THE IMPORTANCE OF INDIVIDUAL WORK IN COLLABORATIVE DESIGN MEETING: IMPACT ON DESIGN TOOLS AND METHODOLOGIES

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ABSTRACT

This paper demonstrates the importance of individual work in collaborative design meetings based on Granger' causality and discusses how this impacts design tools and methodologies.

Based on Tucker's et al. CIAO model of globally collaborative work which allows distinguishing the main modes of interaction during a meeting, our research identifies the patterns or sequences of those interaction modes according to the Granger causality concept. Granger causality makes it possible to identify a temporal precedence of events without necessarily implying causality.

The results show that individual work plays a key role in achieving collaborative work. However, other factors such as the nature of the meetings and the objectives pursued also influence the sequences of interaction of the different modes.

These first results allow making recommendations on collaborative work methodologies and support mechanisms for collaboration. For instance, the ability of digital devices to facilitate the simultaneous individual work of participants in a collective space is a key factor and the ability to preserve sequences for individual work during a design meeting should be monitored to keep global efficiency.

Keywords: Collaborative design, Granger, Design methodology, CSCWD, Design methods

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1 INTRODUCTION

The ability of individuals to collaborate is highly demanded in society, as in the professional world and a fortiori in universities. Collaboration has been at the heart of institutional concerns in recent years and has resulted in the development of numerous research projects. Our Cré@tion project (Collaboration, Reflexion, Activities and Innovative Digital Works) was born in this context. It aims to understand what is at stake when learning about and through collaborative work. It should lead to the development of instrumented collaborative pedagogical practices in school environment using tactile digital technologies. This research is based on previous work on Computer-Supported Cooperative Work (CSCW) (Correia et al., 2018; Wainer and Barsottini, 2007; Wallace et al., 2017). The challenge of the project is to allow the design of models to understand the processes of collaborative work and learning in school and professional spaces.

Based on a partnership in France, between the University of Lille (UL), the University of Technology of Compiègne (UTC), and the Academy of Amiens, this project uses the technology available in *La Halle Numérique* of the UTC (figure 1). This platform consists of five meeting rooms, each of these digital spaces is composed of a large tactile table and a large tactile board. Each of these horizontal and vertical surfaces is equipped with the Ubikey® Office software suite[1] which allows the simultaneous interaction of several people on the same surface. Users can write virtual Post-it® notes, draw, search the web, use canvas, build various types of diagrams and spreadsheets, etc. on both surfaces. These devices are connected to the network and the software allows fluid exchange of data between table and board as well as with any type of terminal (computer, tablet, smartphone) with a network connection and an internet browser (Guerra et al., 2017). Those devices were developed during several research projects at the UTC. They facilitate the collaborative design process of engineering students.

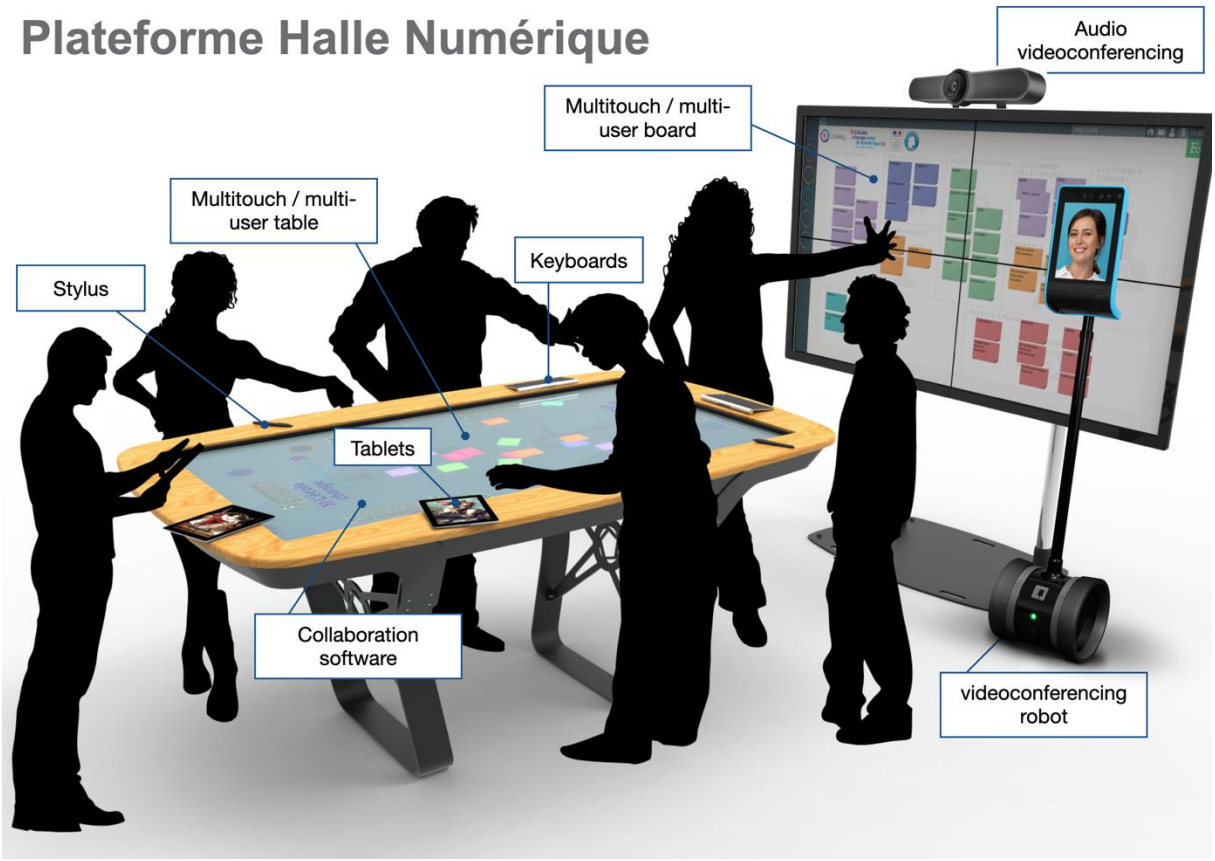

Figure 1. A meeting room in Halle Numérique is composed of a large tactile table and a large tactile board. Other devices could be connected.

[1] See https://www.ubikey.io

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To better understand what is at stake when collaboration occurs during group work, Tucker & al. (Tucker et al., 2019) have analysed collaboration through behaviour, in particular verbalisations (Sizmur, 1996; Soller, 2001) as well as gestures and movements (Zumbach et al., 2005). They have demonstrated the complexity of the notion of collaboration and proposed the concept of globally collaborative work which is formalised by the CIAO model – Collaborative Interaction Analysis mOdel (Tucker, 2020; Tucker et al., 2019). The authors rely on five modes of interaction that describe overall collaborative work in a finer way by identifying individual work, communication, coordination, cooperation and collaboration. They characterised these modes of interaction according to the targeted production and the complexity of interaction required to implement them.

Individual work is defined as the moments when individuals take a step back in order to reflect and construct their ideas (Teasley and Roschelle, 1995) as well as to carry out tasks assigned to them by the group. It is a privileged moment that allows the externalisation of thought using intermediate states of representation (Boujut and Blanco, 2003).

Communication is the transmission of a message from one person to another one or several others via a channel (Shannon, 1948). This mode of interaction allows individuals to introduce new information into the group, providing a starting point for a shared vision (Teasley and Roschelle, 1995).

Coordination refers to the organisation of activities (events, tasks and actions) so that they fit together and synchronise (Baker, 2015).

Cooperative work occurs as a result of the distribution of tasks and responsibilities carried out in order to accomplish a collective task. Indeed, after having distributed and then, each one carried out part of the work and it is then necessary to put the works together (Baudrit, 2007; Bruffee, 1995; Panitz, 1999). This pooling requires negotiation and efforts to synchronise the representations of each of the participants. Adjusting the different pieces of the puzzle therefore requires cooperative work.

Collaborative work, on the other hand, occurs during the co-development, co-construction or co-evolution of a set of tasks that are carried out by all the participants with a common goal (Baker, 2015; Teasley and Roschelle, 1995). At the end of a collaborative work, it is no longer possible to distinguish the individual contribution of each participant, because the contributions of each have been taken up, modified, amended and have come to be enriched with each other. This is what differentiates it from cooperative work, which results from the assembly of individual work.

2 RESEARCH QUESTION AND HYPOTHESES

To enrich the research initiated by the UTC (Gidel et al., 2020; Kendira et al., 2011; Moulin et al., 2016, 2011) we now ask the question of the link between those modes of interaction that constitute the globally collaborative work model. The CIAO model identifies five modes of interaction during a globally collaborative work meeting: individual work, communication, coordination, cooperation and collaboration (Tucker, 2020; Tucker et al., 2019). We would like to identify patterns or sequences of interaction between those modes and ultimately see if collaborative work methodologies and CSCW devices can influence those links.

We analysed the data collected over four consecutive collaborative work meetings in *La Halle Numérique* over the autumn 2019 period in order to test our research hypotheses. We made the following assumptions:

- H1: Individual work precedes (comes before) communication
- H2: Communication precedes (comes before) cooperation and globally collaborative work, these last two modalities being strongly intertwined.

The term “comes before” must be understood in the sense of Granger (Granger, 1980, 1969). It isn't a causal link in the true sense of the word. It is only the translation that an observation has precedence over another one. In the following sections, the term “Granger-causes” means that the value of a first-time series is useful for predicting the value of a second time series at a later time period.

H1 hypothesis might seem counter-intuitive, but it was identified as a possible explanation by (Tucker, 2020; Tucker et al., 2019) and we wanted to verify this hypothesis. When we usually describe collaborative work, we tend to focus on the collaboration itself neglecting what prepares this collaboration. But Tucker identifies that to foster collaboration it is necessary to first allow individual work.

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3 RESEARCH METHODOLOGY

The global experiment population involves 24 students divided into 5 groups of 3 to 5 students in 5 meeting rooms. Each of these meeting rooms is equipped with a digital device consisting of a large tactile board and a large tactile table (figure 1). In order to guarantee an in-depth analysis of the data, we focused the study on a group of 5 individuals in meeting room n°4. This choice was made because of the large amount of data collected over the 4 meetings, i.e. a total of 4h10 video capture and recording of digital traces.
Meetings in *La Halle Numérique* were recorded using a video capture system of 20 cameras ENEO HD/SDI model (4 cameras per meeting room) and 5 semi-spherical microphones ELECTRET (1 microphone per meeting room) over the period of autumn 2019 during design / value analysis teaching meetings at UTC's *Halle Numérique*. The recording principle is based on 4 HD SDI cameras per box as well as an audio recording microphone connected to a QUAD (Blackmagic Multiview 4), itself connected to a recorder. The streamer (EXTRON) with 32 GB internal memory allows synchronising and merge these audio and video streams.

The data comes from four different educational meetings, each one is case based and is introducing specific tools:
• Banknotes transport case: students should identify and analyse the main function and associates technical solutions of a case used for transporting banknotes based on a system that tainted the banknotes in case of robbery. This involves practising functional analysis and formatting a FAST (Function Analysis System Technic) diagram. The video recording time of the meeting is 1h06.
• Causal analysis of the main function of a car windshield ice scraper: students should analyse a situation where an ice scraper is used, understand the causes that require such a function and the expected consequences. Based on this analysis, they must propose alternative solutions. The video recording time of the meeting is 1h30.
• Primary school student's schoolbag: in this case, students are asked to reduce the weight of a primary school student's schoolbag without using digital solutions. To carry out this activity, they must first identify which tool to use, analyse the functions of the different components of the schoolbag and look for solutions, in particular by finding functional synergies. Design to cost model should be used. The video recording time of the meeting is 0h39.
• Recruitment résumé and cover letter: students examine a request from a recruiter who is dissatisfied with these traditional résumé/cover-letter pairing. They were given a list of questions to answer. The tools to be used are sometimes provided while other questions required students to choose which tool to be used. This activity requires the use of several functional analysis tools in order to prepare students for an exam. The video recording time of the meeting is 0h55.
At the end of each case, the students present their final production to the professor for evaluation. Prior to the group activity, a collective briefing is carried out by the teacher and after the group activity, takes place a collective debriefing.

Time	Collaboration	Cooperation	Coordination	Communication	Individual Work	Teacher Intervention
00:11:30	0	0	0	0	0	0
00:12:00	0	0	0	0	0	0
00:12:30	0	0	0	0	0	0
00:13:00	0	0	1	0	1	0
00:13:30	0	0	0	0	1	0
00:14:00	0	0	1	0	1	0
00:14:30	0	0	1	1	1	0
00:15:00	0	0	0	1	1	0
00:15:30	0	0	0	0	0	1
00:16:00	0	0	0	0	0	1
00:16:30	0	0	0	0	1	1
00:17:00	0	0	0	0	0	1
00:17:30	0	0	1	0	0	1
00:18:00	0	0	1	1	1	0
00:18:30	0	0	0	1	1	0

Figure 2. Example of manual coding result

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Each video is analysed by an operator according to the CIAO modes of interaction and the observations are compiled in a spreadsheet (Figure 2). Each interaction is coded according to a time range of thirty seconds. This time range was determined as the right balance to identify the maximum number of actions and changes of actions.
Figure 2 shows the coding of a meeting in a spreadsheet. Each column contains a numerical sequence where the value 1 corresponds to the observation of the interaction and 0 to the absence of observation. The spreadsheets of the four meetings were then exported in CSV format files to be used by Python programs. The curves represented in figures 3, 4 and 5 correspond to the cumulative values of the numerical series observed.
Data have been analysed according to the Granger's Null-hypothesis (H0). This null hypothesis for a test between two series x and y is that lagged x-values do not explain the variation in y. It assumes that x(t) doesn't Granger-cause y(t). The negation of H0 is the Alternative Hypothesis (HA) where a time serie x Granger-causes a time serie y.
We implemented Granger Causality test using the "grangercausalitytests" function present in the statsmodels python library and following the indications of the "machinelearningplus" article[2]. This function takes two time series x and y as inputs and gives results in order to reject or not the H0 between x and y. Among the results of this function we got coefficients corresponding to past values of the first time series. The Null hypothesis for the function "grangercausalitytests" is that the time series x, does not Granger cause the time series y. Grange causality means that past values of x have a statistically significant effect on the current value of y. The null hypothesis that x does not Granger cause y, is rejected if the past values are below a desired size of the test. As in the article, we created a function designed to perform the tests on all combinations of variables of the input dataset in one shot. The result of the function is a matrix where the rows are the response variables and columns are the predictors. The values in the matrix are the P-Values. P-Values lesser than the significance level (0.005), implies H0 hypothesis that the variable x (label in the first line of the table 1) does not cause y (label in the first column of the table 1) can be rejected.

4 RESULTS

We analysed all the data available coming from 4 meetings of the same team carried out in room 4. From meeting 1 to meeting 4. Tables 1 (S2B4, meeting 1), 2 (S3B4, meeting 2), 3 (S4B4, meeting 3) and 4 (S5B4, meeting 4) show the results.
Table 1 gives the results of the Granger test for the series S2B4.

Table 1. Granger test for series S2B4

	Collaboration_x	Cooperation_x	Coordination_x	Communication_x	Individual Work_x	Teacher Intervention_x
Collaboration_y	1.0000	0.0000	0.0766	0.0001	0.0061	0.0383
Cooperation_y	0.0000	1.0000	0.0897	0.0000	0.0053	0.0922
Coordination_y	0.1151	0.1890	1.0000	0.0493	0.0811	0.1437
Communication_y	0.0078	0.1578	0.0000	1.0000	0.0000	0.0104
Individual Work_y	0.3167	0.2501	0.0012	0.0103	1.0000	0.1872
Teacher Intervention_y	0.0040	0.0056	0.0097	0.0524	0.0015	1.0000

Analysing the cells containing 0 as value, we observe that Collaboration and Cooperation are mutually dependent and that in one part Coordination precedes Communication that itself precedes Cooperation and from other part that Individual Work precedes Communication that itself precedes Cooperation.
Figure 3 shows that the augmentation of the Coordination curve precedes the augmentation of the Communication curve which precedes the augmentation of the Collaboration curve.

[2] See https://www.machinelearningplus.com/time-series/granger-causality-test-in-python/ for more information

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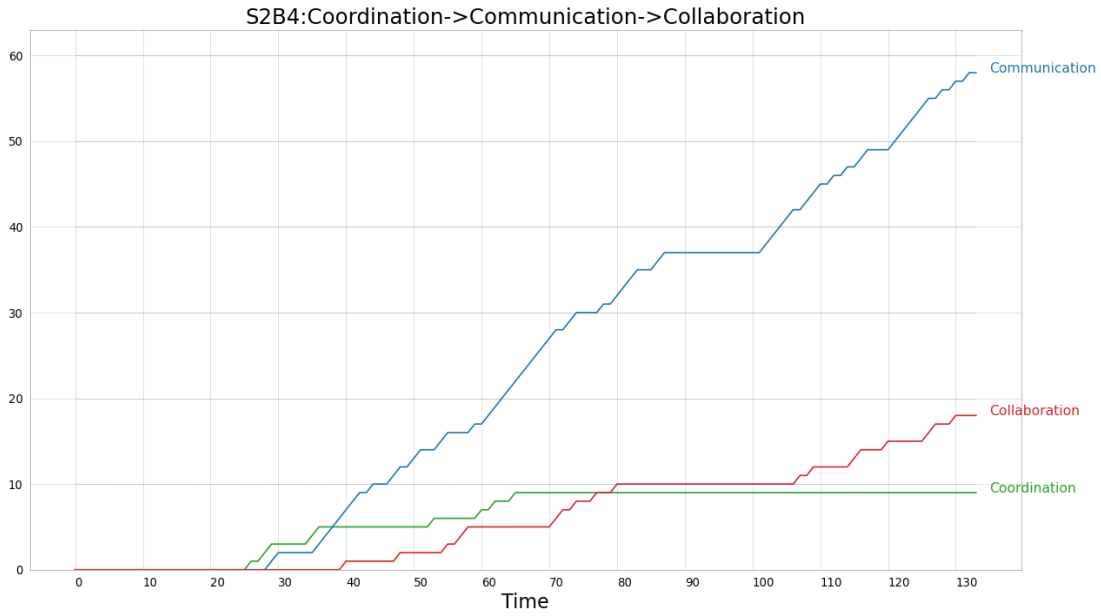

Figure 3. Granger test for series S2B4 Coordination – Communication – Collaboration

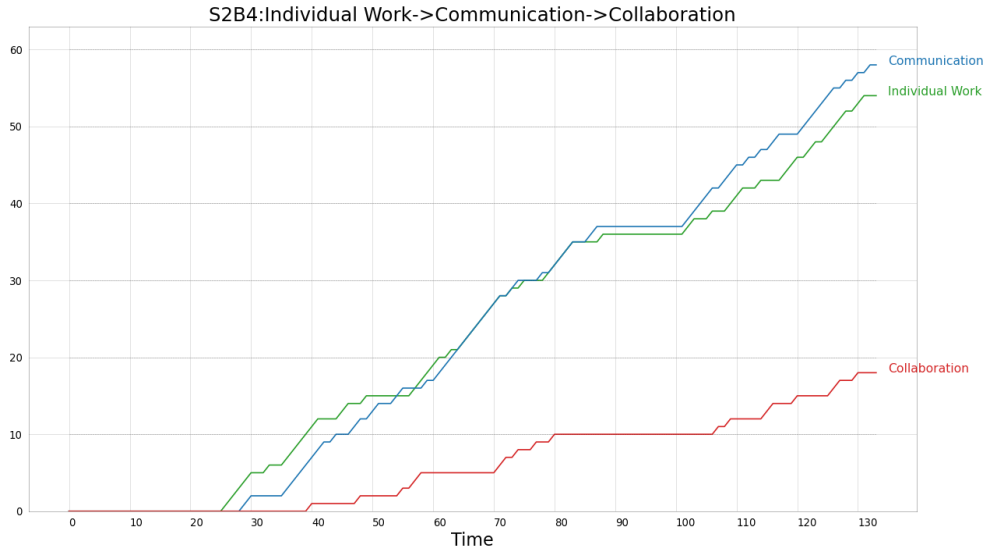

Figure 4. Granger test for series S2B4 Individual work – Communication – Collaboration

Based on Granger's assumptions, we analysed all the data available to us from meeting 1 to meeting 4. Tables 1 (S2B4, meeting 1), 2 (S3B4, meeting 2), 3 (S4B4, meeting 3) and 4 (S5B4, meeting 4) show the interactions causing other interactions (in the sense of Granger).

Table 2. Granger test for series S3B4

	Collaboration_x	Cooperation_x	Coordination_x	Communication_x	Individual Work_x	Teacher Intervention_x
Collaboration_y	1.0000	0.0002	0.0074	0.0014	0.0000	0.0607
Cooperation_y	0.0013	1.0000	0.1752	0.0003	0.0047	0.0090
Coordination_y	0.1625	0.3823	1.0000	0.0000	0.0189	0.0001
Communication_y	0.1877	0.1536	0.0006	1.0000	0.0000	0.0000
Individual Work_y	0.0000	0.0260	0.0345	0.0237	1.0000	0.0001
Teacher Intervention_y	0.0101	0.0058	0.0134	0.0227	0.0095	1.0000

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Table 3. Granger test for series S4B4

	Collaboration_x	Cooperation_x	Coordination_x	Communication_x	Individual Work_x	Teacher Intervention_x
Collaboration_y	1.0000	0.1176	0.0067	0.0000	0.0036	0.2400
Cooperation_y	0.0099	1.0000	0.0000	0.0520	0.0012	0.0204
Coordination_y	0.0233	0.0000	1.0000	0.0255	0.0301	0.0001
Communication_y	0.1936	0.0001	0.0080	1.0000	0.0000	0.0091
Individual Work_y	0.0135	0.0007	0.0141	0.0000	1.0000	0.0000
Teacher Intervention_y	0.0004	0.3740	0.0044	0.0134	0.0026	1.0000

Table 4. Granger test for series S5B4

	Collaboration_x	Cooperation_x	Coordination_x	Communication_x	Individual Work_x	Teacher Intervention_x
Collaboration_y	1.0000	0.0007	0.2592	0.0001	0.0269	0.0001
Cooperation_y	0.0001	1.0000	0.0040	0.0099	0.0029	0.1643
Coordination_y	0.0007	0.2122	1.0000	0.0025	0.0091	0.1752
Communication_y	0.0000	0.0003	0.0818	1.0000	0.0051	0.0075
Individual Work_y	0.0408	0.8791	0.0062	0.0064	1.0000	0.2083
Teacher Intervention_y	0.0101	0.0000	0.0865	0.0014	0.0040	1.0000

We can observe a relationship between individual work and communication interactions in the first three meetings (cf. Table 1, 2 and 3). The values (0.0000) in the cell Individual Work_x, Communication_y make it possible to conclude that the first set of data relating to individual work Granger causes the second - that of communication. This situation is indeed observed at the beginning of the sessions, where each student starts learning the subject individually and then shares his or her understanding with the other team members. The Post-it note writing phases observed on the videos are also representative of this relationship in the various sessions. Indeed, if we take the example of session 2 (S3B4) we observe a reflective phase where each of the members layers their ideas on the canvas supporting the methodological tools, then participates in the debate on the different contents that have been proposed. In the same way, the search for information on a search engine initiated by a student during session 3 (S4B4) had an impact four minutes later on the group's representation of the studied object. Thus, the individual work is followed by an exchange with others and produces a collective interrogation. The result of the case Individual Work_x, Communication_y differs slightly from meeting 4 (0.0051), which seems atypical. This is probably due to the specific nature of meeting 4 that involves several methodological tools instead of one or two in the previous three meetings.
Those results of the first 3 meetings tend to confirm our first hypothesis (H1): individual work mainly precedes the communication phases.

We may also observe that communication predicts cooperation/collaboration interactions in all meetings. We can note that values are very close to each other's in those meetings (S2B4: communication_x cooperation_y, 0.0000 and communication_x collaboration_y, 0.0001, S3B4: communication_x cooperation_y, 0.0003 and communication_x collaboration_y, 0.0014, S4B4: communication_x cooperation_y, 0.0520 and communication_x collaboration_y, 0.0000, S5B4: communication_x cooperation_y, 0.0099 and communication_x collaboration_y, 0.0001).

Therefore, we can observe that Individual work Granger cause Communication and Communication granger cause cooperation/collaboration. This takes place already in the first few minutes of the session. This is the case in session 2 (S3B4) where it starts after four minutes. Indeed, as early as the fourth minute of the session, one of the students raised questions, which are taken up and completed by other members of the group in order to construct a meaningful final common answer. Observing the interactions recorded during session 1 (S2B4) the sequence of individual work / communication /

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cooperation / collaboration activities appears later. 24 minutes of interactions between students are needed before reaching a consensus on the resulting work. During the first 24 minutes, individual work is formalised by intermediate state of representation. This externalisation of the thought process allows communication which in turn precedes the collaboration which results in a common work. This sequence of activities seems structured and supported by the methodological tools.

5 DISCUSSION

We were able to observe a link between different modes of interaction. Based on Granger Causalty tests we know that individual work Granger causes (or precedes) communication. Also, communication Granger causes (or precedes) cooperation/collaboration.
Therefore, this data analysis based on Granger Causalty test confirms the initial results of Tucker & al. (Tucker, 2020; Tucker et al., 2019). That is, data analysis confirms that individual work predisposes collaboration.

These results may seem counter-intuitive, because they imply that to foster collaboration, one must first allow individual work. This can have significant consequences in the organisation of collaborative work meetings and the use of technical devices supporting these meetings. We now know that allowing each person in the group to carry out individual work by granting time and providing individuals with an input interface becomes essential to achieve teamwork.
Although it may seem counter-intuitive at a first glance, it is nevertheless coherent with works on collective intelligence (Woolley et al., 2010), that have demonstrated that collective intelligence increases when each participant in a group could have the same amount of participation in the group.
Based on figures 3 and 4 (graph of meeting 1 S2B4) we can deduce that the coded interactions from the thirtieth minutes follow one another, until an intertwining between individual work and communication. The interactions relating to collaboration are preceded by that of communication, which confirms the hypothesis of the sequence of individual work, communication and collaboration.

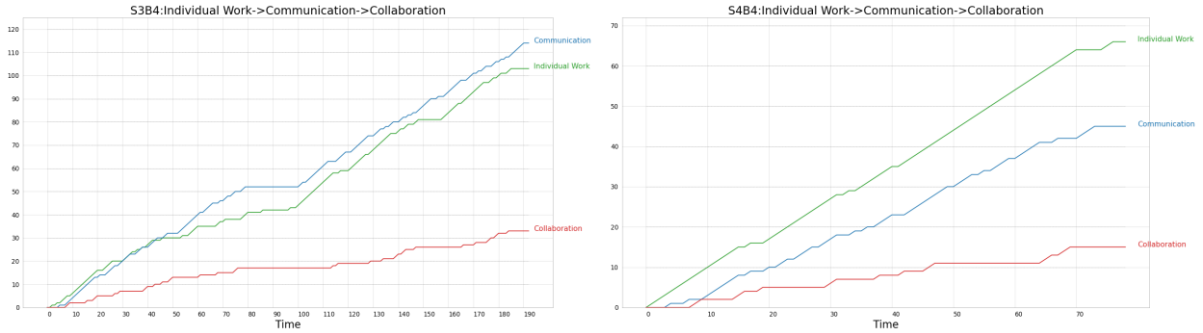

Figure 5. Meeting S3B4 series Individual work – Communication – Collaboration and meeting S4B4 series Individual work – Communication – Collaboration

Figures 5 (Meeting 2, S3B4 and Meeting 3, S4B4) demonstrate a similar dynamic, which takes place much earlier during these two meetings than during the first meeting. This can be explained by the need, during the first meeting, to get to grips with digital and educational tools.

Table 4 shows that one meeting differs from the others. Its configuration induces the construction of individual work with an influence linked to coordination. This can be explained by the nature of this meeting which does not aim to learn one methodological tool like causal analysis, but on the ability to choose the right methodological tools to solve a problem before using them. Therefore, it is necessary for students to coordinate their actions before they can perform work together. The specificity of this last meeting seems to demonstrate that the very nature of the meetings can also have a significant impact on the modes of interaction. Further studies are needed to confirm this hypothesis.

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6 CONCLUSION AND PERSPECTIVES

This research work allows us to better understand the links between the different modes of interaction in a globally collaborative work. We are now able to state that individual work precedes communication that precedes cooperation / collaboration.
These first results demonstrate the importance of individual work phases for globally collaborative work. Consequently, collaborative work methodologies and devices must allow and even facilitate individual work. That is to say that, on the one hand, the interfaces must allow simultaneous individual production of all the participants, and, on the other hand, that the methodologies must integrate sequences to allow these individual expressions. Granting time for simultaneous individual during a collaborative meeting seems to be a key factor.
Finally, even if this remains to be confirmed by more in-depth studies, the variability of the nature of globally collaborative work meetings requires methods and instrumentation (digital devices) allowing a fluid and flexible sequence of the different modes of interaction: individual work, communication, coordination, cooperation, collaboration. Indeed, even if the possibility of carrying out individual work seems to be the basis of the other modes of interaction, the sequence of the different modes of interaction seems to depend on the objectives and the nature of the work meetings.
This research has allowed us to better understand the role of the different modes of interaction in a globally collaborative meeting and to identify patterns or sequences of these modes of interaction. Granger's approach, which makes it possible to identify a temporal precedence of events without necessarily demonstrating its causality, seems promising for a better understanding and analysis of these patterns. This will help ensure that the methods and devices supporting collaboration are well adapted to the needs of users.

Further research is needed to first confirm those results on a wider sample and then investigate in more detail those sequences of interaction.
Also, it would be necessary to better understand and monitor the various parameters that could influence those interactions. We discussed the impact of the meeting typologies and associated methodological tools used in those meetings: this is an interesting path to follow as it could lead to a better understanding of the tools to be used to achieve a better collaboration.
Another research question would be linked to the people themselves. Based on some data analysis other than those used in this study, we could notice that changes in the team configuration also impact patterns or sequences of interactions. This also need to be further investigated in future research.

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