Social creativity and meaning generation in a constructionist environment

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The use of digital tools for "doing mathematics" has been studied both from the meaning making perspective and from the point of view of social interactions. In this study, we discuss how the use of digital tools that support collaboration, exchanging ideas and artifacts among students in a dense and intense way fosters the mechanism of meaning making in a group of 9th grade students that interact with a half-baked microworld. We reemploy the UDGS model to describe meaning making, but this time from a social aspect, using the notion of social and sociomathematical norms. In this context of analysis, we search for instances of social creativity, while investigating the connection between creativity and students' joint mathematical thinking.

Keywords: Digital tools, meaning generation, social creativity, theory integration, Logo-turtle geometry.

THEORETICAL FRAMEWORK

The use of digital tools for creative mathematical thinking has mostly been studied from two different perspectives, focusing respectively either on meaning generation or social interaction. Nonetheless, the availability of digital tools that support both math meaning generation and communication among students has recently highlighted the value of drawing from both perspectives. Following this strand, we attempt to investigate meaning generation itself as a social interaction process. In this paper, we study shared meaning making in a context where the focus is on the social interactions among students. The students worked in groups with a digital medium designed to support tinkering with a 3D Turtle Geometry tool using dynamic manipulation and Logo programming. At the same time, this medium allowed students' online collaboration and communication through shared workspaces.

For this study, we have chosen two theoretical tools. Firstly, the notion of social and sociomathematical norms (Yackel & Cobb, 1996; Kynigos & Theodosopoulou, 2001), which we found useful, as it helped us interpret the social interaction of the students during their communication, in terms of "microcultures" and taken-as-shared behaviors of each group. We found especially useful to consider meanings generated through interaction and the taken as shared as work progressed.

Secondly, the UDGS model (Hoyles, 1987), which although it was first used back in the mid eighties, we found it useful for our research, as it is a tool that describes students' meaning making process while they engage in mathematical exploratory activities with digital media. According to this model, there are four phases of the meaning making process: Using, Discriminating, Generalizing and Synthesizing. At first, students use mathematical and non-mathematical concepts, without much attention to their actual meaning. In the next phase they discriminate elements of mathematics in their constructions and the way they use them. Through the observation of patterns in relations or properties of the Logo commands they use, students generalize their ideas. Finally, they make synthesis of these generalized ideas with typical mathematics that these ideas are based on. In this framework a mathematical meaning is the way that a student understands, uses and thinks of a certain mathematical concept.

In this paper, we discuss a classroom study where different group configurations of students experimented with the "Twisted Rectangle" half-baked microworld (Kynigos, 2007). Half-baked microworlds are incomplete by design, challenging students to explore the reason for the buggy behaviour they show, engaging them in the process of mathematical meaning-making.

The Twisted Rectangle's buggy procedure creates an open skewed rectangle, intriguing students to try to fix and express their own mathematical ideas on how to reconstruct it (Figure 1). To conduct their experiments as they tried to find the bug and then work out the mathematics necessary to fix it, the students needed a medium able to support collaboration, joint planning, argumentation and meaning making.

The Metafora Platform (Dragon, Mavrikis, McLaren, Harrer, Kynigos, Wegerif, & Yang, 2013) was built to encourage students to "learn how to learn together". Group members have tools to make plans, to act as designers, and to publish, argue over and discuss their constructions. This act of designing and publishing (Kafai, 2006) is an externalization of an individual's tacit knowledge, or a group's knowledge, in the case of a joint construction of more than one individual. We were interested in studying how meanings were shared and argued over as an integral part of the students' activity. Artifacts were available at all times for inspection and reconstruction, starting from discriminations of the ideas embedded in the procedure by the designers (Kynigos, 2012). It has been a long time now that Papert and Harel (1991) suggested that when artifacts are published intensively and densely in a learning collective, meaning making process happens naturally. We wanted to study this process in detail, to capture the process of shared meaning making and the kinds of socio-mathematical norms generated, as groups of students jointly tried to fix a buggy artifact and use it to build their own.

In this context of social interaction and building on our previous work (Kynigos & Moustaki, 2013), we wanted to give particular focus on creativity in mathematical thinking. Since we talk about groups, we put emphasis on social creativity. We found Fischer's approach as a good tool for us to think with. Arias and Fischer (2000) emphasize that externalization supports social creativity as students move from vague mental conceptualizations of an idea to a more concrete representation of it. It also allows students to interact with, negotiate around and build upon an idea as the diversity of voices and minds increases. Fischer's group approaches creativity as a social process which has four elements: (1) originality: people or, in this case, students have novel ideas or they are capable of applying prior knowledge in new contexts, (2) expression: students should be able to express and externalize these new ideas, (3) social evaluation: students with different perspectives should be able to evaluate these novel contributions, reflect upon them and improve them, and (4) social appreciation: refers to the credits and acknowledgment from the other participants of the group motivating further creative activities (Fischer, Scharff, & Ye, 2004). Fischer, Giaccardi, Eden, Sugimoto, & Ye (2005) have described the characteristics of situations that, in their approach, support this social aspect of creativity: they are *open-ended* and *complex* so that students will be led to unpredictable results and eventually to experiences of *breakdowns*. Breakdowns offer opportunities for reflection and learning, through the procedure of the back-talk of situations (Fischer et al., 2005). Another form of social creativity is *co-creation* which is a situated experience leading to emerging and sharing creative activities with no explicit goal and meanings in a socio-technical environment through synchronization and improvisation as students share emotions, experiences and representations (ibid).

Although there seems to be a connection between aspects of social creativity and the meaning making process when students work in groups, we found research on these two approaches to be rather fragmented with respect to emphasis on one or the other. In our study we tried to see if these separate views can be usefully integrated in a situation where co-constructing students work in groups that communicate with each other exchanging ideas and different versions of the original figure.

TECHNOLOGY

The Metafora platform brings together students from various backgrounds to solve problems of fixing models which we faulty by pedagogical design (Kynigos, 2012). It hosts three types of tools available to the students at all times: a 3D Turtle Geometry environment, an argumentation tool and a shared workspace for students to make shared plans of their actions as a

Figure 1: The half – baked microworld "Twisted Rectangle" in 3D Math

group. The 3D Math tool (Figure 1) affords Logo-based Turtle Geometry with a feature for dynamic manipulation of variable procedures once executed with a set of values (Kynigos & Psycharis, 2003).

THE STUDY

Research design and methodology

In the study we used the methodological tools of "design research" (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003), which is an empirical study of human activity in real settings. In the implementation of the research, students and teachers were engaged, for several sessions, in an activity with the use of digital tools. This research framework is suitable in the classroom, where the learning ecology is described by means of collaboration and effectiveness in addressing tasks that challenge students to take initiative in specific situations (Collins, Joseph, & Bielaczyz, 2004).

Ten 9th grade students, three mathematics teachers of a public Experimental School in Athens and four researchers participated in the research. The implementation took place in the school pc lab, after-class, in the frame of the school Math Club activities, for twelve sessions of two teaching hours each (about two and a half months). Most of the students were not novice users of 2D Turtleworlds. In the time of the study, students had been taught trigonometry, but not stereometry. They were separated in two groups, and each group was divided in two subgroups. The subgroups of the same group were communicating through Metafora communication tools.

Task analysis

The bug in the procedure given to the students was the absence of a relation between a turn and a length of one of the rectangle sides. This resulted in the procedure producing an "open" figure and the students were faced with the challenge of fixing the bug so that it 'closed' no matter what the variable values were. The challenge required students to find simple sin and cos relations between angles and sides in two triangles lying respectively in two different planes joined only by one common side. Once figured out, the students would have to express these relations with functions allowing for the rectangle to be built with one variable for twist around a vertical axis (wmega), one for a horizontal axis (theta) and one for side length. To do that, the students would have to think about the concept of angle in 3D space.

A useful tool for us to recognize the meanings that students generated was the approach of Henderson and Taimina (2005) of students' conceptualization about angle: as a static geometrical figure, as a number that expresses a magnitude, or as a result of turning. These perspectives of an angle correspond to the static or dynamic definition of it (Mitchelmore & White, 1998). Our hypothesis is that ninth grade students mostly conceptualize angle as a static geometrical figure, which corresponds to the static definitions of angle. In Turtle Geometry however, angles are dynamic turns, rather than static direction relations.

Data collection method

Data collection included conversations between teachers and students, or groups of students, their gestures during their discussions, their constructions on the screen or artifacts that they made by hand. For these reasons we used voice recorders and a camera. A screen-capture software (HyperCam2) was used to record students' interactions with the Metafora tools. We also collected students' manuscripts and drawings. The data corpus was completed by the researchers' field notes.

RESULTS

Episode 1: Elements of social creativity in the phase of discrimination used in the process of generalization

The students of the subgroup 1 used dynamically the variation tool in order to find out which variable of the code corresponded to which spatial characteristic of the "Twisted Rectangle". Founding it difficult to come to a conclusion, they had the idea of reconstructing the figure. They decided to use drinking straws, although there were no straws available till then. The sequence of commands "forward(:length) right(90+:theta/2) up(:wmega) forward(:width)" made the turtle go forward for a distance equal to the variable "length", turn right "90+theta/2" degrees, then pitch up "wmega" degrees and go forward for a distance equal to the "width" variable. Turning right "90+theta/2" degrees seems to be complicated, but "theta" was a structural feature of the figure, related with its buggy behavior. Discriminating the role of "theta" was necessary, so that the students could focus on what was missing to fix the bug. Following this sequence of commands, the turtle drew an angle of the figure. Comparing the two representations of this angle, the one on 3D Math

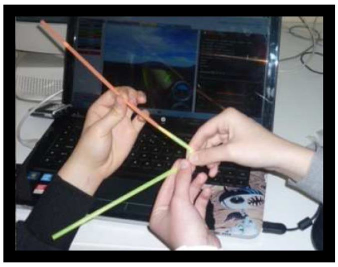
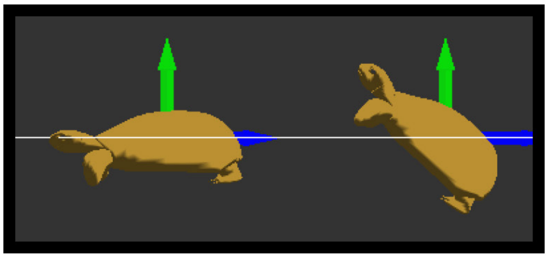



Figure 2: (a) the construction made of drinking straws, (b) the result of command up( )

and the other on the construction of straws, students realized that they are not the same.

Student 1: After fd(:length) it turns right.
Teacher: How much it turns?
Student 1: 90 + theta/2.
Student 2: And after that?
Student 1: up(:wmega). So it goes like this, it has gone up and then goes fd(:width), nice!
Student 2: The figure shouldn't have been like that. Let's do it again...

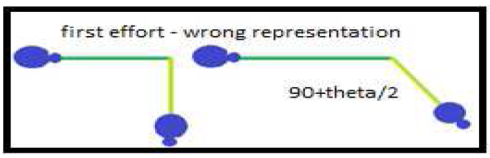
In this dialogue, the students use interchangeably three representations of the shape: the figure inside 3D Math, the logo code and their construction (Papert & Harel, 1991). Trying to represent the geometrical result of a right turn of "90+theta/2" degrees, they constructed an obtuse angle (Figure 3). This construction of the artifact seemed to be a result of their conceptualization of the angle as a static geometrical figure (Henderson & Taimina, 2005; Mitchelmore & White, 1998). According to the UDGS model, this is the phase of "using", as the students used the mathematical concept of angle without having a complete image of it (Hoyles, 1987).

Furthermore, there seems to be a breakdown in their effort. Thinking that their construction of straws was not totally correct, the students decided to explain the logo code step by step.

Student 1: I have second thoughts about this command...
Teacher: Why?
Student 1: If it turns right 90 plus something, then it goes here (she shows 90-theta/2). But it is not right; the figure ends up being wrong.
Student 2: Thanks God that I do not trust the logo code! (Laughing)
Student 1: Just a moment, give me the straws and the eraser. Ah, it goes here.
Student 2: 90+theta/2 to the right.

In the dialogue above, Students 1 and 2 seemed to evaluate their initial construction and improve it, using an eraser (pointing somewhere) as a representation for the turtle. This modification was revealing of the students' thinking. It seemed that in the first model (without the eraser), the straws were not a signifier for the trace of the turtle. They used the straws as a semantic simply for the sides of the angle. Their idea to use an eraser, in order to add a signifier of the turtle to the model, led to an "improvement" of the use of the straws. The straws instantly became not just the signifier of angle edges, but of the turtle's trace, as well. This "improvement" came up as a more concrete representation of an angle, than their initial conceptualization (the angle as a static geometrical object). The extended model (straws and eraser) was the result of "expressing a new idea" (use an eraser as a turtle), after they interacted with the logo code and the figures. The students reflected upon their model and evaluated it due to the distrust to the code.

The novelty of the students' idea to use the straws, the construction of their model, and the reflection upon it, which led to the evaluation and improvement of the model, according to Fischer's approach, can be interpreted as three of the four elements of social creativity; originality, expression and social evaluation.



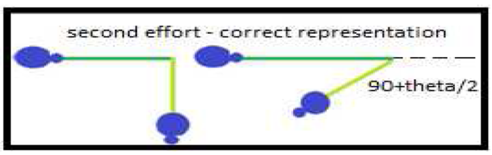


Figure 3: The two representations of the result of the logo command rt(:90+theta/2)

Using their improved model as an instrument (Artigue, 2002), the students started to generate new meanings for the concept of angle, which corresponded to the dynamic definition of it as a turn (Mitchelmore & White, 1998) (Figure 3). In this way, they discriminated the element of turn under their construction and the way they improved it (Hoyles, 1987). Later, as they tried to construct the rest of the figure using straws, they found that the logo commands were following the same pattern.

Student 1: You see? It is fd(:length) lt(90+(:theta)/2) dp(:wmega) fd(:width) instead of fd(:length) rt(90+:theta/2) up(:wmega) fd(:width). Left instead of right and down instead of up.

Student 2: This part of the figure is an angle like the other we have already done.

The students appeared to transfuse a property of the logo code to the figure. They made an abstraction, using a certain pattern of logo commands as a representation of the angle. This observation of patterns of the logo commands is a main characteristic of the "generalization" phase in the UDGS model. When they discovered the same pattern of logo commands elsewhere in the logo code, they recognized it as the symbolic representation of a similar angle, and searched for this angle on the eraser-straw model. In this way, they generated an abstraction, generalizing the concept of an angle and using it. We also suggest that this joint mathematical thinking can be explained through the lens of sociomathematical norms. To be more specific, the argument that a pattern of logo commands defines a certain geometrical figure had been a norm of an accepted mathematical explanation within the group of students.

Episode 2: Creative ideas for synthesizing concepts across context

At the end of the previous session the group managed to address the challenge (Figure 4a). Subgroup 1 and subgroup 2 had different perspectives of the solution (geometrical and algebraic), but they reached to a common solution. The students, reconstructing the code, created a formed and closed "Twisted Rectangle". In this session, the subgroups using the Twisted Rectangle as a building block created their own constructions with 3D Math. Subgroup 1 had constructed a figure that reminded them a logo of a chain store, while subgroup 2 had constructed a "flower". They used the communication tool in order to exchange and combine logo codes and ideas:

Subgroup 2: You could test the code "flower" that we have already tested. We'd like to tell us what you think about it and what you have done... in order to make a combination of our codes!!!

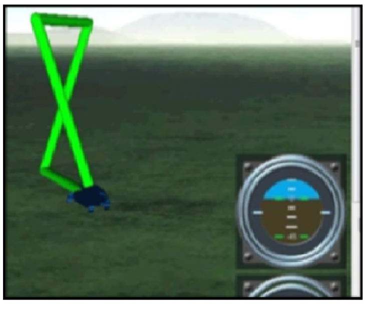
Subgroup 1: We created the code "stem" and combined both codes so we created a new code called "flower with a stem"!

Subgroup 2: Ok. We wanted to make a bigger flower, so we added more variables... We should combine this code now with yours again...

Subgroup 1: Ok! We sent you the new combined code: "The flower with a stem"!

Then, they used the logo of the chain store as a "vase" to put the flower in (Figure 4b).

According to the UDGS model, using the generalized "Twisted Rectangle" as a building block is an instance of meaning making. Observing the students' interactions we notice a dense publishing of their own constructions and an intense exchanging, reflection, combination and improvement of their logo codes (which represent their ideas). Based on the approach



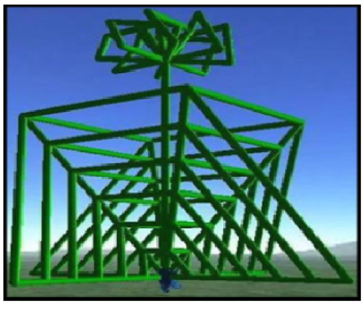


Figure 4: Students' construction: (a) The twisted rectangle, (b) The flower in a vase

of social norms we suggest that this taken-as-shared behaviour was a basis for their communication, which indicated the group "microcultures" (Yackel & Cobb, 1996). This kind of microcultures was characterized by externalization of original ideas and social evaluation of them (through reflection and improvement). According to Fischer and colleague's (2004) approach these are elements of social creativity. Moreover, during the construction of the artifact we noticed the development of taken-as-shared understanding of what was an "appropriate" logo code in order to create a common construction; the two subgroups used variables instead of numbers in their codes.

From our point of view, this shared behaviour of "using variables" is related to the embodiment of the power of generalization that occurs during the meaning making process and indicates a sociomathematical norm. We suggest that this common behaviour was crucial for addressing a task with no explicit goal, like this one. According to Fischer and colleague's (2005) approach and taking under consideration that students used a digital tool which supports communication and sharing of ideas, this situation can be characterized as co-creation which is a form of social creativity.

DISCUSSION

The study discusses two episodes where meaning generation was evident in a context of social creativity in mathematical thinking. In the first episode students of subgroup 1 realized by tinkering with the model of straws that it was not an accurate representation of the Twisted Rectangle because it was static and they improved it using an eraser. Taking a close look at the students' activity, we suggest that they were trying to rebuild their model to be the closer to what the Logo code represented, which was a construction of the Twisted Rectangle, rather than a static result. This novel idea came up early, during the phase of discrimination (of UDGS model) in the meaning generation process. It seems that this idea was shared by the students and used in their attempts to make sense of angle in space which were perceived as joint. The eraser semantic initiated a developing of a socio-mathematical norm about how to think of dynamic angle in space which was then taken as shared in subsequent generalizations of angle and trigonometric relations to twisted rectangle sides.

In the second episode, the students of each subgroup used their shared resolved procedure of a generalized twisted rectangle as a building block to build their own constructions. The two subgroups exchanged their constructions through the Metafora argumentation tool in a dense process focused on negotiating meanings to explain and exchange developing complex models. The ideas of what to build and how it behaves were shared between the two groups which were operating as a new group to show the class what they had done. They were thus conceived and used in a social setting from the beginning and the language developing in the groups seemed to create an atmosphere of social creativity and sharing of these ideas. We take these shared practices and behavior as situated in interaction with the medium of this particular collaboration. From this point of view, we can argue that the Metafora Platform afforded and fostered the emergence of social creativity in the group activities.

In both episodes the learning process seemed to be fostered by social practices, such as the making of shared meaning, common argumentation and beliefs of what is accepted as a solution. Although we were looking at socially emerging meanings, we found the use of UDGS shows helpful to describe meaning generations but this time to try to understand if this meaning making process can be described with these tools as a collective process in emergence of social creativity. More precisely, we found elements of social creativity emerging within the phases of the UDGS model. This study made us reflect that it may be worth readdressing the problem of meaning making in new kinds of collectives now that we have digital media that support communication, collaboration and joint mathematical thinking.

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