A SOCIAL NETWORK ANALYSIS APPROACH TO A DIGITAL INTERACTIVE STORYTELLING IN MATHEMATICS

Maria Polo[1], Umberto Dello Iacono[2], Giuseppe Fiorentino[3], Anna Pierri[4],

[1] University of Cagliari - mpolo.unica.it
[2] University of Campania "L. Vanvitelli" - umberto.delloiacono@unicampania.it
[3] Italian Naval Academy - giuseppe.fiorentino@unipi.it
[4] University of Salerno - apierri@unisa.it

In this paper we present a social analysis of the interactions among the students involved in a trial of the Italian PRIN project "Digital Interactive Storytelling in Mathematics: a Competence-based Social Approach". The instructional design is based on collaborative scripts within a digital storytelling framework where the story follows the interactions among the characters played by the students and an expert (teacher or researcher). We report the results of a trial that involved teachers and students from the upper secondary school, analysing from a Social Network Analysis point of view the interventions of the expert, the involvement/participation of the students and the interactions among peers and with the expert. We also briefly discuss potentialities and limitations of the currently available tools to perform this kind of analysis, in view of the broader perspective offered by the Learning Analytics approach.

1 Introduction

This work reports a social analysis of the interactions among the students in a classroom trial of the PRIN project "Digital Interactive Storytelling in Mathematics: A Competence-based Social Approach", which is focused on competence-oriented online mathematics learning (Albano & Dello Iacono, 2018a). The project aims to provide a methodology for designing digital interactive storytelling in mathematics (DIST-M) frameworks based on a Vygotskian approach, where learning is first socialized and then interiorized (Vygotsky, 1980). From the mathematics education point of view, this also fits the discursive approach to mathematics learning (Sfard, 2001). Moreover, the story(telling) allows a more contextualized competence-based learning and fosters the confluence of narrative and logical-scientific thinking (Bruner, 1986).

The instructional design is based on collaborative scripts within a digital storytelling framework. Starting from a didactically interesting mathematical problem, we devise personalized learning paths where students (divided into groups) and the expert (teacher or researcher) play well-defined roles. The story evolves according to the interactions among the characters and the stimuli coming from the expert, all mediated by the communication tools available on the online learning platform (Moodle).

We report the results of a trial that involved teachers and students from an upper secondary school. In order to better understand the potential of learning platforms as a contextual factor in mathematics learning, we perform a Social Network Analysis of the interactions among the peers and with the expert, and of the involvement/participation of the students (Albano, Pierri & Polo, 2019a). In this way the expert can also analyse (and possibly address in an appropriate way) peer discussions and measure students' engagement.

2 Theoretical framework

This work integrates findings from different research fields and therefore it cannot be cast within a single theoretical framework. However, we briefly recall the main inspiring theoretical aspects. Our activity design is mainly focused on collaborative learning; in particular, on computer-based collaborative learning (Weinberger et al., 2009), where pre-structuring and regulating social and cognitive processes are clearly prescribed. To this aim we use the concept of *script*, which refers to a sequence of actions directed to define a well-known situation (Schank & Abelson, 1977). In didactics, scripts are typically externally imposed and support students within a collaborative/cooperative learning context by means of roles to play and actions to carry out to succeed in the

story and in learning (King, 2007).

We also follow a collaborative and Vygotskian approach, based on social and individual construction of knowledge, which favours the natural development of argumentative and communicative skills. Students, engaged in the activities planned by the scripts, analyse and explain their reasonings and, by thinking, arguing and interacting with their classmates, can validate their own arguments and take into account those of the others.

All this leads to a deeper and more conscious knowledge. In order to improve the collaborative learning experience, we adapt the scripts to individual and group characteristics by means of adaptive collaboration scripts (Baker, 2003), which are more effective in promoting a better self-regulation of learning (Demetriadis & Karakostas, 2008), especially in online environments (Azevedo *et al.*, 2005).

We also consider the Joint Action Theory in Didactics (JATD) (Sensevy, 2012) to conceptualise the educational process and specify the joint action between teacher and pupils, concerning whether or not to provide the answers. Indeed, if the teacher wants to engage students in the didactic process, he should make them responsible for their learning process. If the didactic process is milieu-driven, the teacher must manage the didactic relationship to make the students explore the milieu and its feedbacks.

3 The design of the digital interactive storytelling

All teaching activities take place within a narrative framework, in a situation that can be engaging and familiar to the student. The setting of the story is science fiction where a group of four friends find themselves communicating with aliens, from whom they receive mysterious messages made up of numbers and mathematical operations (as shown in Figure 1).

Fig. 1 - The user interface and the mathematical problem.

Students are faced with the following problem (Mellone & Tortora, 2015) placed in narrative form (Zan, 2012): given four consecutive natural numbers, show that the difference between the product of the second and third and the product of the first and fourth is always 2. The problem is interesting because admits many solving strategies and generalizations and promotes reflections on some fundamental mathematical concepts.

The story evolves over time and each student plays a different role within each scene of the plot (Albano, Pierri & Polo, 2019a), as does the expert who moderates the interactions within the group.

The whole educational path is implemented with Moodle, which provides the tools for all educational activities (Choices, Books, Lessons) and social interactions (Chats and Forums) foreseen by the instructional design (Albano, Dello Iacono, & Fiorentino, 2016). We have chosen and carefully configured the most effective tool for each educational and communicative need. We use chats for all informal communications within the group, excluding the expert, who takes part in the forums to facilitate the transition towards more advanced mathematical communicative registers (Ferrari, 2004).

The appearance of the learning environment has been completely adapted to make it look like a comic book, as shown in Figure 1. A few lines of custom CSS and the use of Labels to access "ghost activities" allowed us to present in this way all the involved activities and resources. Moreover, the extensive use of access conditions allowed us to design several parallel and personalized educational paths according to the roles and groups of all students within the story. Some plugins allowed the dynamic creation of groups and the setup of some synchronous passages (instant polls) well integrated within the narration. Finally, some GeoGebra activities (Albano & Dello Iacono, 2018b) were also integrated within Moodle to support students in the production of conjectures, arguments and proofs (Albano & Dello Iacono, 2019b).

Playing a specific role, each student is actively involved in three consecutive actions: *Inquiry, Conjecture* and *Proof*.

The *Inquiry* foresees that each student comes to the formulation of a personal conjecture about the proposed math problem and shares it with his classmates using a Chat.

The *Conjecture* aims at the social refinement of what has been individually produced, both in terms of content and formal expression. Starting from what everyone has found and shared, students are engaged into a discussion among peers to formulate a shared conjecture to communicate to the expert. While conjecture comparison takes place in the Chat, the communication with the expert foresees a Forum, which encourages and fosters the production of text expressed in more evolved registers.

Finally, the *Proof*, by means of discussion with the expert, leads to the

organization of the shared conjecture arose from the teamwork into a formal mathematical proof.

4 Tools and Data analysis

The standard reports normally available on learning platforms provide a lot of information on students' use of content and activities. However, they do not carry enough information to understand the (kind of) interactions among students, an essential component of collaborative learning. In this work we try to investigate the level of student engagement and the reactions provoked by the expert's interventions analysing their interactions with the help of some automated data collection and visualization tools. For this purpose, the educational design conveys all communicative activities in Chats and Forums, making them effective markers of the interactions among the students. Unfortunately, the most immediate tool, the Chat, for its communicative peculiarities (inherently one-to-many, without identifiable recipients), is not suitable for the type of automatic analysis we have planned. Moreover, the immediate and colloquial register of Chat discussions also imposes an accurate review of the corpus with the elimination of large portions of irrelevant messages before attempting any serious analysis. So, unless some sophisticated natural language preprocessing is used, Chat discussions are difficult to use with automatized tools. Consequently, in this first analysis we only used Forum posts, for which there are some tools for the automated analysis of social interactions.

We used Moodle's Forum Graph (Chan, 2013) plugin to perform a qualitative and quantitative analysis. It scans all interactions within a Forum and creates a directed graph (see Figure 2 for an example) where:

- each node represents a single active user and its size grows according to the number of user messages; this is useful to grasp at a first glance the most active users and the almost silent ones;
- users with different roles are displayed using different colours, so students and teacher/expert can be easily recognized;
- each edge represents the interaction between two active users (i.e. a user responding to a post from another user) and their thickness indicates the number of (mutual) replies.

In this way it is simple to spot influencers and followers within the groups. Additionally, to allow more detailed analysis, the plugin also displays:

- the overall number of started discussions and replies, and the users who made the largest number of posts;
- shows or hides the names of all active users, by labelling the nodes with

their names or numeric IDs;
- the numbers of started threads and given answers for each active user as the pointer hovers the corresponding node.

By clicking on one of the nodes, the plugin also shows a popup window with the log of all threads started/replied by the corresponding user. By clicking on one of these threads, it is displayed within the Forum.

5 Classroom experimentations

In this paper, we report our first attempt to apply some Social Network Analysis tools to a preliminary trial which involved 30 secondary school students and their teacher.

Two classroom experimentation has been run: the first one during the 2017/18 school year with a 9th grade class, the second during following year with a 9th and a 10th grade classes. The school grade has been determined to better integrate the topic of the model problem within the classroom mathematics curriculum. The first experimentation provided precious feedback to fine tune the whole design.

In the following our attention will be focused on the final and most important phase: the Proof. We report excerpts taken from the Forum and analyse the influence of the domain expert (the teacher) on the students, according to the JATD theory.

Our hypothesis is that the storytelling environment, and the social interaction, through forums and chats, can favour the development of argumentative practices among students. So, we used Forum Graph to investigate the interactions within the Forum used during the classroom trial. We performed two types of analysis:
- a quantitative one involving the whole graph, also seen as a complex network;
- a qualitative and semantic one, focusing on the type of intervention and, therefore, on the instructional implications.

The plugin returned graphs as the one shown in Figure 2 where the black node in the middle represent the teacher/expert.
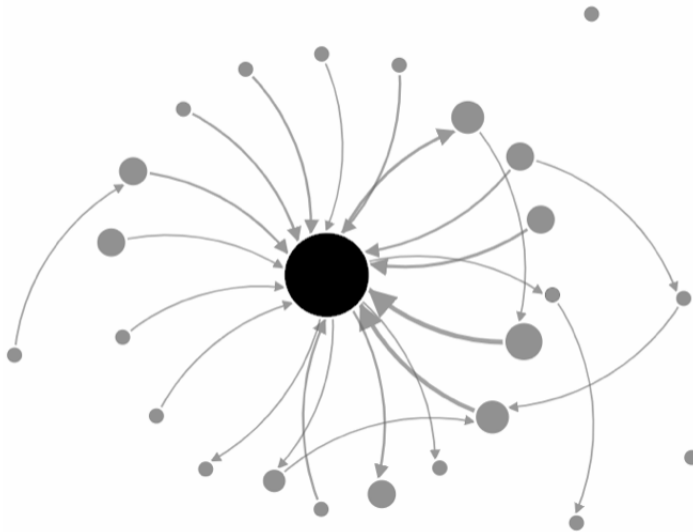
Fig. 2 - The interaction graph produced by Forum Graph.

As expected, being the mediator within the Forum, this is the largest node in the graph. The other nodes represent the students involved in the discussion. Some interesting considerations can be easily derived by carefully inspecting the graph. For instance, we can easily recognize 5 different node sizes corresponding to 5 levels of interaction (in the following denoted as L_1, …, L_5), where $L_\#$ indicates that the corresponding user made # posts (either starting ones or replies). L_1 nodes therefore denote students who:

- started one discussion if no edge connects the node to any of the others (as those in the upper right or lower right corner of Figure 2);
- answered to a single post of another student or of the expert, if only one arrow comes out of the node;
- in the latter case the arrow indicates the user whose post has been answered.

From Figure 2 it is possible to identify 14 L_1 nodes, 2 of which without outgoing arrows. Each of these students started a new discussion that no one, not even the expert, followed up. Figure 2 also shows 1 L_2 node, 5 L_3 nodes, 2 L_4 nodes and 1 L_5 node. In these cases, the thickness of the edge is proportional to the number of interactions between the two connected users, regardless of who answered to whom.

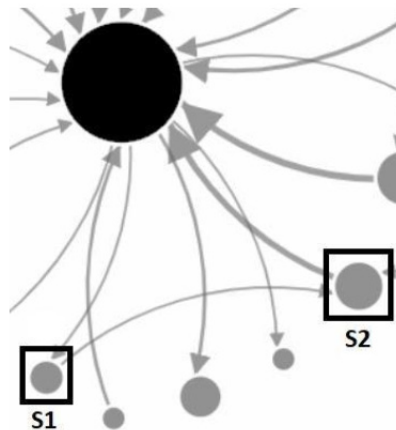Forum Graph also allows to identify some interesting interactions, such as the one highlighted in Figure 3.

Fig. 3 - Focus on students S1 and S2.

Figure 3 highlights the interactions between the expert (the black node) and students S1 and S2. By clicking on any of their nodes, the plugin shows the underlying conversation so we can immediately observe their mutual influence:

> **S1**: *…because, in my opinion, writing the quadruplet in literary form, replacing the smallest number of the quadruplet with b and obtaining the following others by adding the appropriate number, we get a small literary expression that results in the number 2. In fact, from b; (b+1); (b+2); (b+3) where b belongs to the set of natural numbers it follows that [(b+1)*(b+2]-[b*(b+3)] = b^2+2b+1b+2-b^2+3b =2. We can consider this expression as the formula for calculating the various expressions derived from the quadruplets given to us by the aliens. And to explain that it works with any natural number, large or small…*
>
> **Expert**: *…Is the same if we replace a letter to the largest number of the quadruplet? Why are you so convinced that the value you attribute to A is not important? …*
>
> **S2**: *…First of all I thought of taking a letter, say C, as the first number so, for the others, we have: C+1, C+2, C+3. In the quadruplets to get as a result 2 you have to make the subtraction between the product of the second and third number and also the product between the first and fourth number, so, taking into account C, we can calculate (C+1) (C+2) - C(C+3) and if we simplify this small expression we will see that 2 will come out of it because: (C+1) (C+2) - C (C+3) = C^2+ 2C +1C + 2 - C^2+3C=2. This expression, as we have seen, could be the right formula to calculate the quadruplets given by aliens. Moreover, we have seen that whatever value we give to C, either a small or a large number, the result, as we have seen, will always be 2…*

We underline that the discussion in the forum was anticipated by moments of sharing in chat where the informal conversations have anticipated and facilitated the more formal discussion with the expert in the Forum. Indeed S1 states: *[...we cannot communicate with aliens with our language because it is not certain that they understand it so we must use a quadruplet ...]*, as well as S2: *[...In my opinion we must create a quadruplet through a formula, which we will also use for demonstration...].*

According to JATD theory, we can observe how the expert makes inference on student's statements, inducing her to think about their *motu proprio* interaction with the milieu.

By carefully analysing the graph and its peculiarities it is possible to find many interesting hints about how students interact and how the expert can improve and gently drive the overall discussion. In such a way, he leads the teamwork to an initial formal mathematical demonstration, as quoted by the students in the forum with the expression "*Moreover, we have seen that whatever value we give to C, either a small or a large number, the result, as we have seen, will always be 2…*". However, we also underline that the reach of such tools is not limited to the ex post analyses of the interactions; in fact, they can (and should) be used for the early detection of what is going wrong (a discussion that does not start as desired, isolated members or entire groups struggling to establish a fruitful collaborative work) and timely undertake appropriate corrective actions. In this sense, they build a bridge between the simplicity of activity report analysis and the complex insight promised by the forthcoming Learning Analytics tools.

6 Discussion and conclusions

In this work we used a software tools to analyse the complexity of the interactions taking place online within a collaborative learning framework.

We started from the hypothesis that the storytelling environment, and the social interaction, through forums and chats, can favour the development of argumentative practices among students.

Our choice, Forum Graph, allowed a qualitative and quantitative analysis of Forum interactions, giving the teacher a better insight of the global flow of information, identifying influencers and followers. We also used the tool to spot and observe some significant discussions, analysing the argumentative skills of the students, from a qualitative point of view.

We realized that Forum Graph is (also) a valid didactic tool that, by displaying the discussions among students in real time, helps teachers to create an "augmented reality" that allows a better understanding of the social dynamics of the groups, increasing their capacity of analysis and intervention.

Such opportunities are difficult to imagine without the support of eLearning platforms and automated tools. On the other hand, the limitations and needs not met by these tools provide interesting indications for their further development. For instance, the fact that Forum Graph only shows one edge for each pair of users makes it rather difficult to understand the level of mutual influence (since the direction of the arrow, as experimentation revealed, is of little significance). Another currently missing feature, essential in cooperative online frameworks, is the ability to analyse Chats, where the most immediate communication takes place, and therefore is the best place to look for students' convictions and misconceptions. We are aware that this kind of analysis will require the integration of many high level tools such as Natural Language Processing, Big Data techniques and a deep field knowledge, to analyse, "understand" and present data in a form suitable for teaching purposes.

To sum up, tools like Forum Graph build a bridge between what can be easily set-up and used now and the forthcoming generation of tools arising from the Learning Analytics research, whose integration in the learning platforms has just begun.

Acknowledgements

REFERENCES

Albano, G., Dello Iacono, U., & Fiorentino, G. (2016). An online Vygotskian learning activity model in mathematics. *Journal of e-Learning and Knowledge Society (Je-LKS), v.12*, n.3, pp. 159-169.

Albano G., Dello Iacono U. (2018a). DIST-M: scripting collaboration for competence-based mathematics learning. In: Silverman J. Hoyos V. (eds). *Distance Learning, E-Learning and Blended Learning of Mathematics*. p. 115-131, Cham:Springer, doi: https://doi.org/10.1007/978-3-319-90790-1.

Albano, G., Dello Iacono, U. (2018b), GeoGebra in e-learning environments: a possible integration in mathematics and beyond, *Journal of Ambient Intelligence and Humanized Computing*, pp. 1-13.

Albano, G., Pierri, A., & Polo, M. (2019a). Engagement in mathematics through digital interactive storytelling. *Proceedings of the Eleventh Congress of the European*

Society for Research in Mathematics Education (CERME11, February 6 – 10, 2019).

Albano, G., Dello Iacono, U. (2019b). A scaffolding toolkit to foster argumentation and proofs in Mathematics. *International Journal of Educational Technology in Higher Education* 16:4, pp. 1-12.

Azevedo, R., Cromley, J.G. Winters, F.I., Moos, D.C., & Greene, J.A. (2005). Adaptive human scaffolding facilitates adolescents' self-regulated learning with hypermedia. *Instructional science, 33*(5-6), 2005, pp. 381-412.

Baker, M. (2003). Computer-mediated argumentative interactions for the co-elaboration of scientific notions. In: J. Andriessen, M. Baker, & D. Suthers (Eds.), *Arguing to learn: confronting cognitions in computer-supported collaborative learning environments* (Vol. 1, pp. 1-25). Dordrecht: Kluwer.

Bruner, J. S. (1986). *Actual Minds, Possible Worlds*. Cambridge, MA – London: Harvard University Press.

Chan A. (2013). Forum Graph developer and maintainer, CITE, HKU. (https://moodle. org/plugins/report_forumgraph)

Demetriadis, S., & Karakostas, A. (2008, March). Adaptive collaboration scripting: A conceptual framework and a design case study. In *2008 International Conference on Complex, Intelligent and Software Intensive Systems* (pp. 487-492). IEEE.

Ferrari, P.L. (2004). Mathematical language and advanced mathematics learning. In: Johnsen Hoines, M. & Berit Fugelstad, A. (Eds.), *Proceedings of the 28th Conference of PME* (pp. 383–390). Bergen, Norway.

King, A. (2007). Scripting collaborative learning processes: A cognitive perspective. In: F. Fischer, I. Kollar, H. Mandl, & J. Haake (eds.), *Scripting computer-supported collaborative learning: Cognitive, computational and educational perspectives* (pp. 13-37). New York: Springer.

Kobbe, L., Weinberger, A., Dillenbourg, P., Harrer, A., Hamalainen, R., Hakkinen, P., et al. (2007). Specifying computer-supported collaboration scripts. *International Journal of Computer-Supported Collaborative Learning, 2*(2), 211–224.

Mellone M., & Tortora R. (2015). Ambiguity as a cognitive and didactic resource. In: Krainer K., Vondrová N. (Eds.), *Proc. of CERME 9*, Prague, pp. 1434-1439.

Minerba, L., Chessa, A., Coppola, R. C., Mula, G., & Cappellini, G. (2008). A complex network analysis of a health organization. *Igiene e sanità pubblica, 64*(1), 9-25.

Schank, R., Roger, C., & Abelson, R.P. (1977). *Scripts, plans, goals and understandings*. Hillsdale, NJ: Erlbaum.

Vygotsky, L. S. (1980). *Mind in society: The development of higher psychological processes*. Harvard university press.

Sensevy, G. (2012). About the Joint Action Theory in Didactics. *Z Erzieh 15*(3), pp. 503–516.

Sfard, A. (2001). Learning mathematics as developing a discourse. *Proc. of 21st Conference of PME-NA*. Columbus, Ohio: Clearinghouse for Science, Mathematics, and Environmental Education, pp.23-44.

Vygotsky, L. S. (1980). *Mind in society: The development of higher psychological*

processes. Harvard university press.

Weinberger, A., Kollar, I., Dimitriadis, Y., Makitalo-Siegi, K., & Fischer, F. (2009). Computer-supported collaboration scripts. *Technology enhanced learning*, Springer Netherlands, pp. 155–173.

Zan, R. (2012). La dimensione narrativa di un problema: il modello C&D per l'analisi e la (ri)formulazione del testo. Parte I. *L'insegnamento della matematica e delle scienze integrate. Vol.35* A N.2, 4, 2012.