Design of asynchronous mathematical discussions on Padlet: Analysis of students' social modes and teacher's roles

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In this study we focus on the design of a digital environment aimed at mediating a collective asynchronous mathematical discussion. According to the design-based research approach (Cobb et al., 2003), we discuss the design of a digital environment with respect to students' participation and collaborative interactions and teacher's interventions, by referring respectively to a framework to analyse the collaborative processes realised within computer-supported learning environments (Weinberger & Fischer, 2006) and a framework aimed at characterising the teacher's roles in orchestrating mathematical discussions (Cusi & Malara, 2013). The results of this analysis provided us with significant insights that suggest both elements for a re-design of the digital environment and new directions for further research to be developed on the role of the teacher in orchestrating asynchronous mathematical discussions within digital environments.

Keywords: Asynchronous mathematical discussion, design of digital environment, role of the teacher.

Introduction and theoretical background

In this paper we present the first results of a pilot study that is part of a wider research project aimed at investigating the role of digital environments in supporting mathematical discussions conducted in an asynchronous way.

Mathematical discussion can be defined as "a polyphony of articulated voices on a mathematical object, that is one of the motives of the teaching-learning activity" (Bartolini Bussi, 1996, p.16) and, usually, it is delivered synchronously and in presence. The M-$_{AE}$AB (model of aware and effective attitudes and behaviours) construct has been developed to highlight the key roles played by the teacher during mathematical discussions (Cusi & Malara, 2013). This construct identifies two main groups of teacher' roles: (1) the roles belonging to the first group (investigating subject, practical-strategic guide, activator of anticipating thoughts, activator of interpretative processes) are those performed when the teacher poses him/herself as a learner who faces problems making the hidden thinking visible, highlighting the objectives, the choices of the strategies and the interpretation of results; (2) the roles belonging to the second group (guide in fostering a harmonised balance between the syntactic and the semantic level, reflective guide, activator of reflective attitude and metacognitive acts) are those mainly played with the aim of fostering students' reflections at a metacognitive level, focusing on thinking processes and on the effectiveness of the implemented strategies.

Research has already focused on the potentialities of digital resources in supporting synchronous mathematical discussions, highlighting the support that digital technologies give to teachers in monitoring students' work, in collecting their written solutions and in selecting and grouping excerpts from students' solutions to be displayed with the aim of fostering comparison and reflections (Cusi et al., 2017). The role of digital technologies becomes even more decisive when the focus is shifted to asynchronous discussions, which are characterised by a communication between participants that

are separated in space and time (Andresen, 2009). Research on this issue has shown that digital technologies represent a fundamental answer to the request of flexibility in terms of time and space typical of asynchronous discussions (Resta & Laferrière, 2007), since they support the design of environments that can guarantee to students and teachers the opportunity to take their own time in reading others' posts and comments, preparing thoughtful responses and reflecting upon their contributions (Andresen, 2009). Moreover, digital environments can help keep track of students' collaborative work (Resta & Laferrière, 2007) since the use of a written form of communication makes the discussion and the process of collaboration more transparent, enabling the analysis of transcripts from the discussion both in terms of group collaborative processes and of individual contribution to these processes (Macdonald, 2003). Although the fundamental support provided by digital technologies, online interaction, as in-presence interaction, is influenced by the ways the teacher plans, structures and supports it (Resta & Laferrière, 2007). More specifically, Andresen (2009) reports that the instructor's discussion design is more important than any technology chosen to mediate the discussion and, for this reason, in our study the design of the asynchronous mathematical discussion is supported by referring to the M-$_{AE}$AB construct, as detailed in the next paragraph.

Research has highlighted that a key challenge for the development of asynchronous discussions is to effectively engage students since often very few of them actively contribute (Hew & Cheung, 2012). The study presented in this paper addresses the issues of quantity and quality of students' participation in asynchronous mathematical discussions through the lens provided by Weinberger and Fischer (2006)'s framework. This framework, which is aimed at the analysis of the process dimensions of knowledge construction that characterise students' interactions within computer-supported collaborative learning environments, consists of four dimensions. In this study we focus on two of them: the participation dimension, which refers to the quantity and the heterogeneity of participation; and the dimension of social modes of co-construction, that refers to how learners formulate arguments referring (or not) to other learners' contributions. The different social modes are characterised according to the degree with which learners refer to the contributions of the other participants: (a) Externalization (EX), when learners' contributions to the discourse are made without (implicit or explicit) reference to previous contributions; (b) Elicitation (EL), when information, feedback or specific actions from other participants are requested; (c) Quick consensus building (QC), when some contributions are accepted by participants just to move on with the discourse and without taking charge of them; (d) Integration-oriented consensus building (IC), when learners' contributions are integrated and their perspectives are taken over; (e) Conflict-oriented consensus building (CC), when some contributions are replaced, modified or supplemented.

Research context and design of the activity "Digital Mathematical Discussion"

To develop our investigation, we adopted a design-based research (DBR) approach (Cobb et al., 2003), which involves cycles of design, enactment, analysis and re-design. The pilot study documented in this paper is set within the first cycle of DBR and is aimed at investigating the design and implementation of an activity - the "Digital Mathematical Discussion" (in the following, DMD) - to be implemented within a digital environment that involves the combined use of an instant messaging platform (Telegram) and a collaborative web platform (Padlet, https://padlet.com/).

This study involved a group of 31 preservice primary school teachers (in the following, PTs) enrolled at the first year of the master-degree course "Primary education sciences" at Sapienza University of Rome. The PTs were attending a 48 hours course aimed at making them develop reflections on specific mathematical contents and processes and on specific pedagogical aspects of mathematics teaching-learning. This sample was chosen since the teaching methodology adopted during the course encompassed small group collaborative problem solving activities and classroom discussions designed and orchestrated by the teacher educator (one of the authors) starting from groups' written productions to foster comparison and reflections.

The DMD activity in which PTs were involved is structured in two main phases. The first phase consists in a small group activity aimed at collaboratively solving a mathematical problem within Telegram chats. PTs are given a few days (4 days in this study) to collectively face the problem through the chat and to create a shared solution that has to be sent by one member per group to the teacher educator through an institutional platform (e.g. Moodle). The task (Figure 1) proposed for the first phase of the DMD activity was aimed, in tune with other activities within the course, at making PTs experience the use of algebra as a thinking tool by stimulating processes such as exploring, conjecturing, argumenting and proving.

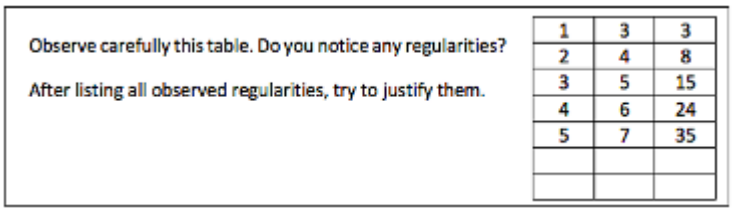

Figure 1: The task faced by PTs within the Telegram chats

The second phase of the activity, carried out within Padlet, starts as soon as all the groups submit their solutions. This second phase involves all the PTs in a collective discussion designed by the teacher educator starting from selected excerpts from the groups' solutions (Cusi et al., 2017) and from significant interactions that emerged in the Telegram chats. The Padlet is structured in columns arranged by the teacher educator, who boosts the discussion through interventions aimed at activating specific roles of the M-$_{AE}$AB construct. Each column in the Padlet concerns a different issue on which the teacher educator wants to focus during the collective discussion. PTs can comment on the teacher educator's inputs and on other PTs' contributions present in the Padlet for a few days (in our study 4 days). At the end of the asynchronous discussion, an in-presence whole-class discussion is carried out in order to further elaborate on salient aspects emerged within the chats and the Padlet, both concerning the mathematical content faced during the activity and meta-reflections related to the experience of conducting an asynchronous discussion in a digital environment. In the study presented in this paper we focus on the second phase of the activity, the collective asynchronous mathematical discussion carried out on Padlet.

Design of the Padlet for the pilot study

After having collected the written answers uploaded by the groups of PTs (totally 5 groups of 5-7 people), the teacher educator enacted the second phase of the DMD activity, by designing the Padlet for the collective discussion. The interventions written at the top of the columns within the Padlet

were designed by referring to the roles identified by the M-$_{AE}$AB construct. At the top of the first, second and third column in the Padlet the teacher educator's interventions are in tune with the role of *activator of reflective attitudes and metacognitive acts*, since they are designed to stimulate reflections by asking to PTs to compare the different formulations of the conjectures, to reflect on them and to identify those that are the most complete, correct and clear. For example, the teacher educator's intervention at the top of the first column is: "All groups formulated the following conjectures. What are the formulations that are the most complete/clear/correct?". The intervention at the top of the fourth column in the Padlet refers both to the roles of *practical-strategic guide* and *activator of interpretative processes*, since the aim is to foster the sharing and comparison between strategies to generalise and to justify: "Some groups observed that the numbers within the even lines in the table are even, while the numbers within the odd lines in the table are odd. How could we justify this conjecture?". Finally, the roles to which the teacher educator's interventions refer in the fifth and sixth columns in the Padlet, added two days later, are those of *activator of interpretative processes* and *reflective guide*, since PTs are asked to focus on some excerpts of the groups' answers to reflect on the role played by the use of algebraic language as a proving tool. This is, for example, one of the teacher educator's interventions within the sixth column in the Padlet: "Some groups introduced algebraic symbolism in their answers. Do you think that all the texts written in the following excerpts are proofs?".

Research questions and methods

Through the combined use of the lenses provided by the two theoretical components presented in the first paragraph, we aim at investigating the following research questions: What kind of collaborative processes, according to Weinberger and Fischer's (2006) participation dimension and the dimension of social modes of co-construction, can be observed during the asynchronous discussion within the second phase of the DMD activity? What are the possible factors that affect the quality and quantity of PTs' participation?

To investigate the ways in which PTs communicated and collaborated with each other within the Padlet, we combined the analysis of the quantity of their participation with the qualitative analysis of their interventions on the Padlet, developed by referring to two of the four dimensions introduced by Weinberger and Fischer (2006), that is the participation dimension and the dimension of social modes of co-construction. The quantity of PTs' participation was investigated by counting the number of interventions written by each PT within the Padlet. The qualitative analysis of PTs' interventions was developed by coding them according to Weinberger and Fischer's categories of social modes of co-construction. A detailed description of the coding is presented in Table 1.

To highlight possible factors affecting PTs' participation in the discussion within the Padlet, we also collected their reflections on the experience of participating in the DMD by means of a written questionnaire (available at Gagliani Caputo et al., 2023). The questions asked in relation to the phase of the DMD activity developed within the Padlet were focused on aspects such as: (1) PTs' opinion about the quantity and quality of messages written by them within the Padlet, (2) the difficulties they faced in participating in the second phase of the DMD activity compared to the first phase, (3) the

usefulness of working in an asynchronous way, (4) the reflections on the comparison between classroom discussions in presence or within the Padlet.

Data analysis

Analysis of PTs' interventions within the Padlet according to the categories of social modes of co-construction

The excerpt in Table 1, taken from the third column of the Padlet, exemplifies how the qualitative analysis of PTs interactions within the Padlet was carried out by coding PTs' interventions according to Weinberger and Fischer's categories of social modes of co-construction. Within the excerpt, a discussion is developed about a conjecture, submitted by one of the groups, on some relationships between consecutive numbers of the third column of the table in Figure 1. At the top of the third column in the Padlet, the teacher educator writes this intervention, in tune with the role of *activator of reflective attitudes and metacognitive acts*: "Do you agree with the following conjectures proposed by two groups?". The two following posts in the third column, created by the teacher educator, consist in the screenshots of the two conjectures to be discussed. The excerpt in Table 1 concerns the discussion about the first conjecture posted in the Padlet, the conjecture is reported in the first line.

Table 1: The coding of the discussion on the first conjecture in the third column of the Padlet

The first conjecture discussed in the third column of the Padlet: "Concerning the third column of the table we can notice that 3+5=8+7=15+9=24+11=35 and therefore each successive number is obtained by adding an odd number to the number you start with."	
Excerpt from the transcript of the Padlet	**Coding of the interventions according to the dimension of social modes of co-construction**
12/12/22, 23:24 O: I agree with the observation, but not with its representation. The sign "equal" is an equivalence sign: the expressions 3+5 and 8+7 are not equal.	CC - PT O agrees on the content of the observation but not on its representation. Indeed, she tries to point out the problematic nature of the representation proposed.
13/12/22, 22:15 T: I agree with what my colleague O said, it could have been written: 3+5=8; 8+7=15; 15+9=24; etc…	IC - PT T explicitly refers to O's contribution and proposes an integration to O's intervention by proposing a new correct representation.
15/12/22, 18:41 V: I agree with what has been observed by the group, but also with what has been specified by O and T, it would have been better to represent it in a different way.	QC - PT V explicitly agrees with O and T's interventions and rephrases them without changing their meanings.

We selected this specific excerpt from the Padlet since it contains interventions that belong to different kinds of categories of social modes of co-construction. Moreover, this excerpt highlights a trend observed in all the excerpts of discussion within the Padlet, that is the total absence of EL interventions. Our hypothesis is that this is due to the fact that PTs did not interpret the Padlet as a virtual place for comparison, open to new explorations to be developed with all the other PTs. This interpretation emerges from PTs' answers to the final questionnaire, as it is testified from this reflection: "Within the Padlet, the observations formulated by the groups were presented as they were and it was not possible a comparison as it happened within Telegram".

Analysis of the quantity of PTs' participation within the Padlet

The results of the analysis of the quantity of PTs' interventions across the columns of the Padlet is summarised in Table 2, which are compared to the roles associated with the teacher educator's interventions that introduce the discussion within each column of the Padlet.

Table 2: Summary of the analysis of the quantity of PTs' interventions

	Column 1 (3 posts)	Column 2	Column 3 (2 posts)	Column 4	Column 5	Column 6
Teacher's roles	Activator of reflective attitudes and metacognitive acts	Activator of reflective attitudes and metacognitive acts	Activator of reflective attitudes and metacognitive acts	Practical-strategic guide, Activator of interpretative processes	Activator of interpretative processes, Reflective guide	Activator of interpretative processes, Reflective guide
Numbers of PTs' interventions	4 (under the first post), 1 (under the second post), 5 (under the third post)	6	3 (under the first post), 3 (under the second post)	2	2	1
PTs that participate to the discussion	I, S, A, V, L, R	C, O, I, V, S, A	O, T, V, I, A, L	C, T	V, I	V

The table shows that only few comments have been written under each post within the Padlet and highlights the low number of PTs that intervened in the discussion. This suggests that, although, in tune with what usually happened during in-presence mathematical discussions during the course, the roles activated by the teacher educator boost effective PTs' reflections and stimulate PTs' interventions that belong to different categories of social modes of co-construction (like in the excerpt in Table 1), the quantity and heterogeneity of PTs' participation is not satisfactory. In fact, among the 31 PTs that took part in the activity, only 9 commented on the Padlet, most of them with a significantly low number of interventions (as it is evident from the third line of Table 2).

Analysis of the PTs' answers to the final questionnaire: Focus on the factors affecting PTs' participation

The analysis of PTs' answers to the written questionnaire enabled us to identify some factors that, in their opinion, prevented them from actively participating in the discussion within the Padlet. In particular, we focused on PTs' answers to the following two questions: Was it difficult for you to insert comments and reactions and to interact with your classmates within the Padlet? According to you, why was the number of messages written in the Telegram chats significantly higher than the number of messages written on the Padlet?

Among the PTs that took part in the discussion within the Padlet, the majority declares that, although it was not difficult for them to work within the Padlet, the absence of notifications made the Padlet environment static and poor if compared with the environment that they experienced within the Telegram chats, where it was easier to receive feedback and to get "curious to check" what the other PTs wrote. Also affective factors played an important role, as two PTs state: "on Telegram we felt

part of a group and we didn't have fear to be wrong" whereas, when working on Padlet, "I reflected much more before sending my comment for fear of making mistakes". Similar issues emerged within the answers provided by some PTs that didn't participate in the collective discussion on Padlet but actively took part in the first phase of the DMD activity, within the Telegram chats. These PTs, in fact, identified the absence of notifications as a blocking factor for their participation in the activity, stressing that not receiving notifications made them forget about the discussion. Moreover, also these PTs stressed on the role played by social and affective factors in limiting their participation, since they felt "more exposed and less comfortable in publishing observations", due to the high number of people involved in the activity within the Padlet, and the "higher pression of feeling judged and fear of making mistakes". Three additional blocking aspects were identified by the PTs that didn't participate in the discussion on Padlet: the fact that Padlet was not a familiar platform for them; the role played by the Padlet's graphic design and the modalities to intervene in the discussion, as these excerpts from the PTs' answers to the questionnaire testify: "its graphic organisation is dispersive and it is an app I'm not used to use", "my mates had already inserted everything I wanted to write" and "I considered useless rewriting what has already been said".

Discussion

The data analysis presented in the previous section highlighted that, although the PTs' interventions within the Padlet belong to different categories of social modes of co-construction, the quantity and heterogeneity of PTs' participation cannot be considered satisfactory. The few number of PTs that actively participated in the discussion can be ascribed to different blocking factors that they mentioned in their answers, such as affective factors or factors related to the constraints of the digital environment where the DMD activity was implemented. Limited PTs' contribution observed within our pilot study is in line with the experience testified by Hew and Cheung (2012) who highlighted the role played by specific constraints, such as the *technical aspects* connected to the digital environments or the difficulties related to a lack of knowledge about the modalities to contribute.

These results, on one side, support us in the identification of elements for a re-design of the DMD activity and of the ways in which it is implemented within the chosen digital environment and, on the other side, suggest new directions for further research to be developed on the role that the teacher plays in orchestrating asynchronous mathematical discussions. These two aspects are strictly interrelated since we believe that the re-design of the DMD activity should focus also on the roles that the teacher plays in commenting and re-launching students' interventions with the aim of fostering their active participation within the discussion and an effective comparison among them. This reflection suggests that, alongside the two groups of roles characterising the M-$_{AE}$AB construct (aimed at supporting the effective activation of both cognitive and metacognitive processes), a third group of roles must be considered to highlight the kinds of interventions that the teacher could propose to foster students' participation and the activation of effective collaborative dynamics in a context of asynchronous mathematical discussions carried out within digital environments. Having identified some blocking factors that prevent students from actively participating in an asynchronous discussion enables us to shift our focus on possible ways of overcoming them. For the re-design of the activity, we will take into account the management of the cognitive load during mathematical discussions (Richland et al., 2017), by focusing on the identification of an effective graphic

organisation of the environment that could make it easier for students to grasp the structure of the whole discussion. An hypothesis of re-design related to this last issue regards also the possibility of making the different columns of the Padlet visible at different times with the aim of making students focus on one aspect of the discussion at a time. Another re-design hypothesis, related to the aim of fostering comparison during the discussion, concerns the possibility of enabling students to use the Telegram chats even during the collective discussion developed through Padlet. The teacher can encourage students to discuss between each other within the chats before commenting on the Padlet to overcome some of the affective blocking factors that emerged from students' answers. In tune with the DBR approach, the re-design of the DMD activity according to these ideas will be the object of a series of teaching experiments to be carried out during the second cycle of our research.

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