EXPLORING STUDENTS' PERSPECTIVES ON THE SUPPORT PROVIDED BY DIGITAL META-SCAFFOLDING

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In this paper we present the results of a study aimed at investigating university students' perspectives on the support provided by specific digital meta-scaffolding elements that characterize the design of a digital resource aimed at fostering students' metacognitive activities when facing problem situations that could be modelled through differential equations. The analysis of the data collected through a written questionnaire enabled us to identify categories of theory-driven and data-driven themes emerging from students' reflections, to highlight the categories that students relate to each digital meta-scaffolding element and to discuss interrelations between different categories.

Keywords: digital resource design, meta-scaffolding, metacognitive activities, problem solving

INTRODUCTION AND THEORETICAL FRAMEWORK

In this paper we present the results of a study developed within the second cycle of a design based research (DBRC, 2003) focused on the design of digital resources (DR) aimed at providing students with meta-scaffolding to support their reasoning processes when facing problem solving activities.

We refer to Holton and Clarke's (2006) 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). Scaffolding is particularly relevant for the design of learning environments aimed at supporting students' problem solving processes, due to the key role played by metacognition in problem solving (Schoenfeld, 1992) and to the strict interrelation between the provided scaffolding and the corresponding acts of metacognition that could be activated (Holton & Clarke, 2006). Moreover, students' effective use of the scaffolding provided within learning environments requires that they activate themselves at the metacognitive level (Holton & Clarke, 2006). This suggests to shift the focus on a specific type of scaffolding, that is meta-scaffolding, defined as the scaffolding for the scaffolding (Pea, 2004).

Metacognitive aspects play a fundamental role also when the focus is on the design of digital environments aimed at supporting problem solving processes, due to the need for a good balance between procedural and metacognitive-scaffolding (Sharma & Hannafin, 2007).

To better characterize the DR-design on which our study is focused, we introduce the notion of *digital meta-scaffolding elements* (DGMEs) to refer to those elements of scaffolding provided, within digital environments, with the aim of fostering students' metacognitive activities (Cusi et al., 2022). The categorization of *metacognitive activities* to which we refer is the one introduced by Meijer et al. (2006), who distinguish between orientating, planning, monitoring, evaluation and elaboration (Table 1 summarizes the activities included within each of these categories).

Categories	Activities included within each category
Orientating	Activating prior knowledge, establishing task demands, identifying important information, re-reading questions carefully, establish givens, observing.

Planning	Looking for particular information in text, sub-goaling, using external source to get explanation, backward reasoning, formulating action plan.
Monitoring	Error detection and correction, noticing inconsistency, checking plausibility, claiming progress in understanding, giving meaning to symbols or formulae.
Evaluation	Explaining strategies, finding similarities, interpreting, quitting, self-critiquing, verifying.
Elaboration	Inferring, checking representations, commenting on the difficulty of problems, commenting on personal habits.

Table 1. Meijer et al.'s (2006) categorization of metacognitive activities

When scaffolding is realized within technology-enhanced learning environments, the feedback provided by digital tools plays a central role. This kind of feedback can be considered, according to Nicol and Macfarlane-Dick's (2006) definition, a form of *external feedback*, which must be interpreted, constructed and internalized by students to have a significant influence on subsequent learning, since the result of this process of internalization is the *internal feedback*, generated by students' monitoring of their interactions with the tasks and the internal and external outcomes of their work. To distinguish between the different information that feedback could provide, we refer to Hattie and Timperley's (2007) levels of feedback: (i) about the task; (ii) about the processing of the task; (iii) about self-regulation; (iv) about the self as a person.

CONTEXT, BACKGROUND AND TASK DESIGN

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 Mathematics course, which is focused on basic knowledge related to different topics (algebra, analytical geometry, goniometry, probability, statistics, calculus) is scheduled for the first term of the first year. 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. Many students enrolled in the Mathematics course face difficulties with this topic, in particular in correctly interpreting the elements that constitute the differential equations that model the problems and in connecting specific properties of the graph of the functions that constitute the problems' solutions to the corresponding characteristics of the represented phenomena. During the first cycle of our design based research, to support students in overcoming these blocks and to foster their activation of metacognitive activities during the resolution of problems, we designed a specific DR: a GeoGebra applet aimed at supporting students when facing a problem that could be modelled by means of 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 main DMSEs included in the first design of the DR were presented in Cusi et al. (2022), together with an analysis of a set of a-posteriori interviews conducted with five pairs of students who tested the DR. Table 2 summarizes the main DMSEs provided through the DR and the metacognitive activities fostered by each of them.

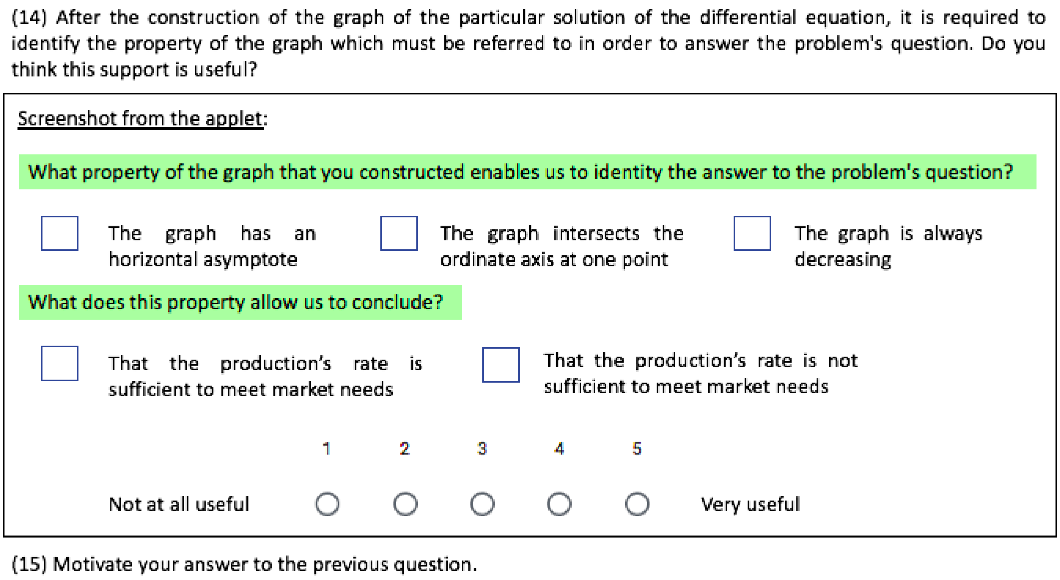
Digital meta-scaffolding elements	**Fostered metacognitive activities**
A) In case they fail in the initial	*Orientating*, since students are supported in the identification of important information and in

construction of the differential equation, students 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*.	establishing given values within the problem's text. *Planning*, since students are guided to look at particular information useful to achieve the goal of constructing the differential equation that models the problem.
B) After the construction of the correct differential equation, students are guided in making the meaning of each term of the equation (y', py, q) explicit.	*Monitoring*, since students are supported in giving meaning to the mathematical objects they are working with and in highlighting their understanding of what they are doing.
C) After having drawn the graph of the solution of the differential equation through GeoGebra, students are asked to identify, within a list of properties of the graph, the property to which they should refer in order to answer the problem's question.	*Orientating*, since students are supported in a careful reading of the question and in the interpretation of the graph in relation to the problem. *Evaluation*, since the focus is on the interpretation of the result of the processes activated to solve the problem.
D) After having inferred that the production's rate is not sufficient to meet market needs, the students are asked to determine the number of months after which there are no more mobile phones ready to be sold. If they fail in answering this final question, they have the opportunity to choose between two possible strategies and are guided toward the implementation of the chosen strategy.	*Planning*, since students are guided in formulating their action plan.
E) If students fail in specific steps of the task, they have the opportunity to use theoretical hints to support their resolution or to check the correctness of their work.	*Orientating*, since students are guided to focus on information that could support their work. *Planning*, since students are enabled to use external sources to get more explanations to organize the resolution process.
F) At each step of the activity, students are provided with reminders about the main results of the previous steps.	*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.
G) Error messages are provided during the whole activity, together with feedback aimed at supporting students	*Monitoring*, since students are guided to detect mistakes and understand possible reasons related

in detecting their mistakes.	to partial failures in the resolution process. *Evaluation*, since students have the opportunity to check their work in progress and to develop a self-critique about the chosen approaches.

Table 2. Digital meta-scaffolding elements and related metacognitive activities

The analysis presented in Cusi et al. (2022) highlighted students' lack of awareness about some of the DMSEs that were part of our DR-design and showed the importance of stimulating their reflections on the scaffolding provided by this DR to make them realize how to take advantage of its use to support both their cognitive and meta-cognitive processes. This result suggested us to re-design the students' activity with the DR with the aim of making them become more aware of the role of specific DMSEs by stimulating their reflections immediately after their use of the DR. For this reason, the study conducted during the second cycle of our design-based research involved the students enrolled in the Mathematics course in an activity that combined the work with the DR with a phase of individual reflections on the experience of using the DR to solve the problem. The phase of students' individual reflections was engendered by asking them to answer a written questionnaire constituted by 25 questions focused on: (a) the students' general difficulties in solving this kind of modeling problems, (b) the effectiveness of the DR in making them overcome these difficulties and (c) the usefulness of the different DMSEs provided by the DR. In this paper we present the first results of our analysis of the students' answers to the questions focused on (c). Each of these questions refers to a different DMSE and is structured like the one in Figure 1.


(14) After the construction of the graph of the particular solution of the differential equation, it is required to identify the property of the graph which must be referred to in order to answer the problem's question. Do you think this support is useful?

Screenshot from the applet:

What property of the graph that you constructed enables us to identity the answer to the problem's question?

☐ The graph has an horizontal asymptote ☐ The graph intersects the ordinate axis at one point ☐ The graph is always decreasing

What does this property allow us to conclude?

☐ That the production's rate is sufficient to meet market needs ☐ That the production's rate is not sufficient to meet market needs

Not at all useful 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Very useful

(15) Motivate your answer to the previous question.

Figure 1. Example of a question on the usefulness of a specific DMSE

RESEARCH QUESTION AND METHODOLOGY

The aim of the research documented in this paper is to answer the following research question: How do the students enrolled in the Mathematics course interpret the role played by the support provided by the DMSEs included in the DR they used?

To investigate students' perspectives on the DMSEs provided by the DR, we collected the answer to the written questionnaire of two groups of students enrolled in the Mathematics course during the academic years 2021-2022 and 2022-2023, who voluntarily participated in the study. The numbers of students who participated in the study were 83 in the academic year 2021-2022 and 63 in the academic year 2022-2023.

We carried out a qualitative analysis of the students' answers to the questions focused on the DMSEs provided by the DR resource. The analysis, which was both theory and data-driven (Cohen et al., 2007), was developed in two subsequent phases. The aim of the *first phase* was to identify categories of themes emerging from students' answers, associated with different interpretations of the received DMSEs. In the *second phase*, we read again through all the data to analyze the students' answers in relation to each of the emerging themes with the aim of highlighting the categories of themes that students mainly connect to each DMSE to characterize the ways in which they interpret the support provided by the different DMSEs and reflect on their use of this support.

ANALYSIS

The following tables summarize the different themes that emerged during the first phase of the data analysis. To provide examples for each theme, excerpts from the students' answers to the questionnaire are inserted in the right columns of the tables.

Table 3 summarizes the *theory-driven themes*, that is those themes that were a-priori considered by referring to the theoretical elements that guided the DR-design.

Themes	Examples from the questionnaire
(1) Metacognitive activities engendered by the DMSEs of the DR (Meijer et al., 2006)	Students' answers can be divided in two main categories, depending whether or not the students recognize the metacognitive activity that the design of the DMSE was aimed at fostering. The following reflection, for example, is in tune with the aim of the DMSE A-design, that is of supporting the orientating metacognitive activity: "*It is an effective guide if you cannot understand how the text should be interpreted.*" (reflection on DMSE A)
(2) Levels of the feedback provided by the DR (Hattie & Timperley, 2007)	Students' answers can be divided in three main categories, depending on how they interpret the received feedback, at the level of: (a) the task: "*Initially I gave the wrong answer and I was not able to understand why. Only thanks to the applet's support I understood my mistake and gave the correct answer.*" (reflection on DMSE D) (b) the processing of the task: "*…since it considerably shortens the time to search for your mistake, it allows a longer and more fruitful reflection on the reasons subtended to the solving process.*" (reflection on DMSE A) (c) the self-regulation: "*Since I understood what are the aspects on which I have more difficulties, thanks to this activity I know what are the aspects that I have to focus on to prepare the examination*" (reflection on DMSE A)

Table 3. Theory-driven themes

Table 4 summarizes the *data-driven themes*, that is those themes that directly emerged from the first reading of the students' answers. Each of the themes in Table 4 is presented in terms of categories corresponding to specific dichotomies between counterposed perspectives on aspects that the students highlighted when they commented about the usefulness of the support provided by the DMSEs.

Themes	Categories within each theme and examples from the questionnaire
(3) Aspect on which the support provided by each DMSE is focused:	**(a)** Focus on the problem solving process: the role of the DMSE's support is recognised in terms of monitoring the problem solving process and of testing students' understanding: "*...taking advantage of the graphical support [Geogebra], we can test the functions previously identified, in order to monitor whether the solving process autonomously considered (we autonomously set) was right. In this way, you can also easily self-assess the correspondence between what you studied and what you really understood.*" (reflection on DMSE C)
	(b) Focus on the product of problem solving: the role of the DMSE's support is recognised only in terms of making the students complete the task determining the right answer: *"If you have some doubts or perplexities, [it] guides you in finding out the right answers and in not making mistakes."* (reflection on DMSE A)
(4) Temporal dimension of the effects boosted by the support provided by each DMSE:	**(a)** Short-term effects: the role of the DMSEs' support is recognized only in relation to the resolution of the specific problem on which the applet is focused: "*The reminders help you in not forgetting the results of the previous questions and this can help in facing the next questions*." (reflection on DMSE F)
	(b) Long-term effects: the role of the DMSEs' support is recognized in relation to the aim of providing the student with a repertoire of strategies that he/she can activate in the future when solving the same kind of problems: "*I found it useful, since the applet placed us in front of two different ways of determining the same solution. This can be useful when facing other problems like this one, since we can choose between one method or another*." (reflection on DMSE D)
(5) Kind of understanding (Skemp, 1976) that each DMSE supports:	**(a)** Instrumental understanding: the role of DMSEs' support is recognized in relation to an idea of mathematical problem solving as a mere application of a set of formulae: *"Formulae and theoretical materials are useful to quickly solve the task. Often if you use theoretical hints in facing a task does not mean that you are not able to solve the task itself, but that you do not remember a formula which, in most cases, you need to learn by rote."* (reflection on DMSE E)
	(b) Relational understanding: the role of DMSEs' support is recognised in relation to the aim of fostering a deep understanding of the strategies that are activated to face the problem: *"...it is useful to deeply understand the meaning of each term of the differential equation. It encourages us to think about it instead of mechanically carrying out the resolution's steps. This leads to a more aware resolution of the problem"* (reflection on DMSE B)
(6) Perspective on the impact	**(a)** Objective perspective: the role of the DMSEs' support is recognised by reflecting on the difficulties that a generic student can face: "*It is very*

of the support provided by each DMSE:	*useful in this phase, since it forces the student to think about the different aspects that often are only quickly interpreted and not enough considered.*" (reflection on DMSE B)
	(b) Subjective perspective: the role of the DMSEs' support is recognised by reflecting on the student's own difficulties: "*I always have difficulties in setting up the solving process, so this element is very useful for me, since it made me understand that I did not have to take the initial number of phones into account*." (reflection on DMSE A)

Table 4. Data-driven themes

The analysis conducted during the second phase enables to highlight how the students reflect on the support provided by the different DMSEs and on their use of this support.

Here, due to space limitations, we limit ourselves to the presentation of some results from the analysis conducted in relation to the DMSE A. The themes that students mainly connect to the DMSE A are theme 1, theme 2, theme 5 and theme 6. The analysis of students' answers to the questions focused on the DMSE A enables us to highlight that most of them grasped that the DMSE A has been designed to mainly foster the orientating and planning metacognitive activities (theme 1). Many of them also refer to the monitoring that the use of this DMSE could activate, focusing on its role in providing a feedback on both the task, by supporting the identification of mistakes, and on the processing of the task, by stimulating reflections aimed at deepening the understanding of the reasons behind specific strategies (theme 2). Their interpretations of the received feedback are often related to the students' personal experience in Mathematics and on their learning difficulties, highlighting a subjective perspective on the impact of the DMSE's support (theme 6). Most of the students' answers are also focused on the importance of being aware of the meanings of the mathematical objects constructed during the resolution process, hence revealing a perspective on the DMSE's support related to the aim of fostering a relational understanding of mathematics (theme 5).

Besides allowing the identification of the themes that are more recurrent in students' answers on the support provided by specific DMSEs, the analysis developed during the second phase enables us also to highlight interrelations between specific categories of themes.

Regarding the DMSE A, we observed that the idea that the DMSE's support is focused on the product of the problem solving process (category b, theme 3) is often combined with a focus on the role played by the DMSE's support in providing a feedback on the task (category a, theme 2) and to the short-term effects of the provided scaffolding (category a, theme 4). This is testified, for example, by this reflection: "*It allows you to proceed with the right data and, even if it was not my case, it allows you to understand how to correctly write the differential equation and to understand your mistake*". On the other hand, the following reflection on DMSE A testifies that often the focus on the problem solving process (category a, theme 3) and on the idea that the DMSE gives a feedback on the processing of the task (category b, theme 2) is combined with a focus on the long-term effects of the DMSE's support (category b, theme 4) and on the idea that the DMSE supports a relational understanding of Mathematics (category b, theme 5): *"It is useful since it allowed me to autonomously find the solution, supporting to solve the specific case starting from the general formula. This helped me to improve my capability of problem solving*".

FINAL REMARKS

In this paper we investigated university students' perspectives on the support provided by DMSEs included in the design of a DR aimed at scaffolding students' problem solving processes in the context of problem situations that could be modelled through differential equations. The qualitative analysis of students' answers to a written questionnaire highlighted, in its first phase, theory-driven and data-driven themes emerging from students' reflections on the provided support and categories within each theme. The coding students' answers according to these categories, during the second phase of our analysis, enabled us, on one side, to identify the themes that are more recurrent in students' reflections on the support provided by each DMSE, and, on the other side, to highlight interrelations between specific categories of themes.

This shed light to the student's interpretations of the role played by the different DMSEs and to the possible utilization schemes that students could develop when interacting with specific DMSEs of the DR. In a previous work (Cusi & Telloni, 2020) we categorized students' instrument-mediated action schemes in their use of a specific element in the design of a DR. For each of these instrument-mediated action schemes, we highlighted a specific, distinguishing between *replacement* function, *diagnostic* function and *elaboration* function. In the next steps of this research, we will refer to the results of the second phase of the analysis documented in this paper to characterize possible categories of instrument-mediated action schemes related to the use of specific DMSEs and corresponding functions of specific elements of the DR-design aimed at providing support at the metacognitive level. For this reason, we plan to combine a systematic analysis of students' answers according to the themes and categories presented in this paper, to a quantitative data analysis in order to map the students' answers' distribution with respect to the identified categories.

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