JUGGLING REFERENCE FRAMES IN THE MICROWORLD MAK-TRACE: THE CASE OF A STUDENT WITH MLD

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This study gives insights into how Logo-like microworlds can affect cognitive development related to mathematics education of students with math learning difficulties. In particular, we analyse the case of a 15-year-old student with dyslexia and severe dyscalculia. Among the various cognitive aspects involved, here we delve into the development of his perspective-taking ability, seen in terms of becoming aware of and juggling two different allocentric frames of reference.

INTRODUCTION AND THEORETICAL BACKGROUND

The ability of perspective-taking (Piaget & Inhelder, 1967; Clements 1999), or being able to embrace different frames of reference based on one's self or on external points of reference, is fundamental both in everyday life and in instruction. The importance of such ability is declared in the Italian National Curriculum Indications (MIUR, 2012) relative to mathematical learning about "Space and Figures". These state that by the end of third grade a student should be able to "…follow simple paths described verbally or graphically, describe a path that he is following, and give instructions to someone so that they follow a given path." (MIUR, 2012, p.50, translated by the authors). Developing the perspective-taking ability may not be straightforward: it involves a transition from "perceptual space" to "representational space" (Piaget & Inhelder, 1967), as well as "connecting different viewpoints" (Clements, 1999, p.3).

While children with a typical development can be assumed to have acquired such ability by the end of primary school, in some children with mathematical learning disabilities (MLD) – including developmental dyscalculia (e.g., Mazzocco & Räsänen, 2013) or more in general mathematical difficulties (as discussed in Karagiannakis et al., in press) – the development of perspective-taking, among other abilities, may be delayed and/or deficient. Although students with MLD may present different mathematical profiles, frequently characterized by the presence of multiple deficits including those of a visual-spatial nature (Andersson & Östergren, 2012; Karagiannakis et al., in press), some remedial interventions that involve microworlds, such as Logo, have been successfully carried out (e.g., Ratcliff & Anderson, 2011).

Our study is part of a larger project investigating qualitative effects of different kinds of remedial interventions for students with MLD. In particular, in this paper, we analyse a student with MLD's cognitive processes involved in juggling different frames of reference, while working in *Mak-Trace*, a Logo-like microworld.

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LOGO-LIKE MICROWORLDS AND STUDENTS WITH MLD

As described in the extensive literature on the topic, the idea of microworld involves considering particular computer software as tools providing informal learning environments that have specific knowledge domains embedded (Hoyles et al., 2002). Logo was the first microworld to be developed and to become popular (Papert, 1980). The early plea to study effects of Logo learning on cognitive skills is still a topic of research today (Ratcliff & Anderson, 2011), especially since the original Logo language has been simplified in various ways and adopted to program real or virtual robots used at different school levels (e.g., Highfield & Mulligan, 2008).

The potential of Logo-like microworlds for fostering learning in students with MLD is documented in the literature. In particular, Vasu and Tyler found that Logo may foster the development of spatial abilities and of critical thinking skills (Vasu & Tyler, 1997), and various other researchers have reported several potential benefits of using Logo with students who have learning difficulties (Atkinson, 1984; Maddux, 1984; Michayluk & Saklofske, 1988; Miller, 2009; Russell, 1986), especially using a more structured, mediated approach (Ratcliff & Anderson, 2011).

The Microworld Mak-Trace

Mak-Trace (Giorgi & Baccaglini-Frank, 2011) is a free application for the iPad and the iPhone in which a character (by default a snail) can be programmed to move and draw on a grid. The character can only be programmed to go forwards (F) or backwards (B) of the distance of one side of the grid-square at a time, or to turn 90° clockwise (R, standing for "turn right" in the snail's perspective) or counterclockwise (analogously L, standing for "turn left"). Therefore, the frame of reference for giving directions is *relative to the character*, not to a North-South-East-West frame relative to the grid. For example, holding the iPad "right side up" if the character's head is pointing downwards – that is the snail is *oppositely oriented* with respect to the programmer – F (the icon with the arrow pointing upwards relative to the grid) will make it move in a vertical line that the programmer will perceive as "descending".

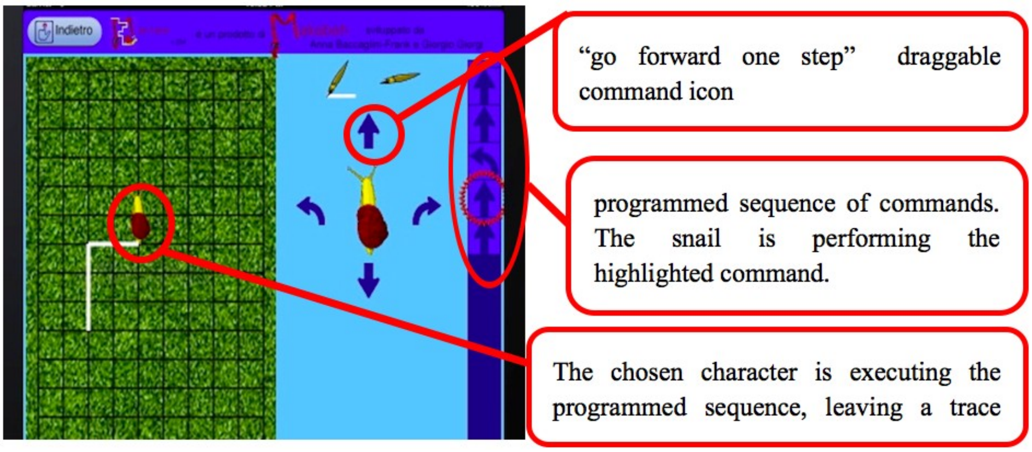

Figure 1: Screenshot of Mak-Trace, where the character is executing a sequence.

Mak-Trace can be seen as a simplified version of Logo; it was designed by one of the authors with the aim of creating an environment accessible to young children, or to students with learning difficulties or disabilities, by trying to offer a more intuitive iconic programming language, with the potential to foster mental planning, visualization and perspective-taking abilities. This aim led to some characterizing design choices. A main difference between Mak-Trace and Logo is the fact that the commands are icons that can be dragged and dropped to build a sequence. Another difference is that Mak-Trace gives no feedback in terms of movements of the character until the student touches "GO". At this point the character executes the whole list of commands in the constructed sequence. Moreover, to make a variation in the constructed sequence, the student has to go back to the "programming mode": automatically the character goes back to its original position and all trace marks are cleaned off the screen.

EGOCENTRIC AND ALLOCENTRIC REFERENCE FRAMES

When we represent the location of objects in the environment we can use different frames of reference (Carlson-Radvansky & Irwin, 1994). It is largely accepted that two main frames are the *egocentric* and the *allocentric* ones. In the former, the representation of objects is referred to the self and to the observer's body; in the latter, spatial relations are represented independently of the self. Grush (2000) refined such distinction, identifying four different uses of the term "allocentric": (A) egocentric space with a non-ego object reference point (*decentred egocentric*); (B) object-centred reference frames; (C) virtual points of view (i.e., maps); (D) "nemocentric" maps. We found this distinction to be quite relevant to our study. In particular, we will take into consideration the first two allocentric frames (A and B in Grush's distinction), because they apply to programming in Mak-Trace. Let's describe the reference frames with an example. Let's say Giovanni and Lucia are in a room, in front of our body looking at us, and Giovanni's left hand is holding Lucia's right hand. In our egocentric frame, we can say that Lucia is in front of us. Using an allocentric A-type frame we might say that Lucia is at the right of Giovanni. So, while the left-right axis is referred to our body, we are using Giovanni as the reference to locate Lucia. In the allocentric B-type frame, we might say that Lucia is to Giovanni's left. In this case, we represent the space as Giovanni might represent it according to his egocentric frame of reference, so "left" is referred to Giovanni's point of view. In other words, the frame's origin is centred on Giovanni and its axes are Giovanni-fixed.

In Mak-Trace the perspective-taking ability consists in embracing the character's moving frame of reference and this requires to coordinate two frames: the decentred egocentric (type A) frame, the character-centred frame (type B). Instead, using an egocentric frame turns out not to be effective, because the iPad usually sits in front of the programmer and terms like "left" and "right" cannot be meaningfully used. In this paper we will analyse processes of juggling of type A and type B frames.

A CASE STUDY: STUDENT WITH MLD JUGGLING FRAMES

The subject in this study, named here Filippo, had been diagnosed with various MLD including dyscalculia and severe dyslexia. From the accounts of his special education teacher (one of the authors), he also was not able to read maps or to give directions (however he did not have difficulty recognizing or naming his left and right hands), he had a short attention span and little – if any – interest in the activities proposed during math class. We planned and carried out a 5-week intervention (globally, 10 hours outside his regular classroom) using Mak-Trace. The tasks he was assigned, that we analyse here, were the following: 1) program the snail to draw a given path; 2) program the snail to draw a square; 3) complete the mazes. Each activity was audio and video-taped, and analyzed according to the frame above.

Task 1: Program the snail to draw a given path

Filippo initially thinks that the commands F, B, R, L make the snail go forwards, backwards, right, and left, where these directions are in the decentred egocentric (A) frame: the forwards-backwards and right-left axes are Filippo-fixed, while the centre of the reference frame is the snail. Therefore Filippo is not able to construct a sequence of commands to make the snail draw a given path. It takes him about 10 minutes, dragging command icons more or less randomly and watching the snail in a confused state, before realizing something is wrong:

Filippo: it is a bit hard. It's never what it… […] I am not understanding anything […] wait…I didn't tell him to go right and he went right. […] These two [R and L] are inverted […] I am not understanding anything […] if this arrow [L] makes it turn right, this one [R] makes it turn left.

Teacher: why does an arrow pointing to the left make it go to the right?

Filippo: Ask the person who designed the game!

For over half an hour Filippo tries to understand how each command could be associated to a snail's movement (translation) on the grid and does not seem to be aware of any reference frames other than the egocentric decentred one that he keeps working in. Clearly, when he realizes that the natural correspondence (R → translation to the East on the grid) does not work (after a long time) he tries to set other correspondences between command icons and movements, but he seems to be overwhelmed and unable to come up with a meaningful correspondence. Filippo comes to an important realization when the teacher helps him analyse the sequence of commands with respect to the trace mark left after the snail executed it:

Filippo: it went backwards, not upwards […]

Teacher: so what do the little arrows refer to?

Filippo: it depends on how the snail is oriented.

We see this as the decisive moment which poses the foundations for the conception of a type B allocentric frame of reference. We note that to embrace a type B frame it is necessary to consider the *snail* as the reference point and the *snail-fixed* axes. Here

Filippo is still only considering his egocentric frame: the snail's rotation can only be perceived from such a frame of reference. However, he states that the type of movement determined by the commands *depends on* the snail, and in particular on its orientation. Although a fundamental step in terms of awareness has been made, Filippo still has trouble embracing the snail's perspective, so when the teacher asks for further explanations on the effects of a command, he appears confused:

Teacher: right for whom?

Filippo: for me, [mutters something], no, for the snail, for both… I don't know! I don't understand…

Filippo refuses to talk any more and uses trial and error to write a sequence of commands (FFRFLFLFRFFLFF) that represents a given path made up of horizontal and vertical adjacent segments. To do this he seems to be embracing the snail's perspective. However along this path the snail is never *oppositely oriented*, which is the situation that creates the greatest difficulties for Filippo.

Task 2: Program the snail to draw a square

The first time Filippo tries to program a sequence to make the snail draw a square starting with the snail pointing upwards, he programs: FFFFLFFFFL [brief pause, he says: "Yes"] B [brief pause] BBBR [long pause] FFFF (Figure 2a). Even though he has hesitations, Filippo is able to program the sequence for the first two sides of the square. He seems to be able to embrace a snail-fixed frame (type B), as shown by the two uses of the command L to make the snail turn, and by the use of the command F to make the snail move along a horizontal segment. From here on, Filippo manifests difficulties: he seems to be programming the third side of the square in a decentred egocentric frame (type A), as shown by his (incorrect) use of the commands B and R; while the fourth side, horizontal in Filippo's frame, is correct again. It is interesting that he uses opposite commands for the first and third sides (F and B, respectively), while for the second and fourth he uses the same command (F). This strengthens our hypothesis that the two pairs of opposite sides were programmed using different frames of reference. In summary, Filippo seems to be mixing the two types of allocentric frames in the same situation, using the snail-fixed frame when it is oriented the same way his frame is or when it is rotated by 90°, and the decentred egocentric frame when his frame and the snail's are *oppositely oriented*.

The second time he tries to program the sequence he composes: FFFFLFFFFL [hesitates, inserts L, erases it, and with the index of his right hand makes the gesture of a counter clockwise turn] FFFF [he says: "I have to always keep the" and does another counter clockwise turn gesture with his right hand] RFFFF (Figure 2b).

So Filippo has now corrected the third side but makes a mistake again on the rotation when the snail is *oppositely oriented*. He re-writes the sequence: FFFFLFFFF [he makes the gesture of a counter clockwise turn with his right hand] LFFFF…[he rotates the iPad so that his frame coincides with the snail's, observing the screen he rotates his right hand counter clockwise]. Now he completes the last turn and side.

Filippo: Done, I found it […] no, I got…lost […] when it is turned around…it goes opposite [*clockwise* rotation gesture with the right hand] so…if I want it to go here [horizontal gesture from left to right with the left hand] … oh, I don't know, I'll try this [RFFFF]… no wait, because this otherwise is like before [he substitutes R with L].

a) b) c)

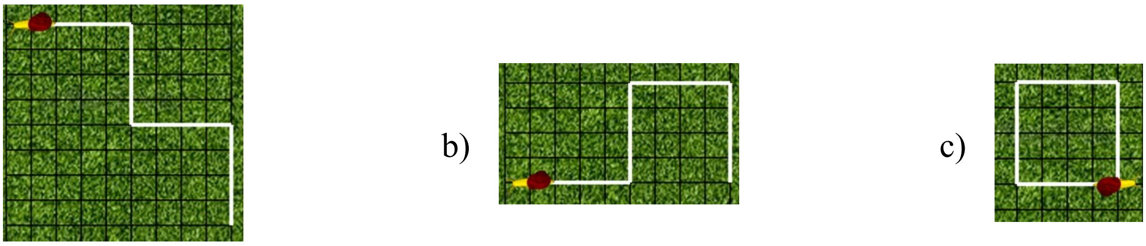

Figure 2: The first (a), second (b) and third (c) traced paths in task 2.

Now the sequence is correct (Figure 2c). We note that rotating the iPad is a gesture that reveals how Filippo is now aware that he should consider the snail's frame of reference, and that this frame is oppositely oriented with respect to his (at the moment of the rotation). This is also testified by the hand gestures, opposite with respect to the previous ones, but even with the rotated iPad he keeps on making mistakes. The way he turns out to solve the task is by remembering the previous sequence he had programmed (second try) and choosing the opposite turn arrow, proceeding by trial and error to successfully compensate his spatial difficulties.

Task 3: Complete the mazes

Filippo is asked to program the snail to get it through a maze. He appears to be convinced of being able to accomplish the task and begins to build a sequence. As in task 2, he stops and hesitates when he needs to program the snail to turn when it is *oppositely oriented*. Filippo grabs a pencil and swivels it around pointing its tip towards himself and making a small rotation in the direction he wants the snail to go:

Filippo: I am doing the snail upside down because otherwise I was getting too stuck.

Whenever the snail is oriented like himself or it is horizontally oriented, Filippo programs more than one segment at a time, but when the frame of reference of the snail is opposite to his (it happens 3 times) he acts as follows. The first time, he uses the word "straight" instead of "forward" to describe the "forward icon". When he has to choose a turn command at the end of the vertical segment he stops and uses the pencil again, as he did the first time. Then he picks up the iPad and rotates it by 180°, thus making the snail's frame coincide with his own, and then he adds R to his sequence. This was the correct choice, but he tests it right away to be sure. The second time, he programs the snail correctly when it has to turn, and the third time he also succeeds in doing this, but he uses the swivelling of the pencil, again. After he successfully concludes the task, Filippo describes how he was able to succeed:

Teacher: When you had to turn, how did you understand when to go left and right? […]

Filippo: I turned the iPad.

Teacher: But weren't you using the pencil, too? Didn't you turn it?

Filippo: Yes […]. You have to imagine [being] the snail.

So Filippo has surely become aware of a new perspective that initially he didn't seem to perceive at all. However, to embrace this type-B perspective, it seems like Filippo is aware that he needs to use some strategy to compensate for his cognitive difficulties.

CONCLUDING REMARKS

The study shows the enhancement of the ability to coordinate different frames of reference in a student with MLD working in a Logo-like microworld. Such enhancement occurred thanks to the specific tasks proposed, the interventions of the teacher (e.g., the use of expressions like "the snail turns", "right for whom?", "refer to…") and the functionalities of Mak-Trace (e.g., the commands are icons that can be spontaneously interpreted in the egocentric frame, but that refer to the snail-fixed frame; the fact that immediate feedback of a programmed sequence is *not* given, etc.), which required continuous juggling between two reference frames. Although this juggling was not spontaneous for the student, due to his disabilities, there was a positive development of his perspective-taking ability. In particular, we observed a transition from not being able to perceive the snail's perspective, and trying to find a way of making sense of the command icons, to recognizing this perspective and trying to embrace it, after a period when the student's confusion seemed to depend on his simultaneous use of the two incompatible frames. Some difficulties persisted but they were partially overcome through different compensatory strategies: trial and error (since there are two choices for the turns), trying to define a rule without embracing the snail's perspective (when the snail is upside down everything is opposite), changing his own perspective (by rotating the iPad or swivelling a pencil pretending it was the snail), and resorting to gestures that bridge one reference frame to the other. In the end the student is aware that he can change frames of reference by mentally trying to "be the snail". Last but not least, similarly to what has been described for Logo, Mak-Trace appeared to help the student to "remain absorbed in a task for a period of time; … tolerate a period of confusion (with appropriate support);… use errors as a source of information about what to try next" (Russell, 1986, p. 103).

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