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Routes of digital tasks for promoting individualization of teaching and learning at university level

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Abstract. Il lavoro descrive il design di percorsi di task digitali rivolti a studenti universitari e mirati a favorire l'individualizzazione dell'insegnamento-apprendimento. Vengono presentate in dettaglio due strutture di task: una sequenza lineare di task sul coordinamento di rappresentazioni multiple di sottoinsiemi del piano e un albero di task sulla probabilità elementare e condizionata. I percorsi di task sono inseriti in cicli metodologico-didattici che prevedono, da parte degli studenti, la ricostruzione della propria interazione nell'ambiente digitale, una riflessione sulle difficoltà incontrate, sul ruolo dei feedback e degli aiuti. In questo studio vengono discussi i risultati di studi pilota focalizzati sulla percezione che gli studenti hanno dei percorsi di task e del loro impatto sull'apprendimento.

1. Introduction

Within the university level of instruction, students and teachers encounter difficulties linked to some detrimental logistic conditions of the university context, like the heterogeneity of the students' backgrounds and motivations, the large number of students per teacher and the consequent impossibility of a close relationship between the learner and the teacher. This implies that students, mainly freshmen, experience either learning difficulties at different levels (cognitive, metacognitive and affective), or psychological obstacles (De Guzman *et al*., 1998; Di Martino & Gregorio, 2018), which require, to be overcome, the development of each learner's autonomy and responsibility about his/her learning, as well as the feeling of being valued as person, against the sense of massification that the university context may induce.

In this respect, a didactic attention to the students' individual attitudes and learning needs is very promising, but, at a time, very difficult to be pursued. The literature in mathematics education highlighted the crucial support that digital environments and resources can give to the teaching/learning at tertiary level (Calvani, 2005; Descamp *et al.,* 2006; Albano & Ferrari, 2008; Hegedus & Moreno-Armella, 2009; Alessio *et al.*, 2019a), and the key role of the technology in task-design (Leung & Baccaglini-Frank, 2017; Pepin *et al.*, 2007). Some scholars focused on different uses of technology for individualized/personalized teaching and learning (Albano *et al.*, 2014; Bardelle & Di Martino, 2012). In tune with these studies, we are carrying on a design-based research (Cusi & Telloni, 2019; Cusi & Telloni, 2020a; Alessio *et al.*, 2019b; Albano & Telloni, 2020), in order to identify suitable characteristics of effective individualized learning paths in digital environments.

Our hypothesis is that carefully designed and dynamically organized digital tasks can foster the individualization of teaching/learning, and hence support the overcoming of the difficulties above discussed.

This paper concerns the design of two routes of digital tasks (RT) and the outcomes of pilot studies involving engineering students of Polytechnic University of Ancona (Marche, Italy); in particular, we focus on the students' perception of the individualization features of the RT and on their impact on learning.

Throughout the paper we refer to *individualization* as the differentiation of learning paths in order to bring students to reach common educational goals (Baldacci, 2006). It differs from *personalization*, which envisages also the differentiation of the educational goals. Our focus on individualization is due to the context of the study, that is courses of Mathematics for Engineering, where there is the need of enabling students to achieve minimum levels of learning for attending subsequent courses. This focus on individualization rather than on personalization influences mainly the choices about how readdressing students within the RT, according to the difficulties they display when interacting with the tasks.

2. Theoretical framework

The design of the RT is guided from two main elements, which we recall in this section: the formative assessment frame and the problem of representation in mathematics. Formative assessment (FA) is an educational method envisaging that teachers and learners take advantage from the outcomes of the learning for adjusting their strategies (Black & Wiliam, 2009). The model developed by Wiliam and Thompson (2007) focuses on five key strategies, aimed at fostering students' awareness and responsibility about learning: (A) clarifying and sharing learning intentions and criteria for success; (B) engineering effective classroom discussions and other learning tasks that elicit evidence of students' understanding; (C) providing feedback that moves learners forward; (D) activating students as instructional resources for one another and (E) activating students as the owners of their own learning. Within the FaSMEd project (Cusi *et al.*, 2017), a technological dimension has been added to the model, concerning the functions of *sending and displaying*; *processing and analyzing*; and *providing an interactive environment*.

The FA model assigns a crucial role to two factors, that is metacognition and feedback, which have been taken into account for designing the RT. Metacognition is intended as the individuals' awareness of their own thinking, their evaluation of thinking and their regulation of them (Wilson & Clarke, 2004); it is an essential practice that, in synergy with the FA strategies, can support students in becoming responsible of their own learning progresses and needs. Metacognition becomes even more important in a digital context, where students are called to *interact* with tasks, hence the focus is naturally put on the action rather than on the reflection. In this perspective, one of our challenges was allowing not only students' interactions with the tasks, but also inducing their argumentative reflections on the experience within the digital environment, in order to increase their awareness on learning.

Feedback is "an information provided by an agent about how the student's present state (of learning and performance) relates to these goals and standards" (Nicol & Macfarlane-Dick, 2006). Feedback is a key tool to enact the individualization within the single tasks of the RT. We designed it according to the levels of feedback discussed by Hattie and Timperley (2007); in particular, the feedback automatically provided are (i) about the task, (ii) about the process of the task and (iii) about self-regulation.

Both the RT we will describe address the coordination between different semiotic systems, which is a source of deep difficulties for students, and, at a time, the heart of any mathematical activity (Duval, 2006). In fact, the impossibility of a direct access to mathematical objects implies that the understanding of them necessarily goes through the coordination of at least two semiotic representations. In this respect, according to Duval (2017), a key activity is the *one-to-one mapping between the meaning units from two semiotic representations*, considered as the "cognitive prerequisite condition to recognize whether two semiotic representations represent the same object" (p. 43). In tune with these ideas, we designed the digital tasks of the RT so that students are allowed to see the joint variation of different representations of the same objects, hence they are supported in one-to-one mapping between semiotic representations. The choice of addressing this learning difficult is due to our hypothesis, grounded on the literature (Drijvers, 2015; Drijvers *et al.,* 2017; Clark-Wilson, 2017) and on our previous experiences (Alessio *et al.*, 2019b; Cusi & Telloni, 2020a), that mathematical explorative interactions with digital tasks and metacognitive reflections on them can significatively support students in handling multiple representations.

2. Design of the RT

In this section we describe two kinds of RT. The choice of designing routes of tasks rather than single tasks is due to a specific educational goal: the need to contrasting the natural speed characterizing the students' interaction with digital resources, grounded on the assumption that "*short time* is considered a major feature of online learning" (Bardelle & Di Martino, 2012, p. 22). On the contrary, we aim at inducing a reflective learning, bringing students to face mathematical contents as problematic fields, taking advantage by different perspectives and multiple representations.

Firstly, we present a *linear sequence* of tasks, according to which all students face the same tasks in the same order; in this case the access to a task becomes available when the previous one is correctly performed. Then,

we focus on a *tree* of tasks dynamically connected, so that each learner faces an individualized sequence of tasks, depending on the difficulties displayed within the digital environment.
In both cases, FA strategy B *(engineering learning tasks that elicit evidence of students' understanding*) is activated. Individualization of teaching and learning is pursued either by means of the structure of the RT, or within the single tasks, where immediate and specific response-feedback are provided (FA strategy C), student is stimulated through various learning channels and he/she is allowed to ask for hints, possibly of different kinds. This last feature represents an activation of FA strategy E, since each student has to become responsible of his/her own learning needs. The implementation and the delivery of the RT to students exploit the functionalities of technology related to *providing an interactive environment* and *sending and displaying.*

3.1 The linear sequence

The *linear sequence* (LS) of tasks concerns the coordination between symbolic and graphical registers in the description of subsets of the plane. The LS is designed as the first of a set of connected activities aimed at favoring the students' meaningful learning of the theory of double integrals (Alessio *et al.*, 2019b). The structure of the LS is shown in Figure 1: as a first step, there is one exploratory activity concerning the correspondence between inequalities and subsets of the Euclidean plane; subsequently, there are six tasks of increasing difficulty on the conversion from the graphical representation to the symbolic one. Three of these tasks require the description in Cartesian coordinates of sets delimited by straight lines and conics, and the remaining ones concern the description of planar sets in polar or elliptic coordinates.

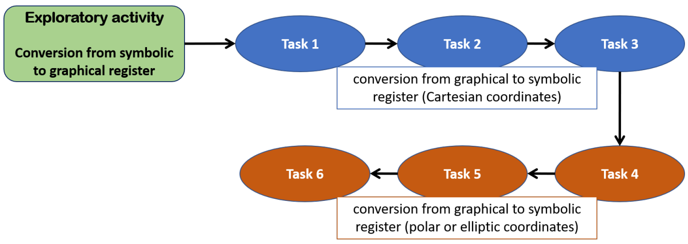

Figure 1. The linear sequence of tasks

In all the tasks of the LS a graph is provided to the student, and he/she is expected to describe it analytically either by multiple-choice questions or by open-ended questions, providing the extreme values of the range of variation of suitable parameters. Each action of the student generates an automatic feedback, which is immediate, facilitative and response-specific (Shute, 2008). In any case, the feedback is strongly dependent upon the action performed; it addresses the task, and, in case of wrong answer, the process and the self-regulation. The aim of this feature is facilitating the student's understanding of how specific modifications of the analytical representation change the graphical representation and vice versa, hence to foster the one-to-one mapping between the meaning units of the graphical and analytical representations (see Section 2).
As an example of the tasks of the LS, we analyse the fifth one of the sequence (see Figure 2).
In this task, the student is required to describe a sector of an annulus. The equations of the curves delimiting the set are not given, but the provided points allow to identify the centre and the radii of the annulus, as well as the slope of the straight line in the graph. The student should determine on his/her own the centre of the polar coordinate system which best describes the subset at stake, and the minimum and maximum values of the parameters ρ and θ. If a wrong answer is submitted, two sliders associated to ρ and θ appear to support the student in exploring the problem (their numerical variation corresponds to a graphical variation on the figure). In this task, differently from the previous ones of the LS, the conversion from the graphical to the analytic description of the set in polar coordinates is not mediated by its representation in Cartesian coordinates, which is included only in the optional hint. This task calls for a change of perspective on the student's side, since he/she is required to strategically thinking for identifying the polar coordinate system which yields the most convenient representation of the subset. This feature is aimed to progressively bring the student towards the overall goal of the activity including the LS, that is supporting a meaningful learning of theory of multiple integrals. After the coordinates of the chosen centre and the extreme values of the parameters ρ and θ have been entered, the program provides overall feedback on the task for a correct answer, and

either on the task, on the process and on self-regulation in case of wrong answer (in fact, the student is guided to correctly solve the task by means of remarks and graphical supports).

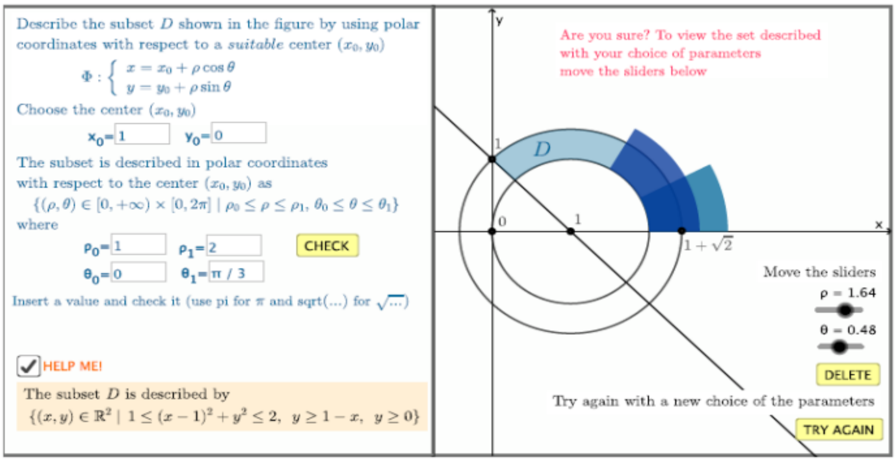

Figure 2. The fifth task of the linear sequence (Alessio *et al.*, 2019b)

In order to promote the students' learning also from the metacognitive point of view, the LS is included in a *methodological-didactical cycle*, envisaging the following phases: P_1) the student receives a question about the recognition of a subset of the Euclidean plane; P_2) the student interacts with the LS; P_3) the student answers to some cognitive and metacognitive questions on the activities (argumentations on the solution, reflections on the mathematical content, difficulties, role of the hints); P_4) the question given in P_1 is submitted again to the student, who can change the previous answer or its justification; P_5) the student provides him/her thoughts about the usefulness of the LS to answer correctly the question received in P_1.

3.2. The tree of tasks

The *tree of tasks* (TT) concerns the elementary and conditional probability and it is addressed to first year Master degree students attending the course of Probability and Mathematical Statistics. A first digital version of the tree is described in (Cusi & Telloni, 2019a), and a recent re-design was realized in order to provide students with feedback, hints and suggestions for requiring hints, as means of scaffolding and meta-scaffolding in facing the tasks (Cusi & Telloni, 2020b; Pea, 2004). We refer here to the first version.
The structure of the TT is shown in Figure 3. The interaction starts from the task T.1, after which the sequence of tasks is determined on the base of the number of mistakes made and of the difficulties displayed.

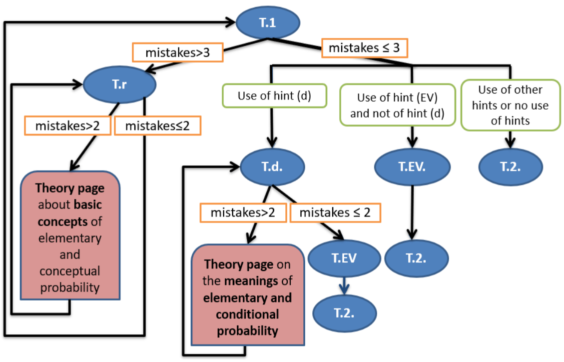

Figure 3. The structure of the tree of tasks (Cusi & Telloni, 2019a)

We describe in detail task T.1, in order to explain how the individualization of the learning path is carried on. Within T.1, a text introduces some events and their probabilities, with random values; the student is required to fill six input fields with the values or the arithmetic expressions of specific probabilities. Three of them are those given in the text; the remaining ones are obtainable by applying the rules for the probability of the complementary event, the probability of the intersection and of the union events, the definition of conditional probability and the property that conditional probability is a real probability with respect to the conditioned event. When facing task T.1, the student can ask for hints having different characteristics (see Figure 4): a

summary of the data given within the text, represented through symbolic expressions (d), the Euler-Venn diagrams of the events (EV), a calculating machine (c), a sheet and a pen (sp) and a list of useful formulae (f). After the completion of the task T.1 or when more than three mistakes have been done, the student receives also an overall feedback about his/her number of mistakes and the hints required; on the base of this information, he/she is addressed to the subsequent task. For example, if he/she made more than three mistakes, he/she is addressed to a reinforcement task (T.r) on the meaning of the probability of the complementary event and of the conditional probability; otherwise, the next tasks depends on the hints required: if he/she asked for the hint (d), that is the symbolic writing of the data, he/she is addressed to a task focused on the interpretation of probabilities given in texts expressed in verbal language.
During the interaction with T.1, student receive immediate, facilitative and response-specific feedback for each action, designed taking into accounts the levels of feedback and the typical misconceptions on elementary and conditional probabilities. An example of this aspect can be seen in Figure 4, where a screenshot of a student's interaction with task T.1 is shown. Also in this case, for promoting the learning also at metacognitive level, a methodological-didactic cycle is envisaged, where student is induced in reflecting on his/her interaction within the digital environment: cognitive and metacognitive questions are submitted either after each faced task, or after the completion of the path, according to the individualized faced sequence of tasks.

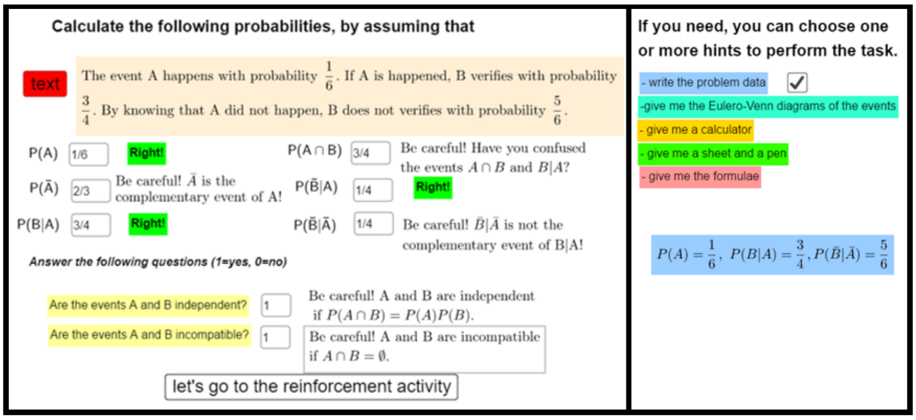

Figure 4. A screenshot from the task T.1 (Cusi & Telloni, 2019a)

4. Context of the study and methodology

Pilot studies on the RT have been carried out with voluntary engineering students at Polytechnic University of Ancona (Marche, Italy), within the project "Didattica Multimediale della Matematica". In particular, the linear sequence of tasks has been proposed to 25 freshmen attending the course of Analisi Matematica 2 and the tree of tasks has been proposed to 15 first year Master degree students attending the course of Probability and Mathematical Statistics. In this study we focus on the students' perception and awareness for what concerns a) the features of individualization characterizing the RT and b) the impact of the RT on their own learning. This research foci have been pursued by collecting open-ended questionnaires submitted to the 40 students involved in the study, after their interaction with the RT. The questionnaires envisage either questions on the mathematical content and the following metacognitive questions: (1) Did you encounter difficulties in facing the tasks? (2) Did you ask for hints? If yes, what hints have you chosen? (3) Were the hints useful? (4) Would you have preferred to use additional or different hints? If yes, what? (5) Was the feedback automatically provided useful? Why? (6) Did the task help you clarify the mathematical content?
We conducted a qualitative analysis of the students' answers; in particular, the answers to the first five questions allowed us to elicit evidences about the focus a) (students' perception about the features of individualization of the RT), while the answer to question (6) give information about the focus b) (students' perception of the impact of the RT on their learning).

5. Outcomes of the pilot studies

The questionnaires highlight different level of students' awareness and perception. For what concern the features of individualization, we identify three levels of awareness. A first category of students' answers reveals a *basic awareness on hints and feedback*: these students, 9 over 40, choose of not use (or do not understand)

the formers and take as a verification (right/wrong) the latter. An example of this kind of answer is that of S1: "*even if sometimes I was in difficulty and I knew that some hints were available, I did not consider of asking for them* [...]. *The automatic messages were useful since told me when I was wrong*". Students giving answers in this category are not able to take advantage by the hints nor by the feedback; typically, they fail in self-regulation and do not complete the route of tasks.
A second category of answers reveals a deeper *awareness on the specific character of hints and feedback*; typically, the 18 students whose answers are in this category notice the response-specificity of feedback and take advantage of its addressing the process of the tasks and the self-regulation. An example of an answer revealing this approach is that of S2 (referred to the LS), saying *"I did not find the equation of the circles, the hint helped me in that; another key hint was the possibility of seeing the joint change of the values of ρ and θ and of the graph; when I faced the initial question again, I had in mind that geometric variation*"; another answers in this category is that of S3 (referred to the TT), saying that "*the message* «$\overline{B}|\overline{A}$ is not the complementary event of $\overline{B}|A$» *surprised me*: *it addressed a doubt that I often have on the conditional probability of complementary events".* Students giving answers in this category are able either to correlate the received feedback with their own typical difficulties, or to use the experience done for solving subsequent problems.
A third category of answers revels a *deep awareness on both the punctual and the structural means of individualization of the RT*: the 13 students giving these answers recognize not only the specific characters of feedback and hints within the single tasks, but also structural characteristics of the RT. Examples of this kind of answers are those one of S4, who worked on the LS ("*I felt gradually more confident as I went on with the exercises; at the subsequent exercise I remembered what I learned at the previous ones* [...]. *At the beginning I preferred of not asking for hints* [...]*, finally I used them since I understood that they may offer a new viewpoint*"), and of S5, who interacts with the TT ("*differently from my classmates*, [after T.1], *I was addressed to an activity where I should have identified what probabilities are given in a text: I felt frustrated since it is just my main difficulty in problems on probability*").
Some of the previous answers shed light also on the students' perception of the impact of the RT on their own learning. About this focus, we identify answers referring mainly on affective aspects, on cognitive aspects and on metacognitive aspects of the learning. An example of the first kind of answer is that of S6, saying "*it was amusing doing exercises online; I felt curious and more comfortable than in class, since none can judge my work*"; there are also some examples of answers revealing negative perceptions, like that of S5 above and that of S7, saying "*I had often the doubt that automatic messages are not correct and that the program was wrong*". Examples of focus on cognitive aspects are the answers given by S7 and S8, saying respectively that "*it was useful the message on the definition of incompatible events, which I did not remember*" and "*the hint giving the formulae helped me to find $P(A \cap B)$ from $P(A|B)$".* Finally, examples of answers addressing metacognitive aspects of learning are those referring to the RT as useful tools of self-assessment, like the following ones: "*the sequence of digital tools allows me of assessing my preparation*", "*I understood what are my most frequent mistakes*".

6. Conclusion

This paper addresses the design and the organization of digital tasks aimed at fostering the individualization of teaching and learning at university level. The choice of constructing routes of tasks with different structures arises from educational needs and allows a high level of flexibility, supporting the individualization. In particular, we describe the design of a linear sequence of tasks and of a tree of tasks. The different structures allow to pursue conveniently peculiar didactic goals: the linear sequence is adequate for make students face all the envisaged steps of a path and in a fixed order, hence for the teaching/learning of basic topics, for example according to increasing levels of difficulty; instead, the tree is adequate for supporting intertwined learning paths, allowing students to face individualized sequences of tasks, which possibly include focused activities with respect to specific difficulties.
By means of the RT we aim to offer an engaging experience of interaction to the students, but also to induce them to a reflective learning, contrasting a hit-an-run approach: this is especially important within digital environments, where students expect mainly to *acting* instead of *reflecting*, and expect of doing that in short time. In this respect, the RT represent an attempt to bring students to deepen mathematical topics from various perspectives, covered by different tasks of the routes and to reflect for a quite long time on the contents.

Moreover, the methodological-didactical cycles including the students' interaction with the RT are aimed to make the students reconstruct their interaction with the tasks and its pitfalls for the learning.
In this study we focused on students' perception of the RT in terms of features of individualization and of usefulness for learning. Students displayed different levels of awareness on the individualization features of the RT; for what concerns the perception of the impact of the RT on the learning, some students' answers focused mainly on affective aspects, other ones on cognitive aspects, other ones on metacognitive aspects.
The students' reflections revealed also some critical issues, that suggest further theoretical research and experimentations: some students did not take advantage of the response-specific feedback, stopping at the verification level of it (right/wrong); moreover, a sort of distrust with respect to the technology arose (see the answer of S7 in the Section 6), which, on the one hand is a symptom of critical thinking, but, on the other hand, should be taken into account in the task-design processes.
As a further development of the research, we would like to study the RT as educational tools, in order to understand in depth their limits and potentialities for mathematics education and to identify other suitable structures, with respect to specific didactical goals. On the other hand, some experiments should be conducted in order to fully understand to what extent the educational effects of the RT depend on the subject they are focused on or on the contexts in which they are used.

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