Can noncomplementarity of agency lead to successful problem þÿsolving? A case study on students interpersona mathematical problem-solving collaboration

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2022-12

Can noncomplementarity of agency lead to successful problem solving? A case study on students' interpersonal behaviors in mathematical problem-solving collaboration

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A R T I C L E   I N F O

A B S T R A C T

In student collaboration, purposeful peer interaction crucial for success on the task. Such collaboration requires adequate and purposeful student agency. Theoretically, the between-individual complementarity of agency behaviors enhances purposeful interaction. However, the level of agency of group members can disrupt the collaborative interactions. We conducted a case study of collaborative mathematical problem solving, where one student's behaviors of noncomplementary agency characterized the group interaction. We examined the video recording of the group by continuous quantitative coding of students' agency behaviors and segmented the interaction process into four phases. We analyzed qualitatively these phases based on the verbal transcript. We found that the target student's agency grew in relation to the other students despite her lack of mathematical competence. The findings provide us with a new perspective to understand the role of the situational individual agency in collaborative learning that underlines the tolerance of noncomplementarity of agency in student collaboration.

1. Introduction

In collaborative learning, purposeful interaction enhances learning outcomes of all group members (van Blankenstein et al., 2011). The purposeful group interaction is built on the students' abilities to maintain joint attention, to elaborate their own thinking, and to respond to other students' suggestions (Barron, 2003; Ding et al., 2007; Esmonde, 2009). According to interpersonal theory (Leary, 1957), purposeful interaction is seen to be related to behaviors of complementarity towards other interlocutors. Student collaboration involves sharing of agency (Mueller et al., 2012). From the perspective of agency, this means adapting one's expressions of agency reciprocally to the agency of the other participant (Markey et al., 2010; Sadler et al., 2009). However, in real life, human interaction may not always follow this principle. The potential lack of agentic complementarity in student interaction in mathematical collaborative problem solving captured our interest and led us to investigate individual situational student agency in relation to peer collaboration.

Many studies lack clarity in the operationalization of the concept of agency (Arnold & Clarke, 2014), especially with regard to defining the actions that display agency (Nieminen & Hilppö, 2020). This study operationalizes agency through interpersonal theory (Leary, 1957), which conceptualizes agency as a person's interpersonal control and power that convey their need to be individually differentiated from others (Gurtman, 2009; Kiesler, 1983; Wiggins, 1991). This differs from the socio-cultural tradition of defining agency as a characteristic of social discourse (e.g., Mueller et al., 2012; Nieminen et al., 2021).

Even though different theoretical approaches examine agency from different perspectives, the fundamental need to examine the notion of student agency arises from understanding learning as a complex social activity that should be meaningful to the learner (Arnold & Clarke, 2014). From a socio-cognitive perspective, individual agency is defined as a person's actions and the contributions of these actions in the context of joint activity of a group (Gresalfi et al., 2009). High individual agency can enhance learning, engagement, and self-regulation in the context of problem solving (Taub et al., 2020) and positive experiences and emotions in school (Hilppö et al., 2016). However, investigating the agency of individuals as part of group collaboration requires careful

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consideration (Suthers, 2013). Interpersonal theory provides tools for this: it examines agency as a situational social variable, that is behaviors of control exerted depending on the social interactional context, that can shed light especially on collaborative problem-solving interactions.

Both socio-cultural approach (e.g., Hilppö et al., 2016) and interpersonal theory acknowledge the importance of agency in human interactions (Wiggins, 1991). For example, Brey and Shutts (2015) suggested that in school children learn to observe the presence of power relations in social interaction, because interaction in school communities reflect clear and salient power structures. Furthermore, interpersonal theory also enables conceptualizing agency as moment-to-moment interpersonal behaviors in relation to other interacting participants, varying from dominance to submission. Even though agency is often examined in relation to rather stable power structures, it is also constructed in situated interactional and relational processes (Lipponen & Kumpulainen, 2011). Recent research has identified patterns of momentary variation on agency in teacher-student interaction (Haataja et al., 2020; Pennings et al., 2018). However, moment-to-moment adaptations of agency in student-student interaction remain unaddressed in the field.

This paper presents a case study which aims at exploring students' interpersonal behaviors as an implementation of their situational agency in relation to their peers. We operationalized agency according to interpersonal theory, as human expressions that vary from dominance to submission in the interaction with others (e.g., Sadler et al., 2009). To capture the moment-to-moment variation of student agency, we carried out continuous coding of video data on student collaboration.

1.1. Complementarity of agency in classroom interaction

To elaborate on the notion of complementarity, the expected adaptation of the behaviors of the interlocutors can be described with the concept of *complementarity* as a variance with a cyclical pattern (Fig. 1). Throughout the decades, several versions of interpersonal circumplex with varying adjectives have been used in literature. In Fig. 1, we have combined the illustration of interpersonal complementarity from Carson (1969) and adjectives from Sadler et al. (2009), on which our coding scheme was based.

The Interpersonal Circle consists of two dimensions, agency and communion. Behaviors of agency fluctuate between assertive/dominant and passive/submissive, and behaviors of communion between warm/sympathetic and irritable/indifferent (Sadler et al., 2009). In this study, we focus on the dimension of agency in student behavior to examine carefully how the individual expression of agency constructs the

Fig. 1. The Interpersonal Circle, based on Carson (1969) and Sadler et al. (2009).

collaboration. Agency, in this context, refers to the individuals' need of being differentiated as an individual, and communion refers to the need of social belonging (Gurtman, 2009; Wiggins, 1991).

In interpersonal interactions, the levels of agency tend to obey the principle of *complementarity* (Carson, 1969). In complementarity, the acts of agency by one person are responded with contrary behaviors (e. g., dominant-submissive) by another (Sadler et al., 2009). In this study, we examined complementarity of agency as a situational characteristic of the student-student interpersonal behaviors. This study focuses on student collaboration from the perspective of purposeful interaction for problem solving, and therefore we chose to focus on agentic behaviors that either enhance or distract the collaboration rather than on behaviors of friendliness or hostility that reflect the social relationships between the participants.

The effects of a lack of complementarity, that is, *noncomplementarity*, on interpersonal agency is a topic that has received little attention in the research community (e.g., Markey et al., 2010). Whereas peer dyads tend to naturally behave complementarily (Markey et al., 2010; Sadler et al., 2009), therapists often use noncomplementarity as a tool in psychotherapy to raise emotions in the client by challenging the expected patterns of interaction (Thomas et al., 2014). The few existing studies on noncomplementarity in peer interaction indicate that when the interlocutors fail in sustaining interpersonal complementarity, it negatively affects their interaction, experience of the other participants (Nowicki & Manheim, 1991), and their success in achieving the shared goals (Estroff & Nowicki, 1992).

Among adult peers (marital couples), agentic complementarity takes place during positive and collaborative interactions rather than conflicts (Cundiff et al., 2015). However, adults can adapt the levels of agency behaviors to support the mood of the other participant in conflict situations (Rehman et al., 2017). In a study with newly acquainted peer dyads and similar coding method to our study, the complementarity of agency did not affect participants' success on solving a collaborative problem task, probably due to the selection of the task for the study, which was collaborative rather than competitive (Markey et al., 2010). It is notable that both these studies (Cundiff et al., 2015; Markey et al., 2010) were conducted without naturalistic tasks (real disagreement in relationship or problem task) and the latter one also used dyads unfamiliar to each other before the data collection. In contrast, the participants of our study worked with peers from their usual learning group. They were familiar with collaborative learning in mathematics, and their teacher was consulted on the suitability of the tasks used in the study.

From the perspective of classroom interaction, the behaviors of student agency, for example student initiatives, can be constructive or deconstructive. When students express agency, they may choose to obey the social norms, such as to raise a hand to express willingness to speak (Böheim et al., 2020) or to choose a way that is not constructive to the shared interactional or learning goals (Rajala, et al., 2016; Nieminen & Tuohilampi, 2020). The students' agency forms in relation to the teacher's agency, and the teacher can support student agency by giving them the responsibility to regulate the learning (Hod et al., 2018; Rajala, et al., 2016). In our data, the role of the teacher is more peripheral than classroom instruction in general, which helps us to investigate the largely unknown variations of interpersonal agency adaptation in student-student interactions.

Additionally, previous experiences, beliefs about oneself as a mathematics learner, and beliefs about one's role in the learning group may affect how the students respond to situational agency (Mueller et al., 2012; Nieminen & Tuohilampi, 2020). Even though the earlier school experiences may stabilize student actions, through participation the students can learn to be creative and active in the learning environment (Kumpulainen et al., 2018). In other words, student agency is situational and relates to the students' previous school experiences and the school's social structures.
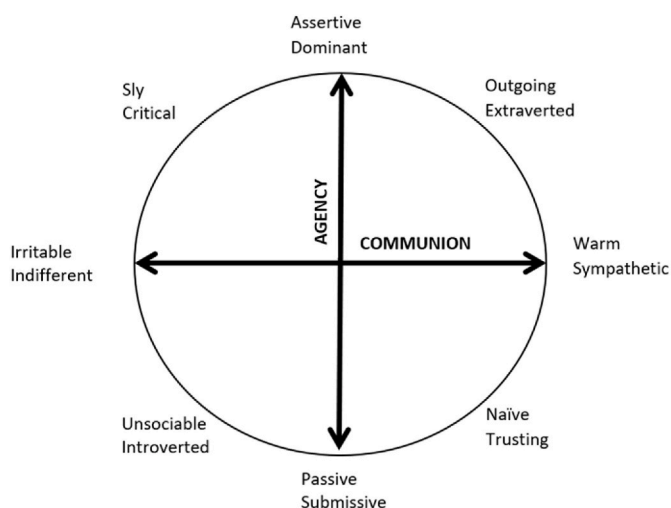
1.2. Agency in purposeful student collaboration

The agency of an individual and the group can be seen to intertwine, as the individuals' interactional behaviors form the basis of the collaboration, but the collective effort can lead to agency that could not have been possible for the individual (Suthers, 2013). Therefore, the students need to be able to use their agency in a manner that enhances collaborative learning (Slof et al., 2016). In a purposeful collaboration, the agentic actions concern both the knowledge and the learning process (Damşa et al., 2010). For example, in the context of collaborative project learning, students with different opinions or perspectives to the learning contents can promote collaboration, whereas disagreements on the problem-solving process or social interaction may harm achieving the goals (Lee et al., 2015).

The goals of the collaboration are in relation to the amount and quality of the emerging student agency: when goals are mathematical, the mathematical knowledge is expected from the agentic students, and students without mathematical knowledge may be excluded from the shared discourse (Nieminen et al., 2021). A recent study in the context of computer-supported collaborative learning found that the ability to express one's agency in a productive way enhanced the learning achievements of the individuals but did not affect the group level (Slof et al., 2016). Investigating interpersonal complementarity within a group through examining pairwise interactions is an established approach (e.g., Maxwell et al., 2012). In our study, we combined the social and individual levels of student agency in relation to collaborative problem solving by first analyzing each student individually, and then interpreting the findings drawing from the collaborative discussion.

1.3. The aim of the research

This case study aims to chart how the changes in students' individual agency behaviors in relation to other students' agency construct the problem-solving interaction. The research question addressed is:

What is the role of agentic noncomplementarity in the collaborative problem-solving process?

2. Methods

The following section details the methods employed in this study that examined the video-recorded interactions of four female students who participated the Research project (Chan et al., 2018).

2.1. Participants

The students were part of a class that was being filmed in a research classroom at the University of Melbourne in 2016. The class participated in the data collection twice in the research classroom. The data we used are from the latter session. The students were therefore familiar with the filming setting as well as with their peers. For this particular session, students also wore biometric wristbands to record their electrodermal activity and heart rate, with the analysis reported in a separate study (Salonen, Haataja, Sherwell, Cunnington, & Chan).

The four students were Nora, Panya, Vera, and Julia (pseudonyms). We selected this group based on the teacher interview. She described high levels of variation in mathematical abilities within this group and indicated that Nora was one of the strongest, and Julia was one of the weakest among the class. Ethics approval was obtained from the university to carry out the research project and caregiver and student consent was obtained prior to the filming.

2.2. Research setting and materials

The project involved the filming of intact classes (24–26 students) of Year 7 students (12–13 years old) with their usual mathematic teachers as the students completed problem-solving tasks individually, in pairs,

and in small groups. The filming was carried out at the University of Melbourne Science of Learning Research Classroom facility, which was equipped with multiple cameras and audio inputs (see Chan & Clarke, 2019). In this study, we focused on the period (~23 min), when the students sitting around a table worked as a group of four. In the beginning of this period, the teacher gave instructions to the whole class asking them to open the envelopes on their table that contained the task sheets and to start working in groups.

Together the students solved a set of four different mathematical problems (see Appendix). The tasks focused on proportional reasoning and contextual variation. The task instructions were printed on separate worksheets and projected on the screen to the front of the classroom. In addition to the task sheets with space for notes, the students had pens, calculators and rulers on the table. At the end of the phase, the teacher told the students to gather the task sheets and place them in an envelope as a sign of having finished the task.

2.3. Analyses

The first and third authors, not familiar with the students or their background, used Sadler's method called Continuous Assessment of Interpersonal Dynamics (CAID, e.g., Lizdek et al., 2012; Sadler et al., 2009) to code the students' behaviors according to interpersonal theory. Recent research has explored momentary teacher-student interaction with this method (e.g., Donker et al., 2021; Haataja et al., 2020; Pennings et al., 2018), but we have not been able to find studies on student-student interaction. The coding involved using a joystick and a CAID Joystick Monitor software (Sadler & Woody, 2016) to analyze the continuous situational interpersonal behaviors of one participant at a time. The levels of student communion and agency were coded simultaneously by watching the video recording. On the software, the raters move a dot on Cartesian coordinates, with Communion on x-axis, ranging from indifference (−1000) to warmth (1000), and Agency on y-axis, ranging from submission (−1000) to dominance (1000) (see Sadler et al., 2009; Wiggins, 1991). The software records the coordinates of the dot every 0.5 s. The adjectives describing interpersonal behaviors (Fig. 1) guided our coding. We interpreted the levels of agency to increase as the participant expressed *dominance* (e.g., used a louder voice, more dominant language, gave directions to other students, and/or controlled the situation with nonverbal behaviors, such as taking the task sheet away from other students), and to decrease with the contrary expressions of *submission* (e.g., silence, or obeying the directions of other students).

The CAID method has been validated by several studies in education (e.g., Pennings et al., 2018) and psychology (e.g., Thomas et al., 2014). To ensure coding validity, two researchers coded the data independently. Both researchers had background as mathematics teachers, and hence had experience in interpreting student mathematical problem-solving collaboration. We calculated the inter-rater reliability with interclass correlation of the 0.5-s sequences of student agency (0.714, $p < .001$). This was in line with previous research that employed the same analysis method (Pennings et al., 2018). After the coding, we continued on the complementarity of agency behaviors. Focusing on one dimension of interpersonal behaviors at a time is the generally used approach (e.g., Cundiff et al., 2015; Haataja et al., 2020) in studies on complementarity (e.g., Markey et al., 2010). Additionally, Goetz et al. (2021) have suggested that studies examining the different dimensions of interpersonal characteristics could complement each other for fine-grained knowledge on classroom relationships. However, our study focuses solely on interpersonal agency for detailed reflection in this regard.

Whereas many previous studies on interpersonal complementarity are purely quantitative (e.g., Markey et al., 2010; Pennings et al., 2018), we combined the quantitative CAID coding with qualitative analysis of the transcript to create a picture of the agency adaptation in the group. The verbal exchange of the group was transcribed verbatim from the

video recordings. This transcript also included timestamps from the video. With the analytical triangulation, we were able to understand how the agency varies in relation to the collaborative problem-solving process.

For the final stage of the analysis, we used the mean scores on student agency between the two raters. As the software records the level of the agency twice a second, we chose to simplify the data the software produced by calculating the moving average of 10 s. With this running mean series, we calculated the Pearson correlation for pairwise variations of the agency. For the validity of this methodological choice, we also calculated the correlations with the raw data and found the results to be similar. We then synchronized the joystick coding with the timestamps of the transcript. We looked at the variation of the agency scores and marked the moments where the between-participant relations of agency seemed to change. Next, we compared these moments to the written transcript of the verbal interaction. Based on this comparison, we divided the collaborative problem-solving process into four phases (similarly to Thomas et al., 2014, for example) to zoom into the role of agency behaviors in problem-solving interaction. We present these phases independently and in relation to the general problem-solving process in the following section. The graphs on the agency coding complement excerpts from the transcript. The excerpts were selected to inform the reader on the narrative. For readability, short parts of the conversation that were not relevant to the interpretation of the interaction were replaced with three hyphens.

3. Findings

To present our findings from the quantitative analysis, Fig. 2 shows the variation of students' interpersonal agency behaviors during collaborative mathematical problem solving. The collaborative phase lasted about 23 min (1394 s) from the moment the teacher asked the students to open the task envelope until the moment when the students felt they were finished with the tasks and closed the envelope.

The graph is based on continuous coding of interpersonal behaviors and shows the moving average of 10 s of the levels of student agency. Each student in the collaboration group has their own line in the graph. If the students' lines are moving in the same direction at the same time (either upwards or downwards), this indicates interpersonal non-complementarity of agency behaviors. On the contrary, if the students' lines are moving in the opposite direction (i.e., one moving upwards while the other moving downwards), this indicates complementarity. For example, in the beginning (0s–360s), Panya's level of agency is generally the highest, as she was having control over the interaction at that point. The agency of the other three students was coded as low until they took more of an agentic role (~90 s).

Pearson's correlation on the 10-s running mean series (Table 1) indicated that there was no strong negative correlation between the participants' agency levels. Between Nora and Panya, Nora and Julia, and Panya and Vera, there was only a slight negative correlation (r

Table 1
Correlations of agency levels of the participants over the group-work phase.

| Participant	M	SD	Nora	Panya	Vera
Nora	92	281			
Panya	87	225	−.342[a]		
Vera	38	285	.299[a]	−.214[a]	
Julia	−580	278	−.292[a]	.203[a]	−.331[a]

[a] Correlation is significant at the 0.01 level (2-tailed).

between −0.34 and −0.21, $p = .01$), whereas the correlation between Nora and Vera ($r = 0.30$) and Panya and Julia ($r = 0.20$) was positive. Nora and Panya sat next to each other, as did Vera and Julia, and the correlations between these pairs were the clearest with respect to agentic complementarity. We examined the group-level interactions based on the qualitative data (video and transcript) to interpret these quantitative findings.

In the qualitative observation, especially the persistent but contradictory behaviors of one student, Vera, captured our attention. Vera seemed to continuously seek individual agency in the group. Based on our quantitative analysis, we were able to identify four phases of agentic behavior of Vera, as presented in Fig. 3. In Phase 1, the students were about to start working and listened to the teacher's instructions, and the general agency level was low. As the group work started, Vera chose to be active and her agency increased rapidly (Phase 2). After that, her agency varied continuously above and below the zero level (Phase 3). Finally, in Phase 4 Vera's agency stabilized to rather high level, and finally it was her who suggested the successful solution to the final task.

In the following, we combine our qualitative and quantitative analyses on the four phases to provide a comprehensive picture of the relation between the momentary student agency and process of collaborative problem solving. We will especially focus on Vera, whose individual agency interestingly increased towards the end of the collaboration, despite the difficulties she had with the mathematical contents of the tasks and with being taken seriously by the other students.

3.1. Setting the agency roles for collaboration

In *Phase 1*, the conversation was mainly not task-related, as the students had finished the previous problem and were not yet allowed to start the next one. The teacher gave general task instructions to the class, and the group was chatting in a low voice about starting the task and joking about the research equipment. As the students mainly listened to the teacher's instructions in Phase 1, their agency was coded as low in general for the range between −1000 and 1000 (Nora $M = −82$, $SD = 66$, Panya $M = 105$, $SD = 119$, Vera $M = −354$, $SD = 259$, Julia $M = −332$, $SD = 230$ in Phase 1). After the teacher's instructions, Nora and Panya immediately took an active role in the group by grabbing the task sheets and telling Vera and Julia what to do. Vera remained quite
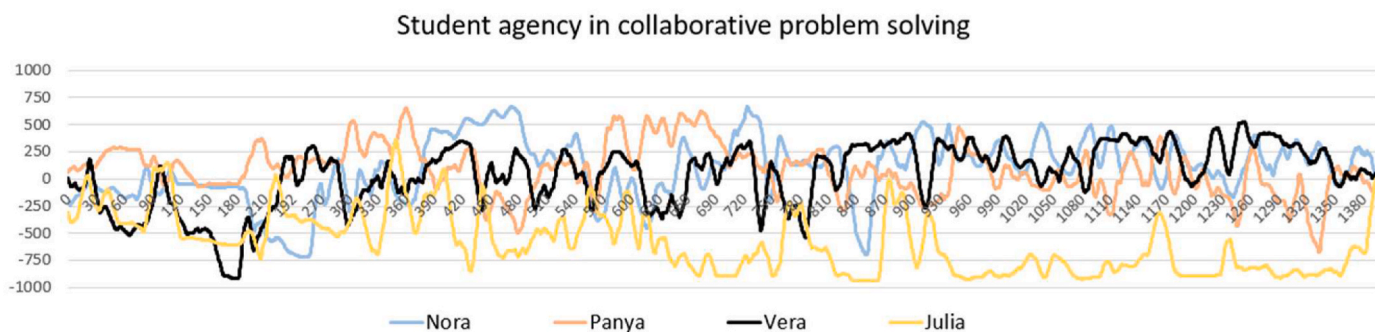
Fig. 2. The varying student agency (x-axis) during collaborative problem solving across time (seconds). The y-axis indicates the level of agency that each student displays. The positive levels of agency indicate dominant and negative levels submissive behaviors.
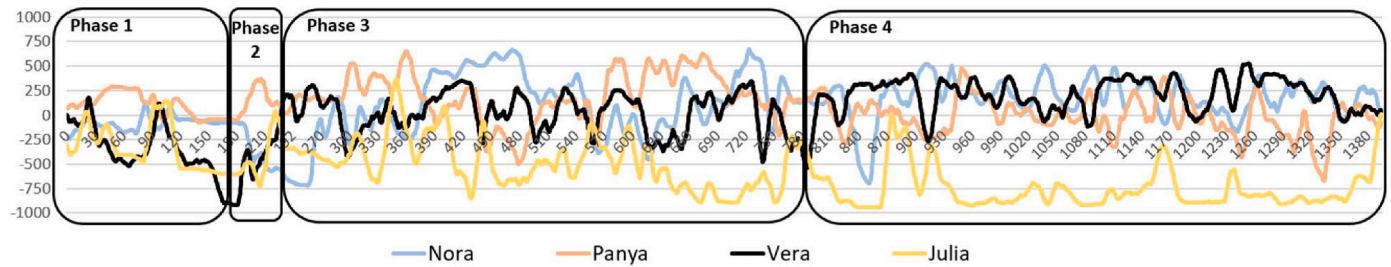
Student agency in collaborative problem solving

Fig. 3. The phases of student agency in the group.

passive, despite joking about taking off the biometric wristband. The first excerpt illustrates the levels of agency in interpersonal relations in this moment. In the beginning, Vera and Julia were excited to start the collaboration, but Nora took the leading role by expressing subtle but clear agency behaviors.

(77–88 s)	Vera:	I'm not sure it's a time thing though.
	Panya:	[To Vera] What is it [the wristband] meant to do? —
	Julia:	Task three, give me task three. All are group work.
	Vera:	Ah, what's in here? [looks inside her pocket] Oh my pass.
	Panya:	I think it - it's going to check my heart beat rate when doing Math. Well, like beeping very hard.
	Julia:	Open it. Open it.
	Vera:	Yeah.
	Nora:	Wait, we are not allowed.

During Phase 2, Vera became involved with the task, and her agency increased from low level in the beginning of this phase to moderate level in the end. However, the mean of her agency level remained similar to Phase 1 ($M = -342, SD = 329$). Similarly, Panya's ($M = 137, SD = 128$) and Julia's ($M = -408, SD = 291$) agency increased towards the end of Phase 2. Nora did not express agency verbally or nonverbally ($M = -416, SD = 204$). Nora directed the problem solving with verbal interaction and kept the task sheets with herself even though Vera asked her to pass them around. Hence, Nora appeared to possess leadership in

the group.

(204–214 s)	Teacher:	[To the whole class] So you've written your table number on the top. —
	Julia:	One, two, three, four, five, six [tables].
	Vera:	Pass the paper around, so we write our own names. —
	Teacher:	[To the whole class] Okay. What were you asked to do with your paper?
	Panya:	[To Julia] Hush child.

This short phase of about 1 min was a period when all the students were involved and seemed even excited to start the new task. However, the conversation was still quite rambling and not goal-oriented. The agentic noncomplementarity was evident, as the agency of three out of four students increased simultaneously. According to the theory, the agency of other students would be expected to decrease when the agency of one student increases. Also, Nora had power over the interaction, as she kept back the task sheet required for starting the collaboration.

3.2. Continuous challenge of agency

Based on the graph, Phase 3 was long and winding (~9 min), and thus we provide a bigger image in Fig. 4. The graph shows the patterns of the variation of agency levels of the four students. In the beginning of Phase 3, the students started working on the first collaborative problem
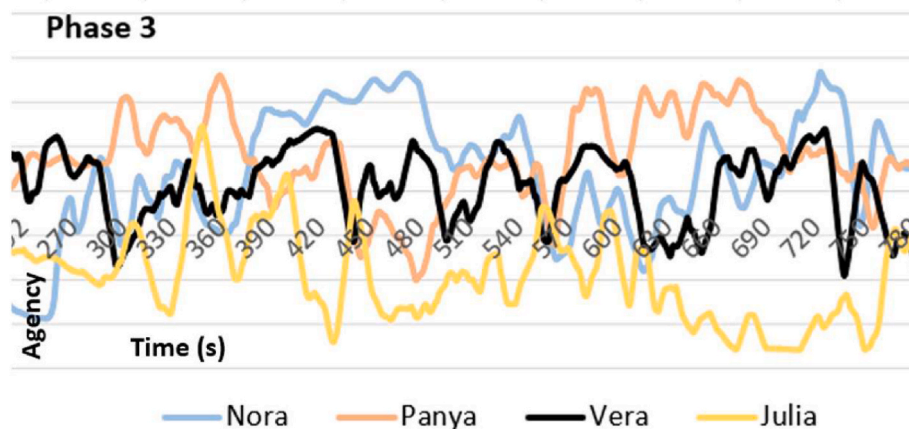

Fig. 4. Phase 3.

task. During Phase 3, Vera's agency ($M = 17$, $SD = 202$) varied but was lower than Nora's ($M = 117$, $SD = 323$) or Panya's ($M = 192$, $SD = 247$) in general. Julia's agency was very low throughout this phase ($M = -485$, $SD = 256$).

In the very beginning of this phase, Vera led the conversation, but it was not task-related. In the moment of 300 s, Nora and Panya started working on and talking about the task and Vera and Julia continued chatting together off task. Soon, when we observed Vera's agency increasing, her verbal message to Nora and Panya was rather disrupting than fostering solving the problem. Nora and Panya had already started to solve the first problem that was about arranging mixtures of liquids according to their strength (Task A).

(301–317 s)	Panya:	Just say concentrate and water. — Umm. Okay.
	Nora:	Arrange the mixtures in the order from weakest to.
	Vera:	Is this Science?
	Panya:	It doesn't mean science, but oh well this is not math. Okay, one cup of orange with three cups of water.
	Nora:	So that will be one quarter.
	—	
	Vera:	This is actually science, because we have one of these questions in ICAS[1] remember.
	Nora:	Wait, this will be one quarter.

[1] ICSA is "International Competitions and Assessments for Schools" in Australia which the students participated in.

In this phase, the group seemed to be competing for leadership than collaborating. Julia's agency was coded to be passive and Vera's agency moderate. Nora and Panya mainly ignored the other two students and kept the task sheet with themselves. The most disruptive moment (330–360 s) was when Panya and Julia wanted to ask the teacher, whether adding orange to a drink, which was mentioned in the task instructions, referred to a whole fruit. In this moment, Vera's agency appeared quite low and she seemed embarrassed. She and Panya expressed the embarrassment with critical comments that appear in the following excerpt.

(335–345 s)	Julia:	Ask Miss, ask Miss H … Miss H, when they say one cup of orange, do they mean like actual orange?
	—	
	Panya:	I was kidding, don't ask that.
	Vera:	No. [to herself, hides her face behind her hand]
	—	
	Panya:	Oh my goodness.
	Teacher:	So they're making orange drink aren't they?

After this moment, Vera's agency increased and she directed her actions towards task-oriented goals. After the teacher left the group, Vera seemed to disrupt the work of Nora and Panya and took the task sheet for herself. However, this was not a successful attempt of participation, as Nora immediately took back the paper.

(374–380 s)	Vera:	I can't see. [grabbing the paper]
	Panya:	Yeah.
	Nora:	Wait no, they are not same. [ignores Vera and grabs the paper back]
	Panya:	Three cups … four … No, they are not the same.
	Vera:	Oi. [to Nora, with an annoyed voice]
	Nora:	There's seven. Yeah I knew that.
	Vera:	Oi, oi, oi, oi.

The short incident above reflects agentic noncomplementarity, as Vera verbally and nonverbally opposed the control Panya and Nora had over the collaboration by demanding to see and hold the task sheet.

After this, Vera's agency was coded to be higher towards the end of the phase. Vera challenged Nora and Panya's competence to solve the task. Vera's agency increased and in a couple of seconds so did Nora's agency, and half a minute later Panya's agency. In the end of this period (360–420 s), the agency of these three students was high, but Julia's was very low. The verbal excerpt below shows how Nora and Panya's attempt to remain in control included being sarcastic towards Vera and Julia's acts of participation.

(381–395 s)	Julia:	We're not doing anything?
	Panya:	Yes, we are.
	Nora:	Good.
	Julia:	Only like me I'm not sitting and asking questions.
	—	
	Vera:	I haven't read the question yet.
	Julia:	Me too. I don't even know how you guys saying one cup of orange with three cups of water.
	—	
	Vera:	You guys are bugging it you can't do that.
	Panya:	[laughing sarcastically] Do you want to do Math, huh?
	Nora:	[laughing sarcastically] Yeah, do you want to.
	Vera:	Yeah, I want to.

After this, and until the end of Phase 3, Vera's agency continued varying between submission and assertiveness. Sometimes Vera's agency behaviors were task-related, and sometimes just joking and chatting. The active role in solving the task remained with Nora. To participate in the next task (Task D), Vera demanded to see the task sheet. As a response, Nora pushed the task sheet to Vera, and with a sarcastic tone in her voice suggested her to take the responsibility of solving the problem. Vera started to read the task aloud, but Panya very quickly interrupted her.

(570–600 s)	Panya:	Okay, first question -
	Vera:	Stop, put it in the middle. [drags the paper towards herself]
	Panya:	[sarcastically] Okay, you guys can take control of that one.
	Nora:	Yeah, if you want, yeah if you want. Okay. In a week, a taxi driver –
	Julia:	Okay. In a week, a taxi driver carried three times as many -
	Vera:	Three times as many women as men and four times as many children as men. I don't know.
	Panya:	Success. (Laughs)
	Julia:	Me too.
	Panya:	Come on, okay now let Nora do it, she'll be like yeah. Nora read it. Okay.

After Panya suggested Nora to take the leading role, Vera's participation was intermittent. She answered one multiplication question, and wanted to underline the final answers on the sheet, but mainly she remained passive in the problem-solving process. Once again, non-complementarity was present in the interaction: when Vera's agency increased, so did Nora and Panya's. However, despite the issues in collaboration and interpersonal complementarity, the students proceeded in solving the problem.

3.3. Collaboration leads to finding the solution

In the final phase (Fig. 5), the overall agency levels of Nora and Panya were lower (Nora $M = 172$, $SD = 199$, Panya $M = -15$, $SD = 188$), whereas Vera's was evidently higher and varied less ($M = 210$, $SD = 172$) than in Phases 1–3. Julia was quiet and her agency was coded as passive towards the end of the collaboration ($M = -755$, $SD = 199$).
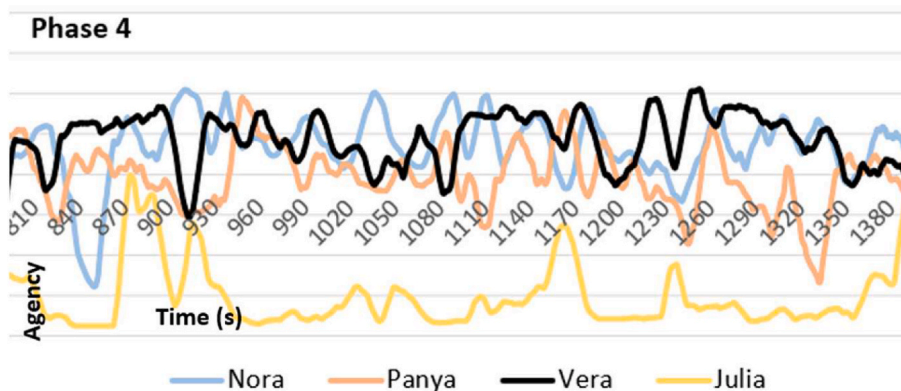
Fig. 5. Phase 4.

In the beginning of Phase 4 (~840–900s), the students started an off-task conversation. In the middle of this conversation, Panya's agency increased (~860–880 s) as she tried to have the group continue working. However, Vera ignored this attempt and continued chatting with Nora and Julia.

(867–876 s)	Vera:	I'm fat.
	Nora:	Yeah?
	Julia:	She's normal.
	Panya:	You know, shush. This conversation is going off topic.
	Nora:	Seriously, this shocks me. — I'm fat. — Have you seen my legs, it's so fat.
	—	
	Nora:	Moving on.
	Vera:	No, I'll tell you who's fat, <student name>.

After this (~890–1000 s), Nora led the group back to the problem, and finally some mutual mathematical argumentation occurred between Nora and Vera. During this mathematical pondering, the two students both conveyed agency, but this time it was collaborative towards the learning goals.

(892–910 s)	Nora:	Because you have to find just two. So what's 7 times, what's 8 times 9? What's? Wait …
	Panya:	Okay.
	Vera:	72.
	Nora:	Yeah. What's 72 divided by 13? Does that go in?
	Julia:	Did you guys join singing in the bus? —
	Vera:	I don't know.
	—	
	Vera:	No, do it, 13 times 5. Oh no, you can't.

Nora and Panya kept the task sheet, but Vera persisted in having her ideas of the solution heard. Even though she was not sure her ideas were correct, she was as active and agentic as Nora. Eventually, Vera's acts of noncomplementarity led to mathematical discussion in the group.

(945–967 s)	Vera:	Stop, stop. No, but stop. This is almost a half.
	Nora:	What?
	—	
	Vera:	Nah, nah.
	Nora:	You sure?
	Vera:	Work it out.
	Nora:	I'm just doing that, because it's correct.
	Vera:	And the least of that - Wait, wait. I don't know if this is big or not. Okay, let's try it. [starts writing on the paper]

After this short moment of collaboration and positive agency of Vera and Nora, Nora finished the task by writing down the final answer and took the last task sheet (~1080 s onwards). After a short moment of off-task chatting, the students started working on the last task (Task C). Like the first task, this one involved arranging fractions according to their size. Vera took the paper from Nora. However, after seeing the task, she seemed to become uncertain about her skills to solve the problem and returned the sheet to the middle of the table.

(1082–1095s)	Vera:	Stop it.
	Nora:	You do it then. [laughing]
	Vera:	Umm, how do you even work it out?
	Panya:	Exactly, let …
	Vera:	[looking at the task] Fine you do one out of, one out of two.
	Panya:	[amused] Why you guessed good. Approximately two litres of water.
	Nora:	No, one out of three.

The excerpt shows that Vera wanted to participate despite being uncertain about how to solve the problem. Vera, Nora, and Panya started pondering about the solution. In the end, the crucial idea that led to a successful solution came from Vera. A moment before, Nora suggested changing the fractions into decimals, but this suggestion was not implemented, probably because it was a difficult calculation to do by hand. However, this may have affected Vera's thinking, as after a while, Vera came up with an idea to see the numbers as divisions instead of fractions. Based on this idea, Nora came up with a suggestion to use a calculator.

(1230–1245s)	Vera:	Oh I know how you do it, you do five divided by three. Five divided … Oh, five divided by 30. Eeeh.
	Nora:	Yeah. Oh, we've calculator.
	Panya	Five divided …
	Nora:	We could have done so much with that.

After the students started using the calculator, the rest of the task was easy to solve. Vera and Nora conducted the calculation and wrote the answers down in collaboration. Vera was even able to transfer her strategy to other tasks, as she said:

	Vera:	Oh my god, I could have done that in my first task.

Straight after this comment, the students finished the task and raised their hands for the teacher to indicate that they are ready.

4. Discussion

Complementarity of interpersonal agency is theoretically related to fruitful interaction (Markey et al., 2010), and is found to relate to engagement and achieving the collaborative learning goals (Taub et al., 2020). Our findings show the need for further micro-level investigations on the complementarity principle, where the agentic complementarity appears as strong negative correlation between participant pairs. The correlations of the students' agency levels were statistically significant

but weaker, some even opposite to what previous studies indicate would be the norm in human interaction (e.g., Pennings et al., 2018; Sadler et al., 2009). Despite this, the student group eventually managed to solve the problem without giving up. This study showed one case that contradicts the assumption of interpersonal interaction and hence led us to ponder about student agency in moment-to-moment peer interaction.

4.1. Theoretical reflections

Vera's persistent resistance of accepting the submissive role that the other students offered her raised the question that if she did not assert agency, would that have affected the success of the problem solving. We think probably not, as Nora and Panya had already come up with procedures that were suitable, if not the most effective, for solving the task. We might still reflect on how Vera's ideas became beneficial for the group despite her lack of mathematical knowledge or self-confidence. The agentic noncomplementarity in the group and Vera's lack of situational mathematical knowledge led to joint success in the problem-solving process. Despite being dismissed by her peers and being uncertain about her own mathematical ideas, Vera was able to communicate agency constructively and break the patterns of interaction in a productive way (cf. Kumpulainen et al., 2018).

Then, why did Vera put so much effort on asserting her agency in the peer interaction? First, Vera seemed to have the courage to restructure the problem-solving process and even the roles in the group (cf. Mueller et al., 2012) with her situational agency. This may be a result of a supportive classroom climate. We do not know how close the group members were as friends, but the group interaction seemed to tolerate relatively large amount of agentic noncomplementarity without emerging negative confrontations. Secondly, Vera may have had intrinsic motivation to learn the mathematical content at hand. In the future, investigating the role and quality of noncomplementarity in both communion and agency with more participants from different schools could inform whether interpersonal noncomplementarity is a social norm in some classes. The research could provide insights into whether noncomplementarity is supported by the teacher or if it emerges from peer interactions, and whether noncomplementarity enhances or hinders the learning of students as individuals and groups.

4.2. Limitations

In this study, we excluded the other dimension of interpersonal behaviors, communion, from the analysis and focused solely on agentic behaviors. This is a limitation of our study but it has also helped us in reflecting on agency in detail and from various perspectives. For example, the sarcasm that Nora and Panya expressed towards Vera could be interpreted as an expression of unfriendliness. Sarcastic behaviors in a teacher's interactions could lead to undesirable changes in classroom relationships (Wanzer et al., 2006). However, the situation for peer interactions among students could be different. From the socio-cultural perspective, agency is constructed in the group discourse (Mueller et al., 2012). Therefore, irony could either be a way to express power (cf. Brey & Shutts, 2015), or to build a shared sense of humor.

Peers have been found to adapt the level of agency they express depending on the context of the interaction. In a situation that might provoke anxiety in the other participant, a person can behave cautiously in their expression of agency to create safe atmosphere (Rehman et al., 2017). We suggest that in addition to the levels of agency, the quality of agency can also vary situationally. Irony can be seen as a very subtle expression of high agency and it depends on the context and relationships whether it creates or distracts jointness. In our case, Vera ignored the sarcasm in the speech of the other students and persistently continued to contribute to the collaboration. Due to our triangulation of quantitative and qualitative data, and using human coders instead of artificial intelligence, we were able to notice those moments when participants say one thing and mean the opposite.

4.3. Methodological implications

Despite being an established method, CAID is relies on the raters' intuition and contextual judgment. Even when the raters watched the video data many times through, some aspects of nonverbal communication may remain unnoticed. Similarly, if using the verbal transcript of the session solely, the researchers lack information on the nonverbal aspects of the interaction. For example, the data included moments when one of the students (often Nora) refused to show the task sheet to other students (especially Vera). Having only one sheet may have affected the noncomplementarity to occur. From the perspective of the methodological development, we should consider how many task sheets we provide to the students in this kind of data collection sessions to support fruitful interaction and successful problem solving.

This kind of passive resistance to collaboration through sitting still and having a hand on the top of the paper would have been missed in the CAID coding had it been conducted on individual students. However, when triangulating the information from the agency coding on *each* participant and transcript on the interaction *between* the participants, we actually interpreted this passiveness as high agency. Therefore, in educational sciences, triangulating data and analyses is essential for the broad understanding and solid interpretations. However, future studies could implement more sophisticated statistical analyses, such as spectral analyses (cf. Pennings et al., 2018), for more detailed understanding of the quantitative variations of the investigated phenomena. As we gain more understanding of interpersonal agency in student interactions in the future, we should also reflect on its relation to socio-cultural agency in terms of whether the latter could be investigated with CAID method to build comprehensive understanding on the complicated concept of agency.

4.4. Practical implications

From a practical viewpoint, the absence of the teacher during the learning process seemed to affect the students' agency (cf. Hod et al., 2018; Rajala, et al., 2016). The students' positions were clearer when the teacher visited the group. Nora and Panya joked with the teacher about the task and Vera and Julia were silent and seemingly embarrassed (mumbling and hiding face behind hands). Nora and Panya's behavior was directed to the teacher and might not reflect the peer relationships but the teacher-student relationship instead. However, the teacher came to guide the group but did not encourage Vera or Julia to be more active in the collaboration and focused on Nora and Panya in the intervention. This demonstrates the relations between structural and situational agency: the structures in the classroom are implemented in situational behaviors, which again direct the construction of the relationships.

However, most of the time the students were on their own. Thus, they had space to regulate their situational agency and the problem-solving process without teacher guidance. Adequate amount of teacher guidance has been suggested to be essential for successful collaborative problem solving (Frith & Frith, 2012). However, the teacher has to be sensitive to the students' own abilities to regulate their problem-solving process and interaction (Anghileri, 2006) and to share the momentary authority in the collaborative group (Mueller et al., 2012). By giving them space, the teacher can make expressing agency possible for some students. At the same time, teachers need expertise on their own students' collaborative skills, as they are only developing throughout the school years. Therefore, when negative expression of agency emerges, students may need teachers' support.

However, the teacher's agency was present in this session in the form of the grouping of the students. The collaboration group, created by the teacher, included students with very different levels of mathematical knowledge. Even though Vera was agentic and active despite the difficulties she had with the mathematics, Julia, whose mathematical knowledge was the weakest according to the teacher interview,

remained almost silent and ignored by the other students throughout the session. This study reminds us to pay attention to the structural agency (e.g., student grouping) even when we investigate interpersonal agency behaviors (cf. Kumpulainen et al., 2018). It especially suggests to teachers to carefully consider whose agency they support and restrict through the student grouping.

4.5. Conclusion

The novel approach to the use of CAID coding in this study focusing solely on the agency dimension provides us with an opportunity to complement interpersonal and socio-cultural definitions of agency, by noticing the presence of the structural agency in the formation of the situational interpersonal agency behaviors.

Theoretically, agentic complementarity means reciprocity in individual variations (Sadler et al., 2009), whereas shared learning goals require collaboration and sharing of the agency. Our data showed that the purposeful use of high levels of agency of one student can benefit the group in achieving its goals. Accepting the agentic noncomplementarity was beneficial for the group, as the learning goals were collaborative rather than competitive (cf. Markey et al., 2010). However, this acceptance requires social skills that protect the students from quarreling or pursuing one's individual interests. Teachers can strategically acknowledge the purposeful use of noncomplementarity of agency as a part of collaborative problem-solving. This could help students to notice those moments, when gentle opposing of other students' agency could benefit achieving the shared goals.

Author statement

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David J. Clarke Conceptualization, Investigation, Supervision, Funding acquisition.

Declarations of competing interest

None.

Acknowledgements

Appendix. Group Tasks

Task A. A group of friends are making some orange drink for a party. They are mixing different amounts of orange concentrate and water. Arrange the mixtures in order from weakest orange flavour to strongest orange flavour:

  (i) Mixture A – one cup of orange with three cups of water
 (ii) Mixture B – three cups of orange with two cups of water
(iii) Mixture C – two cups of orange with four cups of water

(iv) Mixture D – three cups of orange with four cups of water

Explain your answer.

Task B. A recipe for lemon cordial involves mixing teaspoons of lemon juice with teaspoons of sugar. Arrange the following mixtures in order according to which is the sweetest – from least sweet to most sweet.

  (i) Mixture W – three teaspoons of lemon juice with five teaspoons of sugar
 (ii) Mixture X – four teaspoons of lemon juice with six teaspoons of sugar
(iii) Mixture Y – six teaspoons of lemon juice with seven teaspoons of sugar
(iv) Mixture Z – five teaspoons of lemon juice with four teaspoons of sugar

Explain your answer.

Task C. A paint company makes four shades of brown paint:

  (i) Mixture K - By mixing 1 L of white paint with 2 L of dark brown paint
 (ii) Mixture L - By mixing 2 L of white paint with 3 L of dark brown paint
(iii) Mixture M - By mixing 5 L of white paint with 8 L of dark brown paint
(iv) Mixture N - By mixing 7 L of white paint with 12 L of dark brown paint.

Arrange the mixtures in order from lightest brown to darkest brown. Explain your answer.

Task D. In a week, a taxi driver carried three times as many women as men and four times as many children as men. If he carried 36 children, how many women did he carry that week? Explain your answer.

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