# STUDENTS' REFLECTIONS ON THE DESIGN OF DIGITAL RESOURCES TO SCAFFOLD METACOGNITIVE ACTIVITIES

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*In this paper we investigate the efficiency of the design of a digital resource aimed at scaffolding students' metacognitive processes during problem solving activities. We develop this investigation by focusing on students' a-posteriori reflections on their interaction with the digital resource. Through the analysis of students' reflections, we highlight the digital meta-scaffolding elements that are relevant for students and their level of awareness about the provided metacognitive support.*

## INTRODUCTION AND BACKGROUND

The research documented in this paper is set within a wider study that concerns the design and implementation of digital resources to foster individualization processes at university level (Cusi & Telloni, 2020A-B). In particular, we focus on students' reflections on *digital meta-scaffolding elements* (in the following, DMSEs), that is on the elements of scaffolding provided, within digital environments, with the aim of fostering students' metacognitive processes.

Research in mathematics education has widely stressed the key-role played by metacognition in problem solving (Schoenfeld, 1992; Holton & Clarke, 2006). Here we adopt Holton and Clarke's (2006) definition of metacognition as "any thinking act that operates on a cognitive thought in order to assist in the process of learning or the solution of a problem" (p.133). This definition shifts the focus on the idea of "acts" to distinguish them from all the factors that could influence metacognition but are not metacognitive in themselves (such as beliefs, intuition and knowledge). In tune with this idea, we refer to Meijer et al.'s (2006) categorization of metacognitive activities, defined as "the strategic application of metacognitive knowledge to achieve cognitive goals" (p.209). We focus on five categories of metacognitive activities identified by the authors: (1) *orientating*, which involves activities such as activating prior knowledge, establishing task demands, identifying important information, re-reading questions carefully, establish givens, observing; (2) *planning*, which involves activities such as looking for particular information in text, sub-goaling, using external source to get explanation, backward reasoning, formulating action plan; (3) *monitoring*, which involves activities such as error detection and correction, noticing inconsistency, checking plausibility, claiming progress in understanding, giving meaning to symbols or formulae; (4) *evaluation*, which involves activities such as explaining strategies, finding similarities, interpreting, quitting, self-critiquing, verifying; (5) *elaboration*, which involves activities such as inferring, checking representations, commenting on the difficulty of problems, commenting on personal habits.



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When the focus is on fostering students' metacognitive activities within digital learning environments, the design of DMSEs provided to students deserves special attention. The close interrelation between metacognition and scaffolding has been highlighted by Holton and Clarke (2006), who assert that acts of scaffolding and acts of metacognition could be potentially identified. Moreover, students' effective use of the scaffolding provided to them and their subsequent development of awareness about the role of scaffolding require that they activate themselves at the metacognitive level (Holton & Clarke, 2006). This is in tune with Pea's (2004) reflection on the crucial role played by meta-scaffolding, conceived as the scaffolding for the scaffolding. This is particularly relevant in the context of digital environments, where a good balance between procedural and metacognitive scaffolding is needed (Sharma & Hannafin, 2007). Our previous studies (Cusi & Telloni, 2020A-B) confirmed these reflections, highlighting university students' widespread lack of awareness about the aims of the DMSEs provided to them within specific digital learning environments. In particular, we highlighted how this issue is interrelated with students' lack of awareness about their weaknesses and learning needs and with their lack of metacognitive control in monitoring their problem-solving processes.

## THE RESEARCH CONTEXT AND THE DESIGN OF DMSES

The context of this study is a Mathematics course for students enrolled in the "Chemistry and pharmaceutical technologies" degree course at Sapienza University of Rome (Italy). The course, scheduled for the first term of the first year, is aimed at providing students with basic Mathematics notions useful to be applied in the study of pharmaceutical chemistry. The course program covers basic knowledge related to different topics: algebra, analytical geometry, goniometry, probability, statistics, calculus. Within the part of the program devoted to calculus, the topic of differential equations is faced, with a focus on linear equations with constant coefficients and on their use in modelling simple problems. For many students enrolled in the Mathematics course it is the first approach to this content, since it is usually not faced in most upper secondary schools in Italy. The experience of the teacher of the course (one of the authors) during previous academic years has shown widespread students' difficulties with this topic. In particular, the written examinations have highlighted students' blocks in carrying out two fundamental processes: (a) the aware construction of the differential equations that models these kinds of problems (often students construct these equations in an automatic way and are not aware of the meanings of the different terms that appear within them); (b) the effective interpretation of the graph of the function that represents the problem's solution, by connecting specific properties of the graph to the corresponding characteristics of the represented phenomenon.

To support students in overcoming these blocks, we designed a digital resource (a GeoGebra applet) to be used to face a problem that could be modelled through a linear differential equation with constant coefficients. The text of the problem is: "An industry produces mobile phones at a rate of 20% per month. Every month, 150 mobile phones are sold. Suppose that at time t = 0 there are 700 mobile phones ready to be sold. Is the production's rate sufficient to meet market needs?". The digital resource has been designed to include specific DMSEs aimed at fostering metacognitive activities during students' resolution of the problem. Table 1 summarizes the main DMSEs provided to students and the metacognitive activities fostered by each DMSE. The design of the digital resource does not include DMSEs aimed at fostering students' reflections on their difficulties in solving the problem or on their personal habits in doing problem solving. For this reason, the *elaboration* category is missing in Table 1.

| Digital meta-scaffolding elements | Fostered metacognitive activities |
|---|---|
| 1) During the whole activity, students are guided to follow the different steps that structure the resolution process. At the beginning, two sub-goals are set: to construct the differential equation that models the problem and to sketch the graph of its solution. | *Planning*, since sub-goals are stated, and students are supported to formulate an action plan. |
| 2) If students fail in the initial construction of the differential equation, they are provided with the general form of the equation they have to construct ($y' = py + q$) and guided, by means of specific questions, to read the problem's text, identifying the information that could help them in determine the coefficients $p$ and $q$. | *Orientating*, since students are supported in the identification of important information and in establishing given values within the problem's text.<br>*Planning*, since students are guided to look at particular information in the problem's text and in selecting pieces of information useful to achieve the goal of constructing the differential equation that models the problem. |
| 3) After students' construction of the correct differential equation, they are asked to interpret the equation, making the meaning of each term of the equation ($y'$,$py$,$q$) explicit. | *Monitoring*, since students are supported in the interpretation of the differential equation in relation to the problem (highlighting, or not, their progress in the understanding of what they are doing) and in giving meaning to the mathematical objects they are working with. |
| 4) Theoretical hints are provided to students if they fail in specific steps of the task. Students can | *Orientating*, since students are guided to focus on important information that could support their work on the task. |

| | |
|---|---|
| autonomously use these hints to be supported in their resolution of the differential equation or if they want to check the correctness of their work. | *Planning*, since students are enabled to use external sources to get more explanations. |
| 5) After students' resolution of the differential equation, they can choose to use GeoGebra to draw the graph of its solution. Afterwards, they are supported in the interpretation of the graph in relation to the problem. Specifically, students are asked to identify, within a list of properties of the graph, the property to which they should refer in order to answer to the problem's question. | *Orientating*, since students are supported in a careful re-reading of the questions and in the interpretation of the constructed graph.<br>*Evaluation*, since the focus is on the interpretation of the result of the employing process, which could also give strength to the explanation of the strategy suggested at the beginning (constructing and solving an equation, then drawing the graph of its solution). |
| 6) During the whole activity, at each step students are provided with reminders about the main results of the previous steps. Students are also asked to make the strategies implemented during the employing process explicit, by selecting the correct strategy within a list of possible strategies. | *Planning*, since students are guided in formulating their action plan.<br>*Monitoring*, since students are supported in referring to the outcomes of the previous steps of the problem's resolution and in keeping track of their work. |
| 7) During the whole activity, error messages are provided, together with partial corrections, that is operative hints aimed at supporting students in detecting their mistakes. | *Monitoring*, since students are guided to detect mistakes and understand possible reasons related to partial failures in the resolution process.<br>*Evaluation*, since students have the opportunity to check their work in progress and to develop a self-critique about the chosen approaches. |

Table 1: DMSEs and related metacognitive activities

## RESEARCH QUESTIONS AND RESEARCH METHODOLOGY

The aim of this study is to investigate the efficiency our design, by focusing on students' a-posteriori reflections on their interaction with the digital resource presented in the previous section. In particular, we address the following research questions: (1)

*What DMSEs of the digital resource are relevant for students who interacted with it and why*? (2) *What aims related to the design of DMSEs are students aware of*?

To investigate these issues, we developed an exploratory study with a group of 11 students that were attending the course in Autumn 2021. The students, enrolled on voluntary basis, worked in small groups (5 groups of 2 or 3 students) at distance, by means of the Zoom platform. During the groups' work, which lasted from 20 to 30 minutes (no time limit was a-priori set), one student for each group shared his/her screen and directly interacted with the digital resource. Each group's work was video-recorded to keep track of both the students' interaction with the digital resource and the dialogues between students. The choice of making students work in small groups was specifically aimed at fostering their explicitation of cognitive and metacognitive processes while working with the digital resource. Moreover, two researchers (two of the authors) were always present during the groups' work. One of them took notes about the observed interactions, the other played the role of tutor, posing specific questions to the students to make them share their cognitive and metacognitive processes and to support their reflection on DMSEs.

Here we focus on the reflections carried out by the students during a short interview developed by the tutor, immediately after students have completed their work with the digital resource. During the interview, students were asked to provide feedback about the effectiveness of the design of the digital resource in supporting their resolution of the problem and to identify the most supportive elements of this design. We analysed the transcripts of the interviews by highlighting: (a) the DMSEs on which students focused; (b) the ways in which students reflected on these DMSEs; (c) students' metacognitive activities emerging during the interviews. The results of this analysis are presented in the following section.

## ANALYSIS

The DMSE on which almost all the groups' reflections are focused (4 groups referred to it) is the first one, that is the choice of structuring the task in different steps. F, a student from group 3, for example, states: "All the steps are in order, so nothing is lost, the procedure that needs to be done is clearer to me". The general idea that students share is that they have assimilated this scaffolding, as testified in this reflection:

> "…[the resolution process] is much more schematized and ordered. The mental order is much easier to be achieved in this way, because it [the digital resource] asks exactly what the procedure is and creates a mental set" (A, group 2).

Although students widely focus on the ordered structure of the digital resource and on the possibility of re-constructing all the passages developed within the resolution steps, DMSE 6 (giving reminders about the results of the previous steps and asking students to identify a correct employing strategy within a list of possible strategies) is more implicit in students' reflections. However, some students propose interesting reflections about the effectiveness of DMSE 6 in making the employing strategies explicit. They stress, in particular, that asking students to identify their strategies among different options enabled them to make the reasons connected to these strategies more explicit to themselves. This idea is evident in V's (group 2) reflection:

> "To answer to the question that asks what we have to do to determine the particular solution [of the differential equation], we must have understood what 0 and 700 represent and why we have to replace x with 0 and y with 700."

The further DMSE on which most of the groups (3 groups) focus is the seventh, that is the error messages that are provided, together with partial corrections. S (group 5) proposes strategic use of DMSE 7 that she carried out when working on the digital resource: "When you try to put an answer and it is wrong, it [the digital resource] gives you some suggestions to get you to the right answer. This is useful". The following reflections highlight, in particular, that students appreciate the immediate feedback provided through DMSE 7, interpreting it as an opportunity to reflect about mistakes:

> "The messages that come out are very useful, because they immediately tell you where you went wrong and they also refer to the theory so you can immediately see your error." (F, group 2)

> "In fact, they give you a second chance, they make you think about the mistake you made. They also tell you if you can go ahead or if you need to review something." (A, group 2)

F's reflection enables us to shift our attention on a DMSE on which only two groups focused, that is the theoretical hints provided within the digital resource (DMSE 4). Besides F (group 4), only one other student, A (group 2), implicitly mentions this element, declaring her awareness about the importance of referring to theoretical tools when facing this kind of tasks: "You have to make reference to the theory you assimilated during the course, then you have to specifically use it to face this problem". This assertion could also be interpreted in terms of an *elaboration* activity emerging during the interview, since A is providing to herself feedback about self-regulation.

The other DMSEs are rarely mentioned in students' reflections. The DMSE 2 (supporting students' reading of the problem's text to identify the information that have to be used to model the problem), in particular, is never mentioned by students. This is certainly due to the fact that one group did not receive this scaffolding since they were able to immediately construct the correct equation and other two groups made minor mistakes in the construction of the equation, so this DMSE was not really necessary for them. As regards the other two groups, we think that they did not mention the DMSE 2 because the difficulty they faced was not related to the identification of the information useful to construct the equation, but to how to use this information.

Although few students spontaneously propose reflections on DMSE 3 (support in the interpretation of the constructed equation in relation to the problem) and DMSE 5 (support in the interpretation of the graph in relation to the problem), our analysis enabled us to show that reflecting on these two DMSEs during the interview fostered the *evaluation* and *elaboration* activities. The following reflection testifies, for example, the awareness about the role of DMSE 5 in guiding students' effective use of the graph within the resolution process:

> "This question is useful to understand how to extrapolate, from the graph, the information we need to solve the problem, therefore how to obtain the needed information from the modeling of the problem" (R, group 1).

DMSE 3 is explicitly mentioned only by V (group 2), who declares that a lack in her approach is that she did not deepen the interpretation of the different components of the differential equation in relation to the problem. Therefore, even if students do not mention DMSE 3 as relevant for them, the reflection on the difficulty faced in interacting with this DMSE boosted their *elaboration* activity during the interview, making them become more aware of their difficulties and develop self-critique. The reflection on DMSE 5 also boosted the development of the *evaluation* and *elaboration* activities during the interview. This is testified by the following reflection, in which a student highlights the interrelation between facing difficulties when interacting with this DMSE and becoming more aware of unclear aspects of the strategy adopted to solve the problem:

> "When we got stuck on this question related to the graph, then understanding what was the right answer, among the three answers, helped us a lot. We were more confident about other things and we got stuck on this one, but then I understood why." (S, group 5)

Our analysis highlighted also other examples of how the students' reflection on the effectiveness of the DMSEs make them develop *evaluation* and *elaboration* activities. It happened especially when students focused on those elements that disoriented them, as testified in the following reflection, developed by V (group 2) when speaking about the confusion they faced in the initial part of their work on the task:

> "In fact, we were wrong because when you write the Cauchy problem, you write like this, not as we did. In my opinion, the problem is not in the formulation of the task and in how it is set up. We were really wrong because we have read the request with little attention".

## FINAL DISCUSSION

The analysis presented in the previous section enabled us to show that not all the DMSEs included in our design are relevant for students. Students mostly mention the support provided by the structuring of the task in different steps (DMSE 1), the reminders about the results of the previous steps and the guide in making the employing strategies explicit (DMSE 6), the error messages associated to partial corrections (DMSE 7) and the theoretical hints (DMSE 4). This result shows that students are more aware of those DMSEs that simplify the task by suggesting what are the actions required to reach the solution or of those that keep them in pursuit of specific goals.

The fact that students never or rarely mentioned the DMSEs directly aimed at supporting the phases of construction of a formal representation to solve the problem (DMSE 2) and of interpretation of the representations with which they interact (DMSE

3 and 5) suggests us the need of a re-design of the digital resource with the aim of enriching the meta-level of the provided scaffolding, enabling students to become aware of the role of specific DMSEs within the digital resource. The problems related to the students' lack of this awareness have been also highlighted during the phase of students' work with the digital resources, when, in tune with our previous studies (Cusi & Telloni, 2020B), the tutor played a crucial role in making students effectively exploit the provided scaffolding. The different excerpts that show students' development of *evaluation* and *elaboration* activities when reflecting, during the interviews, on the usefulness of the provided DMSEs, testify the importance of fostering this kind of reflection as a further element of the meta-scaffolding itself.

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