addition, a general set of indicators with which to assess the quality of collaborative activities, or upon which to compare students' collaborative learning activities, have been lacking (Strijbos, 2011).

Our theoretical understanding of CPS builds on the Assessment and Teaching of 21st century project and its extensive theoretical framework for technology-enhanced formative assessment of CPS skills (ATC21S; Hesse, Care, Buder, Sassenberg and Griffin, 2015; Scoular, Care and Hesse, 2017). In this study, CPS refers to a shared activity in dyads or in small groups to transform a problem state into a desired goal state (Hesse et al., 2015). CPS competency can be defined as a set of sub-skills, which consists of five strands of individual and group level capacities under the broad skill classes of social and cognitive skills (Hesse et al., 2015). Following Hesse and colleagues (2015), social skills (i.e. participation, perspective taking, social regulation) are about managing participants (including oneself), referring to the "collaborative" part of collaborative problem solving. Cognitive skills (i.e. task regulation, knowledge building) are about managing the task, referring to the "problem solving" part of collaborative problem solving. "Participation" refers to the readiness to share information and externalize thoughts, "perspective taking" means the ability to take into account the others' perspectives and, "social regulation" points to the awareness of the strengths and the weaknesses of the group members (i.e. group/team awareness, see Franssen, Kirschner and Erkens, 2011). "Task regulation" is defined as planning and monitoring skills for developing strategies for problem solving and shared

problem representation (i.e. “Joint problem space”, see Barron, 2003; Roschelle and Teasley, 1995) whereas “knowledge building” here refers to the ability to learn and build knowledge through group interaction. In high-quality CPS activity, social and cognitive skills are inherent, may overlap, and are implemented in accordance with situational needs (Hesse et al., 2015). The way in which the participants are able to manage these intermingling aspects of CPS is seen as critical to high quality CPS (e.g. Barron, 2003).

Even though collaboration and CPS are regarded as crucial skills for future learning and are already a part of today’s learning environments, much research on CPS skills in online environments has focused on problem solution by the individual. As described earlier, one part of CPS is the task and the other part is the infrastructure within which the participants create and share knowledge, monitor their progress, and detect and repair the breakdowns in communicative acts that may hamper the involvement of collaboration (Alterman and Harsch, 2017; Roschelle and Teasley, 1995). This paper concentrates on the latter part of CPS. The process of constructing and maintaining shared understanding of the task at hand is at the core for collaborative learning to evolve (Roschelle and Teasley, 1995; Dillenbourg, Lemaignan, Sangin, Nova and Molinari, 2016). But compared with co-located collaboration, in an online setting the creation of shared understanding requires additional effort from the participants (Dillenbourg et al., 2016), since to regulate interaction and achieve agreement is much more complex (Alterman and Harsch, 2017). In this regard, there may be pressure to achieve joint goals with reduced amounts of sharing (Alterman and Harsch, 2017).

This study recognises the substantial role of social aspects in CPS (e.g. Barron, 2003; Wegerif, Fujita, Doney, Perez Linares, Richards and van Rhyn, 2017). In technology-enhanced assessment environments, current technologies are typically inadequate to the task of automatically analysing the content of online communication. In this study, we move beyond individual skill level to interpersonal processes with focus on the content and the episodes of interaction of collaborating dyads as they participate in CPS assessment processes. The specific aim of this paper is to explore and visualise how micro-interaction processes (Davis, Horn, Block, Phillips, Evans, Diamond and Shen, 2015) in dyads evolve during online formative assessment; especially focusing on the group relational aspects of CPS. It is assumed that in spite of similarity in students’ CPS performance scores, variations in micro-interaction processes may occur across pairs. Studying these patterns may provide insights into CPS and enhance understanding about how to better support acquisition of these skills.

2. Methods

2.1 Participants and Tasks

The research participants ($n = 20$) were students enrolled in a master level teacher education program at a Finnish university. Students were randomly assigned to their pairs. In the study, student pairs completed one bundle of assessment tasks in an online assessment environment, developed during the ATC21S project. In the project, an online environment for formative assessment of CPS skills, based on the aforementioned CPS skills (Hesse et al., 2015) was developed at the Assessment Research Centre at the University of Melbourne. Its primary goal was to maximise the developmental progression of individuals’ skills, such as those in CPS. The environment is based on human-to-human approaches to assessing CPS (Care, Griffin, Scoular, Awwal and Zoanetti, 2015) and comprises a set of online interactive and collaborative problem solving tasks in STEM domains. In the tasks, student pairs are given a unique subset of resources required to solve the problem. To fully understand the problem space and to identify all the necessary resources, students need to rely on their partner (Care et al., 2015; Care, Scoular, & Griffin, 2016). The communication takes place via free form chat interface.

The assessment bundle used in this study comprised four tasks, lasting approximately 60-90 minutes. During the tasks, student pairs (Students A and B) were seated in different classrooms to ensure that the only means of communication was the chat interface. In this study, the bundle comprised following tasks (see Care et al., 2015): “Laughing Clowns” and “Olive Oil”, which are content-free tasks, and “Plant growth” and “Small pyramids”, which are content-dependent. Laughing Clowns, which is the focus of this paper, is a symmetric task whereas the other three are designed asymmetric. Symmetric refers to the characteristic that both students within a collaborative pair are presented with

the same stimulus content and actionable artefacts within the online task space; asymmetric referring to the characteristic that each student within a pair is presented with different information and different actionable artefacts.

In laughing Clowns, two participants are presented with a clown machine and 12 balls to be shared with them. The goal for the students is to determine whether their clown machines work in the same way. In order to do this, the two students need to share information and discuss the rules as well as negotiate how many balls they should each use. The students must place the balls into the clown's mouth while it is moving in order to determine the rule governing the direction the balls will go (Entry: Left, Middle, Right, and Exit = position 1, 2, 3). Each student must then indicate whether or not they believe the two machines work in the same way. Students do not have access to each other's screen.

2.2 Data Collection

2.2.1 Objective Measures and Process Data: Auto-Scoring, Activity Logs and Screen Recordings

Students' work in the assessment environment was assessed individually, with the scoring based on their actions which included movement of artefacts, and the occurrence of chat to collaborate. Students' completion of the assessment tasks generated log file data (i.e. activity log) and the patterns in these data were automatically coded by the scoring engine according to the Rasch model as indicators of CPS elements, producing information on students' social and cognitive skill levels (Adams, Vista, Scoular, Awwal, Griffin and Care, 2015). The activity log shows the events between two students working on the task. For example, Table 1 displays the task and player IDs (Task 23, Student A or B), the page of the task (here page 1), actions (e.g. the event type), the contents of the chat (text exchanged), and their timestamps.

Table 1. A section from an activity log of a student pair (task Laughing Clowns) (Note: Translated from Finnish).

Task	Page	Player	Event type	Contents	Timestamps
23	1	A	Chat	Do you have any clue what we're supposed to do here?	06/10/2015 16.45
23	1	B	Chat	I don't know I'm thinking :D	06/10/2015 16.45
23	1	A	Chat	Yeah, would you throw first?	06/10/2015 16.45
23	1	B	Chat	Let's throw a ball and see what happens	06/10/2015 16.45
23	1	B	Action	startDrag:ball1:70:150	06/10/2015 16.45
23	1	B	Action	stopDrag:ball1:70:150	06/10/2015 16.45
23	1	B	Action	startDrag:ball1:70:150	06/10/2015 16.45
23	1	B	Action	stopDrag:ball1:509:135	06/10/2015 16.45
23	1	B	Action	dropShuteL:ball1:509:135	06/10/2015 16.45
23	1	B	Chat	Where did it come out for you	06/10/2015 16.46

In addition, CamStudio™ software (see <http://camstudio.org>) was used for the recording of all the screen activity during the CPS sessions. In the beginning of the session, students were informed of the recording intention and were given detailed instructions how to start recording their portal session and how to save their data. During the portal session, the students were also requested to check whether the program was running accurately.

2.2.2 Subjective Measures: Cued Retrospective Reporting

To obtain subjective measures on the CPS processes, the process-tracing method as cued retrospective reporting (CRR) (e.g. van Gog, Paas, van Merriënboer and Witte, 2005) was used, as applied in problem-solving tasks. CRR is defined as a verbal reporting procedure, in which participants are invited to verbalise their thought processes during the task performance retrospectively, based on a cue or cues of their performance (van Gog et al., 2005). In this study, through verbal reporting the aim was to make

explicit the CPS process in terms of students' self-monitoring of why and how they took the actions, especially as a student pair. In this study, the CRR interview was cued with the screen activity data, including the mouse operations and chat discussions recorded during the assessment session (for an example of a screen capture, see Figure 1). The CRR sessions were videotaped. During the interview, the video camera was directed towards the computer screen (showing the screen capture video recorded during the CPS session) in order to capture the exact point of time discussed. These were also marked down in the transcriptions of the interviews.

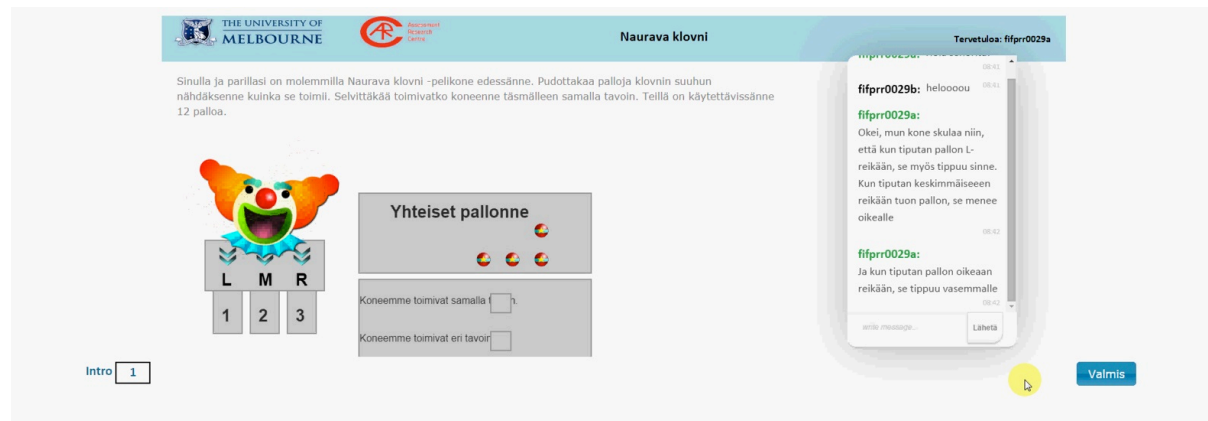


Figure 1. A screen capture from the activity data used as a cue in the CRR sessions (Student A's perspective, Laughing Clowns).

Table 2. Examples of verbal reports of a student pair acquired in cued retrospective reporting (Student A and B, Laughing Clowns) (Note: Translated from Finnish).

Student A	Student B
<p>Task 1 Laughing Clowns</p> <p>[...] Well hmm, here, in this exercise I realised at once what it is all about. Uh, maybe I was a bit hasty in the sense that I didn't fully read this task instruction, that we have some balls in common, but I sort of realised how my computer was functioning. Like one can see it from this, I realised at once what the task is. And then I just tried it out a few times how the thing was functioning and reported [gives a laugh] right away. I don't know whether one could have like [a short laugh] built some cooperation there so that one would first have told the instruction in the way one understood it. But, on the other hand as I knew who my partner was, I know that [the partner] too is really smart and good at these, so... and then, I just (thought) that she's likely to get it from there quite quickly as well. [...]</p>	<p>Task 1 Laughing Clowns</p> <p>[...] Well my partner (didn't realise perhaps) that I had checked it. Then at one point I still tested and then I wrote down where they go, so that if I drop there from L [Left]. And then I tried to test the same ones [to see] if it goes always in the same way. But then at some point when my partner's messages appeared there so then I tried with those, and then did it at the same time, and then I wrote it down like that [as letters and numbers in chat] so that where they go from those. Because if I just had looked how they go (--) if I drop from L [Left] for instance, so that it will go to number one, so I would not necessarily have remembered it then. And then I wrote it there already, (--), like it will probably go. [...]</p>

2.3 Data Analysis

To better understand how CPS processes unfold at pair level as micro-interactions (Davis et al., 2015), an analysis technique triangulation was used (Humble, 2009; Meadows and Morse, 2001). The analysis relied on the CPS performance measures, obtained from the assessment environment, combined with directed content analysis on the process tracing data (Pöysä-Tarhonen, Care, Awwal, Häkkinen and Ahonen, 2016). Grounded on these results, for this paper two qualitative case-based portraits were chosen and were visualized using activity logs from the assessment environment, notated with the coded CRR data.

2.3.1 Autoscoring of CPS Skill Levels

The assessment environment automatically codes activity logs for individual student performance measures as social and cognitive skills (skill levels between 1-6, see Adams et al., 2015). These data were used for acquiring a general overview of the CPS skill levels of the participating students. At this point, four pairs (eight students) were chosen for further analysis, based on equal technical quality and availability of all the data (including activity logs from the assessment environment, screen recordings, CRR data).

2.3.2 Directed Content Analysis

CRR interviews resulted in qualitative accounts as retrospective reports concerning the social and cognitive aspects of CPS processes from the perspective of an individual student (see Table 2). Directed content analysis that includes the application of conceptual categories to a new context (Hsieh and Shannon, 2005; Humble, 2009) was applied to the transcribed CRR data. The categorization matrix applied the same behavioural indicators of CPS elements as defined by Hesse and others (2015), used in the automated coding procedures in the assessment environment (Adams et al., 2015). In the analysis, the unit of analysis was an episode or passage; a minimum unit, where a certain criterion of the pre-determined category of a particular CPS element was observed. In Table 3 the categorization matrix of Laughing Clowns is presented (see Care et al., 2015 for more examples).

Accordingly, in the assessment environment, the combination of the CPS elements and their behavioural indicators (representing 19 sub-elements) are task-specific, based on the different characteristics of the tasks (Care et al., 2015). Also, not all the elements are present in the different tasks. As a categorizing matrix, the assessment criteria thus included “Social” and “Cognitive” as the main categories and the task specific sub-elements of social and cognitive as subcategories. In addition, if the content was related to CPS but could not be connected to any of the CPS elements in the predetermined coding category, it was placed in a residual category named “Unclassified”. Those parts of the transcribed CRR data where no criteria could be found were left uncoded. In this paper, the residual category was not included in the process visualizations.

Table 3. The categorization matrix of the behavioural indicators of CPS elements in Laughing Clowns.

Skill/Element	Behaviour
Social:	
Interaction	Interacting with partner
Audience awareness	Adapts contributions to increase understanding of the others
Responsibility initiative	Takes responsibility for progress for the group
Cognitive:	
Resource management	Manages resources
Systematicity	Implements possible solutions to a problem
Relationship	Identifies connections and patterns between elements of knowledge
Solution	Correct answer

To ensure trustworthiness of the deductive approach applied in this study, a double coding procedure was used (Schreier, 2012). As the code definitions are clear, subcategories do not overlap (Adams et al., 2015). Two rounds of coding by the first author produced, as expected, approximately the same results, which is seen to indicate a good quality of the deductive categorization matrix (Schreier, 2012). Also, to ensure sound interpretation of the data, the coding of the first task of two pairs were verified by a co-author. For data analysis, Atlas.ti[®]-data analysis software was first used. Next, the coded data were exported as xml to Microsoft Excel for organizing, analysing and visualizing the data. At this phase, based on the categorized data, cumulative frequency distributions were first calculated to summarize the appearance of coded CPS elements by individual students across four different CPS tasks that comprise the assessment bundle. Next, relative frequencies were calculated in pairs across different tasks.

2.3.3 Process Visualizations of the Micro-Interaction Episodes

Even though the ATC21S assessment environment captures all the text exchanged between students via the chat interface, to assess for collaboration over the problem solving processes, the focus has been on placement and occurrence of chat actions during the CPS process (Adams et al., 2015). However, in this study, we broadened our analysis to search for the evidence of collaboration students provide by combining the activity logs with students' interpretations (CRR data) of CPS processes for tracking the micro-interaction processes (Davis et al., 2015) in pairs. In this study, following Davis and colleagues (2015), the dyadic interactions were not treated as a single interaction thread but seen as accumulation of many periods of interactions of various lengths of time (Davis et al., 2015). In the fine-grained analysis of the contents of CPS processes in pairs, the grounding assumptions were based on the design principles of the particular processes to be activated in a certain task (Care et al., 2015). The aim was to determine the beginnings and endings of these micro-interactions within a student pair. Finally, the visualizations of the micro-interactions were notated with coded CRR data.

3. Results

3.1 How Do Collaborative Problem Solving Elements Appear in Different Tasks (Individual level)?

CPS performance measures of all research participants, based on automated scoring of the assessment environment, did not show strong differences between individual students, especially in social aspects (social skills between were 5-6, cognitive skills between 3-6), therefore not allowing for clearly distinguishing between “successful” or “less successful” pairs in CPS. Directed content analysis of CRR data resulted in frequency distribution of CPS elements of individuals across tasks. The sums of social and cognitive elements of the individual students are presented in Figure 2.

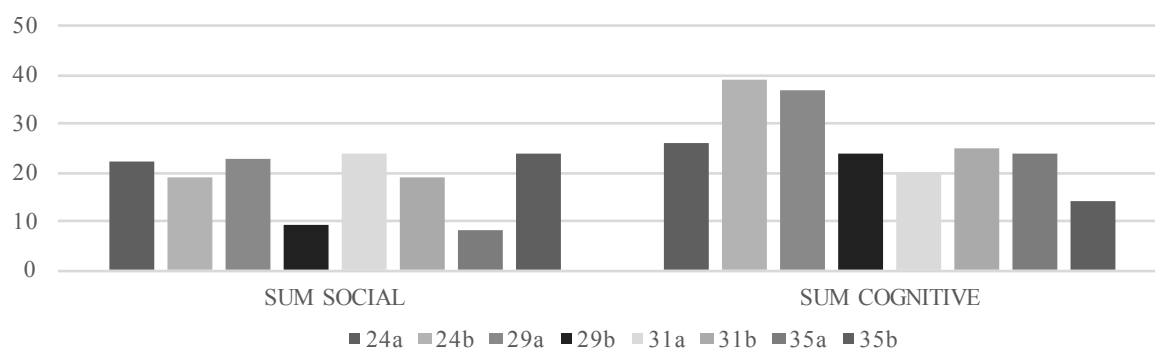


Figure 2. The sum of frequency distributions of different CPS elements of individual participants in all the tasks. The participants are displayed by their student IDs, such as Student 24a, 24b etc.

Based on the directed content analysis, for this paper two cases (Pair 24 and 29) were chosen for visualizations as contrasting micro-interactions. The CPS skill levels showed only slight difference in skill levels, Pair 29 with lower social skill level (Student A: social 5, cognitive 4; Student B: social 5, cognitive 3) and Pair 24 with higher social skill levels (Student A: social 6, cognitive 5; Student B: social 6, cognitive 3). However, the content analysis of the task Laughing Clowns revealed a lack of social aspects in interpretations of Pair 29 when completing the task whereas for Pair 24 social and cognitive aspects were balanced (see Table 4 for relative frequencies of social and cognitive aspects in pairs). Due to the limited space in this paper, these brief examples are chosen to illustrate the contrast in the most condensed and continuous form, as opposed to the micro-interactions in the other three tasks that would require more comprehensive extrapolation. The examples are, however, representative of the general quality of the data corpus produced by these two pairs across the four different tasks.

Table 4. Relative frequency distributions of social and cognitive aspects, based on CRR interviews (Pair 24 and 29); seen in relation to the designed task elements of Laughing Clowns.

Laughing Clowns	Social aspects %	Cognitive aspects %
CPS elements (Task design)	43	57
Student interpretations:		
Pair 24 (altogether)	50	50
Student A	50	50
Student B	50	50
Pair 29 (altogether)	0	100
Student A	0	100
Student B	0	100

3.2 Micro-interactions in Pairs: Two Contrasting Cases as Joint Solution Endeavour Versus Individual Solution Endeavour

The micro-interactions confirmed these fundamentally different CPS processes (for excerpts, see Figure 3 and 4). The pattern of Pair 24 (“Joint solution endeavour”) depicts an ideal dual-problem space (Barron, 2003; see also Alterman and Harsch, 2017) where participants simultaneously focus and develop the content space (cognitive aspects) and the relational space (collaborative aspects). In the content space they jointly make sense of the significant elements of the task and jointly reason out the task logic whereas in relational space they show being able to manage their interpersonal relations as they collaborate (Alterman and Harsch, 2017). Pair 29, in turn, showed significant challenges in this respect (“Individual solution endeavour”), which leads to self-focused problem-solving trajectories in collaborative context (Schneider and Pea, 2014).

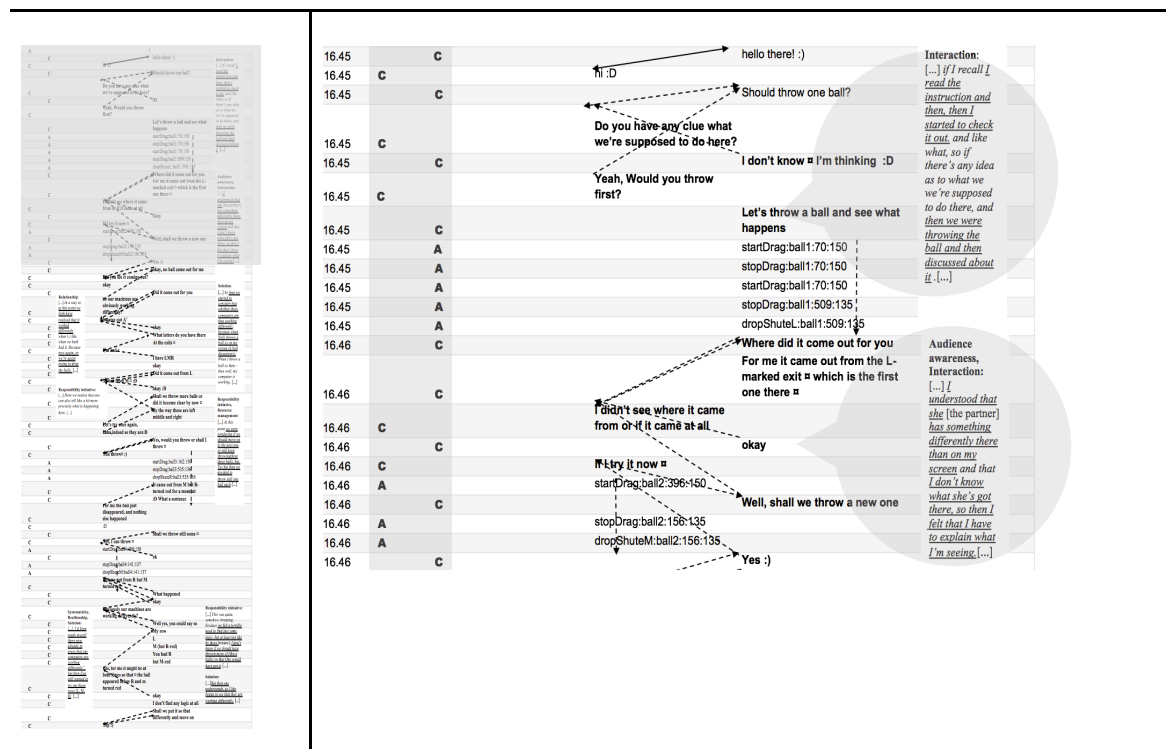


Figure 3. Joint solution endeavour (Pair 24, Laughing Clowns). The full episode and an excerpt (grey area), including a time-stamped, condensed activity pattern (A= action, C= chat); dialogue extracted from the activity log, speech bubbles contain excerpts from the coded CRR data. (Note: Translated from Finnish)

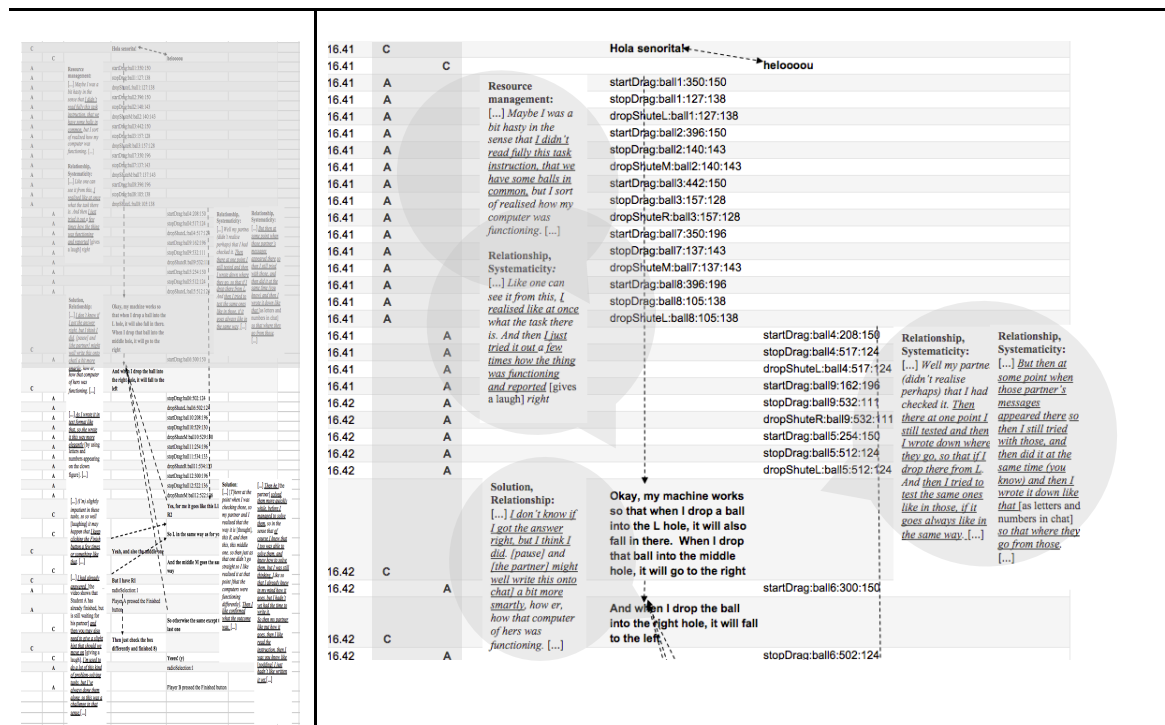


Figure 4. Individual solution endeavour (Pair 29, Laughing Clowns). The full episode and an excerpt (grey area), including a time-stamped, condensed activity pattern (A= action, C= chat); dialogue extracted from the activity log, speech bubbles contain excerpts from the coded CRR data. (Note: Translated from Finnish)

In regard to social aspects of CPS, in Laughing Clowns the fundamental requirement for successful completion of the task is interaction between participants (Care et al., 2015). Participants need to be aware that their balls are shared and that the most effective way of finding the solution is to assign the balls so that both students may have adequate and equal opportunity to trial their machine and reach a conclusion (see Pair 24). However, in contrast to Pair 24, after the opening messages, Pair 29 does not discuss the allocation, but starts working independently, dropping and dragging the balls without interacting and coordinating their efforts by any means, with Student A first. Also, evidence of audience awareness (i.e. how a participant adapts contributions to increase understanding of the others) as another social skill indicator of the task is missing with Pair 29. Students who are proficient in this area are likely to interact with their partner between ball drops and adapt their behaviour to best suit their partner's needs (in contrast, see Pair 24).

In terms of cognitive aspects of CPS, students with low proficiency of resource management skills may only concern themselves with checking how their machine functions, thereby monopolising use of resources, which seems to be the situation with Pair 29, while more skilled students are likely to recognize the need for shared use of the balls and share them equally (Pair 24) (Care et al., 2015). Moreover, to reach solution, the students need to identify the relationship between entry and exit point of balls and determine if there is a consistency in how the machines function; the pair needs to construct a way of representing this information that communicates to each partner as well as being able to understand other forms of representation that the partner uses. For example, Pair 29, Student A provides a narrative while Student B lists pieces of information). Skilful students will also challenge the patterns and test the assumptions that underpin their observations, which does not occur with Pair 29. The final step comprises the students comparing their representations such that a decision concerning the similarity of clown machine functioning can be made (Solution). Pair 24 communicated throughout their activities, whereas Pair 29 only discussed their shared understanding towards the end. If the task was not forced for collaboration with the last concluding question, Student 29A would have been able to solve the task quite independently.

4. Discussion and Conclusions

The aim of this study was to explore the micro-level interactions in pairs that occur during the online assessment and thereby provide case-based portraits, focusing especially on the group relational aspects of CPS that may otherwise remain unexplored. In small group collaboration, there are multiple interacting elements that contribute to the structure and flow of collaboration, such as aforementioned elements related to joint problem space (Alterman and Harsch, 2017; Roschelle and Teasley, 1995). Significant challenges in collaboration may arise if participants do not attempt to coordinate their individual perspectives into the joint problem space, as witnessed in this study. Participants who sense co-presence perceive each other and pay attention to each other, which is, however, more demanding when students are operating in online settings (Alterman and Harsch, 2017).

Accordingly, the degree of shared understanding the pairs need to reach is related to the task they need to perform (Dillenbourg et al., 2016), which sets requirements for pedagogical design in this regard. But, as Dillenbourg et al. (2016) point out, in collaborative learning, in general, the tasks are primarily designed to facilitate shared meaning and collaboration. However, these practices should not be considered as something that would automatically happen: pedagogical designs can be perceived and interpreted rather differently by different participants (e.g. Arvaja and Pöysä-Tarhonen, 2013). In our example, the symmetry of the task might have diluted the effect of interdependence designed in the tasks and thereby highlights the motivational aspects in regard. In this sense, to better understand how participants produce learning in collaborative situations requires not only to focus on how they build shared meaning, but how they engage in this activity (Dillenbourg et al., 2016). Engagement may appear at various levels, i.e. at behavioural level (i.e. effort and contributing to the task), social level (i.e. the quality socio-emotional interaction and equitable participation) and at cognitive levels (i.e. planning, monitoring and evaluation) (e.g. Sinha, Kempler Rogat, Adams-Wiggins and Hmelo-Silver, 2015). In relatively limited collaborative situations, like the case here, a rather shallow interactional quality might be enough to complete the task. However, in the other tasks studied, being richer and asymmetrical, the other participant's resources and understanding becomes more critical. Yet, similar patterns of interactional difficulties or even breakdowns can be found with the same dyad; but, due to the increasing complexity, not in such linear modes as presented here.

As our exploratory case study was conducted in a highly structured assessment environment online, characterized by a challenging communication channel (chat) as dyads as the unit of analysis, to be able to generalize the contrasting cases beyond this special research design requires replication with more subjects. In addition, it should be noted that is unclear whether and how the assessment situation, even being voluntary, impacted the ways in which students collaborated. Also, to include novel methods, such as dual eye tracking during working on online collaborative tasks, analysed in respect to identified key interactional events or, focusing e.g. on "micro-monitoring" of partner's behaviour in dyads (Schneider and Pea, 2013), could enrich the study. But, our case-based approach, with multiple data and phases of analysis that carefully displays processes of dyads building shared understanding and acquiring CPS practices is still rare even in the area of collaborative learning (Schwarz and Baker, 2017; Stahl, 2017). Therefore, through analysing temporal interaction processes in dyads, e.g. by identifying special problems in the appropriation and use of assessment practices online, this approach has the full potential to inform pedagogical design and refinement of practices in this respect.

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