STUDENTS' USE OF DIGITAL SCAFFOLDING AT UNIVERSITY LEVEL: EMERGENCE OF UTILIZATION SCHEMES

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This paper is focused on a pilot study involving a group of first year engineering students and concerning the design and implementation of two digital tasks on multiple representations of subsets of the plane. The tasks were engineered in order to provide university students with hints and feedback aimed at scaffolding their work. The analysis of the video-recordings of the students' screens while interacting with the tasks, supported by the reflections developed by students during audio-recorded interviews after the activity, enabled us to highlight utilization schemes that characterize students' use of digital tools for scaffolding their learning. We will also discuss how this analysis gave us suggestions for a future re-design of the tasks.

Keywords: teaching at university level, digital scaffolding, feedback

INTRODUCTION AND BACKGROUND

The teaching experiment reported in this paper is part of a wider study aimed at identifying effective tools and methods for the design and implementation of teaching-learning paths at university level (Alessio, Demeio & Telloni, in press). In particular, in tune with recent research (Descamps et al. 2006, Albano & Ferrari 2008, Calvani 2005), we focus on the role of digital tools and e-learning environments in supporting the teaching-learning processes at this level, because of the strong impact they could have on cognitive, metacognitive and affective levels of learning (Albano & Ferrari, 2008).

Here we present two digital tasks that we designed with the aim of providing students with hints and feedback to scaffold their work on the tasks. These tasks, focused on representations of subsets of the plane, are part of a set of online activities addressed to first year engineering students of the Università Politecnica delle Marche (Italy) attending to Calculus courses [1]. We will analyse students' interaction with the digital tasks, with the aim of identifying the instrument-mediated action schemes (Rabardel, 2002) that emerge and of collecting evidence to inform the future re-design of the tasks.

FEEDBACK AND SCAFFOLDING WITHIN A DIGITAL ENVIRONMENT

In the last years, the role of scaffolding in technology-enhanced environments has become a focus of interest for research on the use of digital tools in mathematics education. We refer to Holton and Clarke's (2007) definition of scaffolding, as an "act of teaching that (i) supports the immediate construction of knowledge by the learner; and (ii) provides the basis for the future independent learning of the individual" (p.131). Holton and Clarke (2007) stress on the fact that metacognition is an essential element in students' use of the provided scaffolding and subsequent development of awareness. When scaffolding is realized within technology-enhanced learning environments, the feedback provided by digital tools plays a central role.

In her review of literature on task-level formative feedback, Shute (2008) identifies some characteristics of effective feedback: it should be provided after learners have attempted a solution, it should be presented in small enough pieces so that it is not overwhelming and discarded, it should be written or via computer so that it could be perceived as unbiased and objective by learners, it should include elements of both verification (judgment of whether an answer is correct) and elaboration (relevant cues to guide the learner toward a correct answer).

In this paper, we interpret, in terms of *co-action*, the students' work with specific tools within a digital environment, to scaffold their learning. The term co-action is introduced by Hegedus and Moreno-Armella (2009) to interpret the nature of the relationship between a user and an environment (in particular, a software environment) *as actors and re-actors* in performing actions. They extend Rabardel's (2002) notion of *instrumentation processes*, that is those relative to the emergence and evolution of *utilization schemes* and instrument-mediated actions. Rabardel distinguishes two types of utilization schemes: the *usage schemes*, which are orientated towards tasks corresponding to the specific actions and activities directly related to the artifact; and the *instrument-mediated action schemes*, which incorporate usage schemes as constituents and "make up what Vygotsky called instrumental acts, which, due to the introduction of the instrument, involve a restructuring of the activity directed towards the subject's main goal" (Rabardel 2002, p. 83).

Hegedus and Moreno-Armella (2009) stress that the dynamic for co-action is possible thanks to what they call *border objects*, that is digital-dynamic embodiments of mathematical objects, initially defined within a paper-and-pencil environment, which can be meaningfully explored within the digital environment.

DESIGN OF DIGITAL TASKS

In this paper we study how first year engineering students, attending to a course on Multivariable Calculus (MC), interact with two digital tasks focused on different representations of subsets of the plane. MC is a pervasive topic in Mathematics for Engineering, since it is a prerequisite course for specialized subjects. According to the literature (Kashefi et al, 2012), many of the critical issues in MC are related with the coordination between multiple procedures and different representation registers. These difficulties arise in many fields of application, such as the calculation of a double integral, in which often students are not able to visualize the integration domain provided analytically, or in typical Mechanics problem, in which students need to find a parametrization, that is an analytic description, for a set given graphically. Martínez-Planell and Trigueros Gaisman (2012), focusing on two-variable functions, highlighted that, in order to help students to encapsulate this notion, they should be given opportunities to identify domain and range of functions in different representation registers and carry out the necessary transformations between registers to be able to relate information across them. The potentialities of digital technologies in supporting the learner's handling of multiple representations, widely recognised by research (Drijvers, 2013), make them effective tools to foster the understanding of Calculus topics (see, for example, Tall, Smith & Piez, 2001), in particular in the context of MC (Kashefi et al, 2012).

Following these suggestions, we designed and implemented online tasks with the software Geogebra, focused on conversions between different representation registers and designed with the aim of providing students with the necessary scaffolding to carry out these conversions. Here we focus on two tasks that require to describe a region in the plane (represented graphically) in polar coordinates (ρ,θ), by inserting the minimum and maximum values of the parameters ρ and θ in input fields (specific descriptions of the two tasks are in Table 1 and Table 2, together with screenshots that highlight the hints that are provided). The two tasks have the same structure: (a) a brief summary of the transformation between Cartesian and polar coordinates is provided on the screen; (b) within the graphical representation, some information is given (for example, coordinates of points), but itis not sufficient to perform the task; (c) students are asked to select one further piece of information among three alternative options (only one option is sufficient to describe analytically the region, another one is useful and one is useless); (d) students can change the selected information while they are working on the task; (e) students can submit their answers even if they do not select the further piece of information; (f) if the students submit wrong range for ρ and θ, a warning message appears on the screen together with two sliders for ρ and θ; (g) as the students move the sliders between the minimum and the maximum values previously inserted, the program dynamically shades the corresponding set in the Euclidean plane.

Task 1: The subset of the plane is a sector of a circle centred in the origin of the axes. To describe it analytically, students have to identify a further information (the ordinate of P) needed to determine the minimum value of the parameter θ (π/6). Here, the student has tried to answer without selecting the needed information.

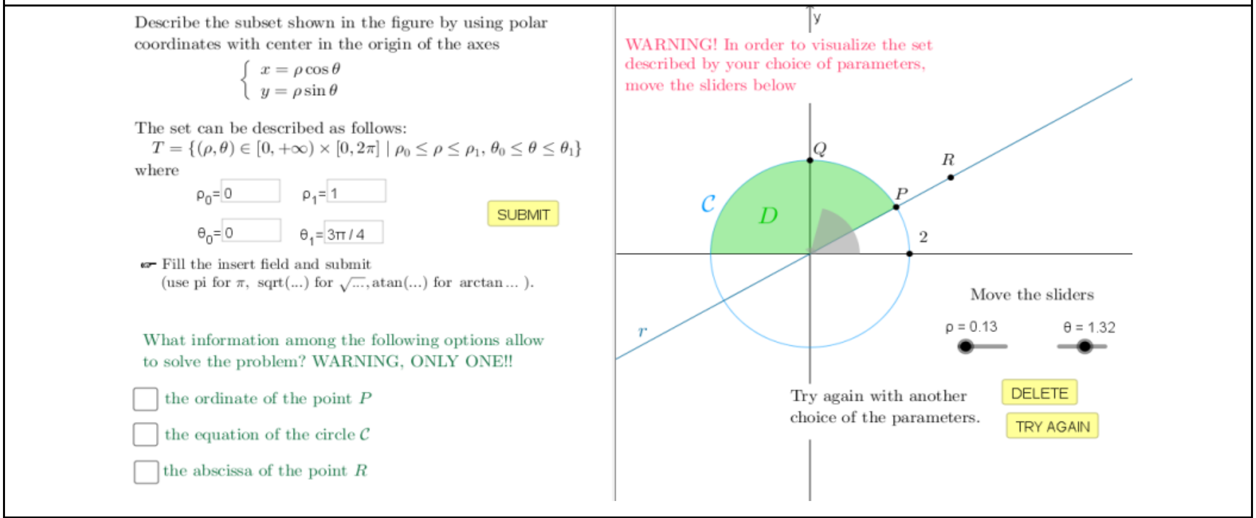

Table 1. Screenshot and description of task 1

Task 2: The subset of the plane is a sector of an annulus. The information provided in the graphical representation are enough to determine the centre of the polar coordinates system, the radii of the annulus and the maximum value of the angle θ. A further information (equation of s) is needed to determine the minimum value of θ (arctan2). Here, the student has not chosen this information.

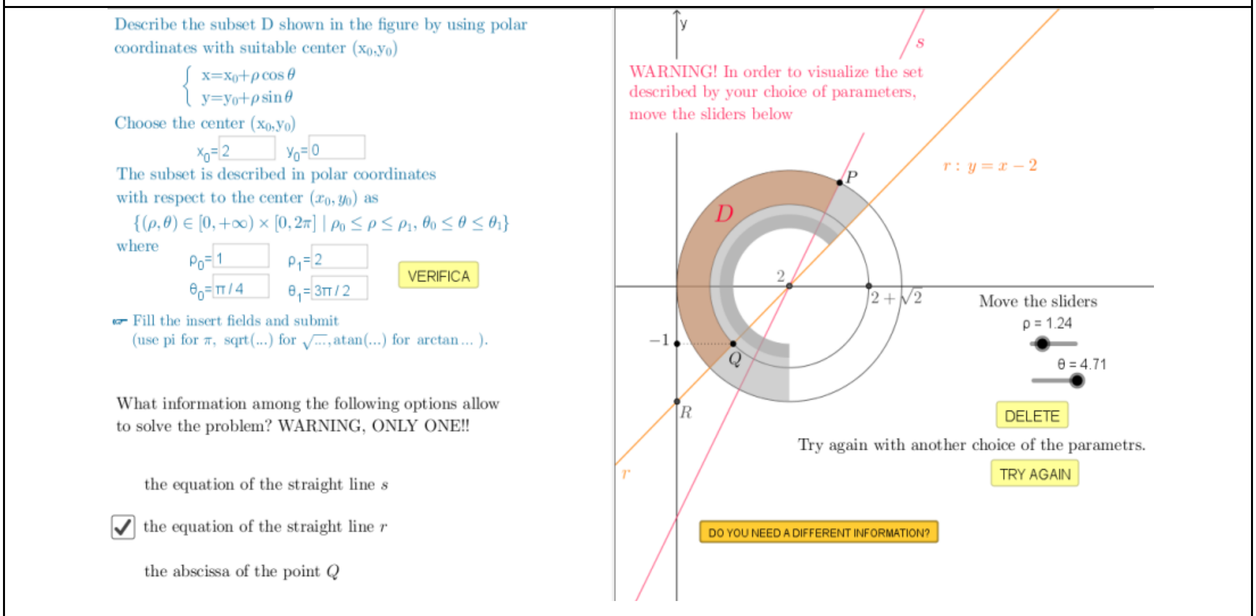

Table 2. Screenshot and description of task 2

This design of feedback and scaffolding is in tune with what Narciss & Huth (2004, in Shute, 2008) call informative tutoring, that is elaborated feedback that present verification (without supplying the correct answer) and strategic hints on how to proceed; moreover, it automatically appears after students have submitted a solution and it is presented in small and specific pieces (Shute, 2008). In particular, in this paper we focus on sliders as part of the scaffold within the environment, since they have been engineered in order to allow a direct and dynamic comparison between the representation in polar coordinates and the graph of the region. In order to examine how students use sliders to identify where the mistakes are, we decided not to provide information about the exact location of mistakes.

RESEARCH AIMS AND METHODOLOGY

The exploratory study documented in this paper has both a didactical and a research aim. The didactical aim is to test the effectiveness of the design of digital tasks (and, in particular, of specific hints and feedback) to scaffold students' learning, focusing on evidences that could inform the future re-design of the tasks.

The research aim is to analyse students' *instrumentation processes*, referring to Hegedus and Moreno-Armella's (2009) extended definition. When the students perform specific *actions* on the digital tools provided within the tasks, they have to interpret the *environment's re-actions* (that is the feedback from the environment) to activate the effective strategies to perform the task. In this paper, we focus, in particular, on two re-actions of the environment: the message that appears when the students submit their answers and the *border objects* (Hegendus & Moreno-Armella, 2009) which appear together with this message, that is the shaded figures that can be dynamically transformed through the use of the sliders. The main aim of our analysis will be to study the emergence of *instrument-mediated action schemes* (Rabardel, 2002) throughout the activity in the students' use of the sliders.

To analyse the co-actions between the students and the digital environments, we observed the students' interactions with the digital tasks and video-recorded them by using the software CamStudio. For each student, we developed an analytic description of his/her use of sliders, aimed at identifying categories of *instrument-mediated action schemes* that students adopt in using the sliders to scaffold their work on the tasks.

To collect further evidence about our re-construction of students' schemes (and, in general, about students' strategic approaches in exploiting the provided scaffolding), we designed a set of questions that we asked to students, during an audio-recorded interview, after their completion of the two tasks. For each task, students were asked to reflect about: (1) their selection and use of the needed further piece of information; (2) their use of sliders to perform the task; (3) the influence of their experience with task 1 when they faced task 2; (4) the usefulness of the feedback and tools provided to face the two tasks.

DATA ANALYSIS

In this section we discuss the main results from a pilot study that involved 15 first year engineering students attending to a MC course [2]. The students, who volunteered to participate in the study, individually faced, in a computer room, the two tasks described in the previous paragraph. Here we present the main results of our analysis of the data (video-recordings of the students' interaction with the task and audio-recordings of the interviews). We propose three paradigmatic examples, which enable to highlight categories of *instrument-mediated action schemes* related to the use of sliders to scaffold the students' work on the tasks.

When we analysed the video-recordings of students' screens in order to develop an analytic description of each student's interaction with the tool 'sliders', we focused on the following aspects: What sliders does the student use and in what order? How quickly does he/she move each slider and in what ways? How could the sequences of actions performed by the student be characterised?

Our analysis enabled us to identify three main *instrument-mediated action schemes* developed by students when they use the sliders to scaffold their work on the tasks. Each scheme could be associated with specific functions of the sliders, according to students' strategic use of them. We named these functions as *replacement* function, *diagnostic* function and *elaboration* function.

The *scheme related to the replacement function* of a tool is activated by those students who rely completely on the information that can be provided by digital tools, using them to find out the answers, without referring to theoretical knowledge.

The *scheme related to the diagnostic function* of a tool emerges when students use the tool to control the correctness of their answers, often before submitting their response, and to detect where the mistake is and, possibly, even how it could be corrected. This scheme is characterised by an alternation of the use of the tool and the reference to theoretical knowledge to find out the answers.

The *scheme related to the elaboration function* of a tool arises when the students refer to the tool to deepen their understanding of the theoretical knowledge subtended to the task and their interpretation of the representations involved in it. Also, in this scheme the use of the tool is alternated to the reference to theoretical knowledge.

Often, students adopt strategies that highlight combinations of more than one of these schemes.

Table 3 summarises our analytic description of three students' interaction with the tool 'slider': in the second column we summarise the description of the interaction with the sliders referring to the questions previously listed, while, in column 3, we summarise our re-construction of students' strategic approaches to the use of sliders, highlighting the instrument-mediated action schemes that emerge. To perform this re-construction, we referred also to the audio-recorded interviews. We stress that this re-construction is the result of our interpretation of what we observed in the videos and of what students declare in the interviews.

Student	**Description of the interaction with the sliders**	**Strategic approach**
Mario	He repeatedly uses the sliders in task 2. After having tried to substitute "known" values ($\pi/6$, $\pi/3$…) in the θ_0 input field and received a warning message, he works outside the digital environment, then he uses the slider tool. He alternatively moves the sliders very quickly. Each slider is moved throughout the whole interval (from the minimum to the maximum value of the parameter or vice-versa).	In the interview he declares that in both tasks he initially relied on perception, referring to 'known' values of angles and that in task 2 he used the slider to identify where he made a mistake (the values of θ_0): "when someone makes a mistake, as the $\pi/6$ I wrote, through the slider he can see (where) $\pi/6$ (is) and says 'it is clear! I made a mistake!'". Thanks to this, he identifies the further information needed to determine the exact value of this angle. He developed, therefore, the *scheme related to the diagnostic function* of the sliders.
Federico	He uses the sliders in both the tasks, with pauses between one use and the following one. The movements are almost slow and localized within the interval of variability of each parameter (he focuses on small sub-intervals containing the extreme value he has to determine). The sliders are moved one at a time, depending	He initially tries to insert a value in each input field to immediately display, on the screen, the effects of his choice (the environment's *re-action*), then he works separately at the identification of the different values to be written in the input fields, decomposing the problem in sub-problems. Since the movements of the sliders are slow and localised during the whole activity, it seems that he aims at understanding how each slider works and what information it provides to highlight the different roles played by ρ_0, ρ_1, θ_0, θ_1.

	on the parameter (ρ or θ) on which he wants to focus. He inserts one value at a time in the input fields (or two values that limit the same interval), and he clicks on "verify" to highlight the effects of his choice.	In this way, he is activating a local control of his work to deepen his understanding of the meanings subtended to the representation in polar coordinates. The main *scheme* connected to this approach is, therefore, the one *related to the elaboration function* of the sliders.
Giulia	In both the tasks, initially she inserts values corresponding to empty sets (for example $\theta_1 < \theta_0$) or to sets outside the visible window (ρ_0=10 and ρ_1=20), so she is not able to visualize the described set nor to use the sliders. Then, when this tool becomes available, she repeatedly uses the sliders, moving them throughout the whole interval, by means of fast movements. The sliders are alternatively moved very quickly.	In the second phase of her exploration, she uses the sliders not only to highlight where she made mistakes (*scheme related to the diagnostic function* of the sliders), but also to identify possible values of θ and ρ without performing calculations (in the interview she says that she used the sliders to understand "how the spaces were filled", "how the angle was moved"). In fact, she moves the θ and ρ sliders until the shaded region coincides with the one to be represented and insert the values she reads in the sliders. Therefore, she activates also a *scheme related to the replacement function* of sliders. At the beginning she only slightly modifies the values (for example, she writes ρ_0=1,42 instead of ρ_0=1,41[3]), as if she is not aware that most of them are only approximate values of θ_0, θ_1, ρ_0 and ρ_1. Then she works outside the digital environment to determine the correct values. We hypothesise that she realised the need of referring to theoretical knowledge, using the information she did not use in the other phases of her exploration.

Table 3. Analytic description and strategic approach to the use of the sliders

As in the three paradigmatic examples that we presented, our analysis enabled us to highlight that most of the students used sliders activating *the scheme related to their diagnostic function* or a combination of this scheme with others. Specifically, four students activated only the scheme related to the *diagnostic* function; other four students activated, alternatively, the schemes related to both the *diagnostic and elaboration* function; and one student activated, alternatively, the schemes related *to the three functions*. Finally, two students activated only the scheme related to *replacement* function. The remaining four students did not activate any of these schemes because they gave the correct answers without using the sliders.

CONCLUSIONS

In this paper we analysed university students' interaction with digital tasks that require to perform conversions from the graphical to the symbolic registers in the representation of subsets of the plane. The focus of our analysis was on students' development of *instrument-mediated action schemes* in the use of a digital tool provided within the tasks – the sliders - to scaffold their work.

We analysed the video-recordings of students' screens during the activity, performing an analytical description of students' use of sliders. This first step of analysis highlighted different behaviours in relation to the parameters to which we referred to code the video-recordings of students' screens (frequency of the use of the sliders, speed of the movements on the slider, extension of the movement, order in the use of the sliders). We, then, looked at this analytic description referring to students' audio-interviews to re-construct the typical strategic approaches in their use of sliders to scaffold their work on the tasks. This re-construction enabled us to highlight three main *instrument-mediated action* *schemes* associated with three specific functions of the sliders: *replacement* function, *diagnostic* function and *elaboration* function. Our analysis highlighted that most of the students adopted approaches that could be characterised by a combination of these schemes. In particular, in our data, the scheme connected to the *elaboration function* seems to be always activated to support the one related to the *diagnostic function*.

Our design was mainly aimed at creating an environment that could scaffold students' work on the tasks, fostering their activation of the scheme connected to the diagnostic function of the tool 'slider'. Although the analysis of the data showed the effectiveness of the design in this sense, the emergence of other schemes induces us to develop further reflections.

First of all, the emergence of the scheme connected to the *replacement function* displays a widespread pitfall of digital technologies, that is the risk that students thoughtlessly rely to digital tools without activating a metacognitive control on their use. This lack of metacognitive control is also connected to other "problematic approaches" that we observed. For example, some students did not use the offered information (necessary to perform the task) and mainly relied on perception. These students seem to implicitly have assumed that further information is optional and that all the angles involved in the required analytical description are "known". This is an example of implicature (Boero et al., 2008), that is an additional assumption with respect to the actual content of an information. We have deliberately chosen to give the possibility to submit the range of variation of the parameters even if the additional information was not used by students to highlight these implicit assumptions. Many students, in their interviews, displayed to have understood the need of balancing between perception, use of digital tools and reference to theoretical knowledge. Therefore, this aspect of the design was effective in making them reflect on their behaviour.

The identification of students who activated only the scheme connected to the *replacement function* suggests us that the explicit recommendation of using sliders when students send an incorrect answer is not enough. The intertwining of explicit (directive) scaffolding and tacit (less directive) scaffolding is therefore not well balanced. To better enable students to activate themselves at the metacognitive level, we will perform a re-design of these tasks to realize what Pea (2004) calls meta-scaffolding, offering feedback that support students in understanding how to use these digital tools to scaffold their work.

On the other hand, the occurrence of the scheme related to the *elaboration function* suggests us to better exploit this potentiality of digital tools in our future re-design, to guide students' interpretation of mathematical representations and deepen their understanding. Our idea is to insert the re-design of these tasks in a longer sequence of tasks with similar characteristics to foster an evolution of the schemes activated by students toward those connected to the *elaboration function*. Our expectation is that, in this way, students' metacognitive control of their work could develop, and the scaffolding could be spontaneously faded. The re-design and implementation of this sequence of tasks will be the focus of our future research, through which we will test the aforementioned hypothesis and also investigate the possible evolution of the schemes activated by students through the whole sequence.

NOTES

1. The online activities were developed and implemented within the University project "Didattica Multimediale della Matematica" (multi-media didactic of mathematics).

2. The topic introduced in the MC course are: description of subsets of the plane in Cartesian, polar and elliptic coordinates, theory of curves, calculus of functions of several variables (limits, derivative, differentiability), constrained maxima and minima, multiple integrals, integrals over curves and surfaces, vector fields, conservativity, work and flow of a vector field, ordinary differential equations.

3. According to our implementation, Geogebra displays 1.41 when the user writes sqrt(2).

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Published in: 14th International Conference on Technology in Mathematics Teaching 2019

DOI: 10.17185/duepublico/70785

URN: urn:nbn:de:hbz:464-20191121-171203-4