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Orchestrating affective, cognitive and metacognitive dimensions of undergraduate mathematics learning in digital environments

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This paper focuses on the notion of orchestration and explores its possible meaning in digital environment in the new distance/blended setting caused by pandemic. I review the literature about the concept of orchestration. Starting from the description of a learning scenario, the emergence of a new possible meaning of orchestration arises and some insights for further research are given.

Keywords: university, orchestration, digital environment, blended learning

Introduction and context of the study

This paper wants to contribute to the debate on the theoretical construct of orchestration. The metaphor of orchestration has been largely exploited in education, both in mathematics education research and in research about technology-enhanced learning environments. However, the recent new context of digital education created by the pandemic, involving distance or mixed forms of participation in lessons (all the students at home or some students in the classroom and others at home), seems to highlight a needed evolution of the concept of orchestration.

The study is embedded in the such a context of distance learning caused by the pandemic. University courses moved to digital platforms for synchronous lectures (in our case Microsoft Teams), supported by Learning Management Systems (in our case Moodle) for providing students with materials and individual or group learning activities. According to previous studies, our experience in teaching mathematics courses (especially Linear Algebra) for freshmen engineering students confirms that the didactic contract rules of the teacher and of the students are not aligned:

At the mathematics (subject) level, both in the UK and in France, the lecturer expected that the text of the lecture would be used by the students, not only to learn and understand the concepts, but also as a model for certain mathematical practices, in particular mathematical proof. In France, we observed that the novice students did not adhere to this rule, and searched for worked examples (as models for such practices) in different kinds of resources such as their tutorial notes, textbooks and websites. [...] students were searching for worked examples trying to reproduce techniques (Gueudet & Pepin, 2018, p. 69, 71)

This is even more true in degree courses (such as Engineering degree) where mathematics is considered as a service subject, which often leads students to make the equivalence between learning mathematics and learning (by rote) mathematical procedures. In order to fostering change in students' attitude towards mathematics learning, I started to be interested in designing and exploiting digital activities, which students can be engaged in. Before the pandemic, the Information Engineering students attended all together (almost 150 students) face-to-face Linear Algebra lectures, addressing the topic from both theoretical and procedural point of view. Then they were offered a 2-hours session per week in smaller group, consisting of 50 students, in order to work on and deepen the content of the week lectures, supported by a tutor. Due to my interest, I designed and provided students with

digital activities (e.g. Albano & Pierri, 2014; Albano, 2017), already implemented before the pandemic, with the didactic purpose of helping them in constructing relational mathematics/conceptual understanding of mathematics, as opposite to instrumental mathematics/procedural understanding (Skemp, 1976; Hiebert, 1986). Such activities have been designed according to an asynchronous setting and thus engaged students in their personal study time/space outside the classroom, so that they could participate at their own pace working at their home or wherever. In the weekly tutoring sessions, the students could discuss the activities with the tutor, as well as the tutor, having access to the digital platform where the students worked on the designed activities, could focus her interventions on the points of greatest difficulty detected. The new distance setting forced us to rethink the structure of synchronous lectures, with particular reference to the interactions and the involvement of the students that no longer could be the same than in a traditional face-to-face lecture. So I was concerned with two interrelated issues: finding out which Moodle tools offered support for interactivity and designing their use in order to enable students to develop relational mathematics knowledge. On one hand, questioning and answering is recognized as one of the most effective practice for promoting interactivity. On the other hand, conceptual understanding is not just a cognitive issue, but it is affected by affective (beliefs, perceptions, attitudes) and metacognitive (learners' awareness and control of their own learning processes) factors. This means that any successful teaching/learning intervention should take into account all these three learning dimensions (cognitive, metacognitive and affective). I was interested in exploiting tools allowing to implement closed-ended questions/answers sessions and to collect and display right away the class-wide distribution of responses. Two tools offered by Moodle are Quiz and Feedback. The former allows to create (self-)assessment tasks. The latter allows to construct and submit a survey. Feedback falls into the category of so-called classroom response system (CRS). One of the early works on the use of such systems (Siau et al., 2006) points out some relevant pedagogical and curriculum issues, that can be valid also for the Quiz, including 'when to introduce the questions, what questions to ask, and how much class time to allocate' (ibid, p. 402). In this paper we state that the design issue should be focused on a learning scenario where each tool serves a particular purpose within a more general didactical objective. The metaphor of orchestration immediately comes to mind and it will be the underlying concept through the rest of the paper.

Theoretical framework

In this section we make a review of the concept of orchestration in technology-based educational research and mathematics education.

Dillenbourg (2013) refers to orchestration as a form a management (regulation process) of integrated pedagogical and technical scenarios, including on one hand activities, that can be face-to-face or online, and on the other hand tools enabling the implementation of the activities. In his view, orchestration is not concerned only with learning, but also with various extrinsic constraints (time, space, discipline, curriculum,...). This is one of the features that distinguishes orchestration from instructional design, in addition to the fact that it relates to a group of students rather than an individual and that the teacher's control prevails over that of the system. Dillenbourg states that 'orchestration' strengthens the teachers' potential in steering classroom activities and enables teachers to view things otherwise invisible. In response to Dillenbourg position, Kollar & Fischer

(2013) argue that the metaphor of music orchestra can be effective if it refers not only to the arrangement aspects (that is real-time management of activities and events) but also to whole process underlying the creation of music, which includes composing and conducting aspects too. They consider orchestration as “the process of creating, adapting and enacting a technology-enhanced learning scenario under complex classroom conditions” (ibid, p. 508). In their view, what Dillenbourg refers to as orchestrating actually means conducting. Composing consists of describing a scenario, constituted by resources and tools, specifying how they are combined and used by the teacher. Arranging is what the teacher does adapting the defined scenario to her classroom’s constraints. All the three processes are essential for technology-enhanced learning (TEL) being effective in classroom. Finally, they emphasise that the main objective of TEL is to facilitate student learning, which should always be taken into account. A further conceptualization of orchestration concerns the way in which the students are involved in the activities: individual, small groups, large groups. The design can foresee more than one mode of involvement or the real constraints can ask for changing the designed ones. Weinberger & Papadopoulos (2016) introduce the idea of orchestration of different social modes of learning. Students can learn individually or collaboratively, in small and large groups. Orchestrating social modes of learning means organizing learning choosing one of them or merging some of them. They argue that the transition from one social mode to another one should be carefully planned by the teacher taking into account how each of them help the students to reach the global learning objectives of the course. The teacher is recognized as the centre of a complex technology-enhanced environment, where technology both requires to be orchestrated and can facilitate orchestration.

In mathematics education, Trouche (2004) proposes the term ‘instrumental orchestration’ in a computerized learning environment (CLE). An instrument encompasses an artifact (i.e. a given object) together with utilizations schemes socially constructed by the subject. The process which gives rise to an instrument is called instrumental genesis. Trouche highlights that the complex artifacts present in CLE produce a set of instruments. The process of instrumental genesis as well as the articulation of instruments in CLE cannot be left to the students themselves but demands the guidance of the teacher, which can be done by means of instrumental orchestration. In this strand, Drijvers and colleagues (2009) propose a three layer model: *didactical configuration*, meaning the setting of the teaching environment equipped with artifacts (technological tools and tasks); *exploitation mode*, that is the way the teacher uses the didactical configuration in order to reach her didactical objectives; *didactical performance*, referring to ad hoc and run-time decisions taken by the teacher while teaching. Within the Theory of Semiotic Mediation (Bartolini Bussi & Mariotti, 2008), two different meanings of orchestration come into play: one referred to Trouche in relation to the use of artifacts, and one related to mathematical discussion, intended as the coordination of various voices emerged by the students with the voice of the mathematicians.

In this paper we want to investigate the potential of the concept of orchestration as lens to analyse a learning scenario, implemented in a distance setting and based on the exploitation of technological tools offered by digital learning platforms. What is being orchestrated? The tools? The purposes for which the various tools are used? Something different?

A learning scenario

In this section we present an actual learning scenario, implemented in a Linear Algebra distance course for freshmen Information Engineering students, equipped with Teams and Moodle. The course provides the students with synchronous online lectures (7 hours per week), tutoring sessions (2 hours per week), didactical material (videos, books, notes from digital board, worked-out exercises, slides) and resources (weekly tasks, quizzes, FAQ forum, periodic workshops for reviewing macro-sections of course contents). Various questions arose: concerning the precise didactical purpose of promoting conceptual understanding, how can Quiz be used? and Feedback? And how to handle the use of both so that one can take advantages of the other one?

The scenario and its implementation in class can be analysed in terms of orchestration. I choose to refer to Drijvers et al. (2009) orchestration model. I designed a didactical configuration, arranging an environment composed of three artifacts: a Moodle Feedback activity, investigating students' perception of their mastery on a given topic; a Moodle Quiz activity, investigating students' learning on the same topic; a Teams talk session for discussing the outcomes of the previous activities. The exploitation mode concerned the way I designed each artifact, described below, and the delivery timeline, which envisaged first the delivery of an affective activity, then a cognitive activity and finally a discussion that possibly moved to the metacognitive level. The design and the outcomes of the activities have been analysed both content-based and using the "in class" observation of the teacher-student interaction. The data have been collected by using Moodle reports related to Feedback and Quiz activities and recording the Teams talk session. I carried out a survey, by means of the Moodle Feedback tool, to collect students' opinions on their level of knowledge for the topic of linear systems. Thus I submitted the closed-ended question in Figure 1.

Received answers: 96

Questions: 1

If you had to assess your level of understanding and mastery of the concepts presented so far on linear systems, which answer do you think you would fall into?

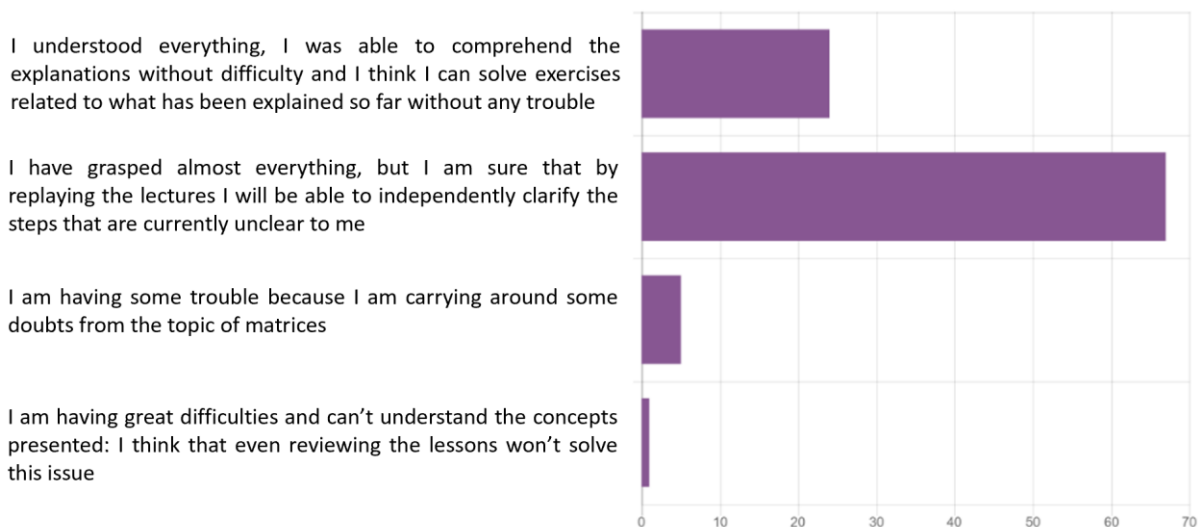


Figure 1: Results of the Feedback

I collected 96 answers, pointing that most of the students were satisfied with their comprehension of the topic (Figure 1). Indeed 25% of all the participants were completely convinced of their mastery, about 70% of the students admitted to having some doubts which they felt they could clarify by studying in more depth with the support of the recorded lectures, very few students reported having gaps from the preliminary topic or being unable to recover the gap. After showing the students and commenting on the graph in Figure 2, the mood in the class was very positive as it reflected the fact that the students felt very confident with the subject matter.

In the next lesson, I submitted a short quiz to the students: the first question shown in Figure 2 dealt with the notion of solution of a linear system, while the second question shown in Figure 3 dealt with the discussion of systems with echelon matrices. The former can be classified as an exercise, since establishing whether an item is correct or not requires direct application of previous knowledge, that is a definition. The latter can be classified as a problem, since it requires a certain reorganisation of the information given in the text and pieces of knowledge about linear systems and matrices in order to draw conclusions about the correctness or otherwise of the items at hand.

Let us consider the following linear system:

$$\begin{cases} x + 2y + z + t = 2, \\ 3x + 4y + z + 2t = 5, \\ 2x + 2y + t = 3. \end{cases}$$

Indicate which one(s) of the following statements is true.

- (2,1,1,-2) is a solution of the linear system
- $\forall y, z \in \mathbb{R}$ (z+1,y,z,-2y-2z+1) is a solution of the linear system
- none of the other items is true
- the system is incompatible
- the solutions of the linear system are $(x,y,x-1,-2x-2y+3) \forall x, y \in \mathbb{R}$

Figure 2: Question 1 of the Quiz

Let $Ax=b$ a linear system of 4 equations in 4 variables, and let A be an echelon matrix.

Indicate which one(s) of the following item is true.

- If A has a zero row, the linear system is incompatible
- None of the other items is true
- If $b=0$, the linear system has only the zero solution
- If each non-zero row of A corresponds to a non-zero row of b, the linear system is compatible
- If A has two non zero rows, the system has ∞^2 solutions

Figure 3: Question 2 of the Quiz

Figure 4 shows the graph (produced by Moodle) of the marks (between 0 and 1,5 per question) received by the participants in the Quiz, with the total number of students distributed by grade range.

Numero complessivo di studenti ripartiti per intervallo di valutazione

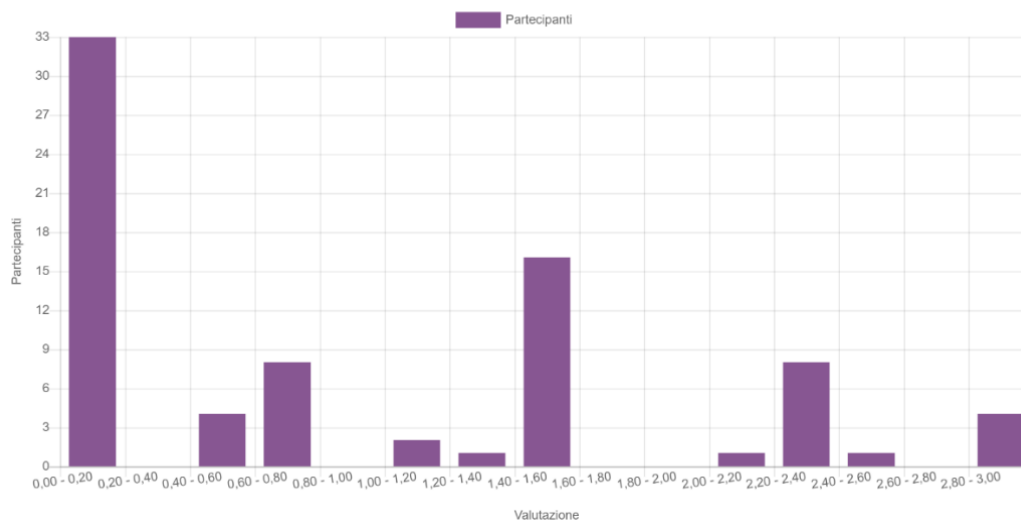


Figure 4: Results of the Quiz

After showing the results of the Quiz, everyone was astonished: they made evident a great gap between the students' perception of their mastery of the topic showed by Feedback and their actual mastery in solving the questions on the topic posed by Quiz. Thus the teacher started a collective discussion aimed at making sense of the gap. In terms of orchestration, the way in which the teacher led the discussion, the questions she chose to ask to guide the students' reflection, the mirroring of some of the students' interventions and the recapitulation of what emerged from the discussion concerns didactical performance. The discussion started with a question concerning the first question of the Quiz (Figure 2):

Teacher: How do you determine which of the items presented is correct? Tell me which strategy you used.

Student 1: Prof, I solved by using Gauss and got different solutions.

Various students agreed with Student 1, so the teacher asked for someone who acted differently.

Student 2: Yes, me, Prof. When he asked me if that 4-uple was a solution of the system I substituted it in and saw if it was equivalent.

Using this intervention, the teacher focused the students' attention on the definition of solution of a linear system and launched a collective discussion about its potential to investigate the items: it could be directly applied to items 1, 2 and 5, and depending on their value of truth some inferences could be done concerning the correctness of the remaining items. Then the students proceeded to apply the strategy come out from the discussion to answer to Question 1.

Once completed, the teacher opened a further strand of discussion concerning the difference between the approach used by most of the students and the one used by few, as Student 2, which turned out successful. The teacher highlighted that the request of the question was to establish the value of truth of the items, whilst many of them seemed to have acted as if the request had been 'solve the linear system'. Some students recognized that, taking this approach, they missed some correct items, since they were not able to recognize the equivalence between what they got solving the system and further description of the same solution set. From the discussion the need of a relational approach in contrast

to an instrumental approach emerged. This let the teacher shift the focus to Feedback results and gave her interpretation of the results, based on the assumption of students' procedural learning, confirmed by Quiz outcomes and discussion:

Teacher: the perception of your mastery emerged from Feedback is not false because I am sure you know how to carry out exercises but you have to move a bit further ... a few days ago someone asked me if in the exam quiz there will be theory questions ... of course, this is a theory question.

The lecture proceeded discussing question 2 (see Figure 3). It was particularly suitable for activating relational knowledge, both because the question dealt with a generic linear system (therefore no solving procedures could be applied as in the previous case) and several items were "if... then..." propositions, which brought into play reasoning and argumentation competencies.

Insight for new research

The previous learning scenario does not remain confined to distance learning, but it is inherited by the face-to-face lectures. Indeed, most of the students attend lectures equipped with their personal mobile device (smartphones, iPads and notebooks), thus lectures can be redesigned according to BYOD approach. In my view, this scenario poses the issue of a further development of research. In mathematics education the concept of orchestration has been developed mainly with the perspective of guiding students' instrumental genesis. This is not the focus of the paper due to the general-purpose nature of the digital artefacts used by the students. But the instrumental genesis of the teacher using the digital tools could be a very interesting focus to be developed. For example, as we teach remotely, we develop many new schemes and sets of artefacts for teaching, and it can even influence how we teach in-person (providing evidence of the development of a scheme). Taking up Dillenbourg's idea of technology as something that makes visible what was invisible, we can look at what has been made visible by the orchestration performed in the above learning scenario. The use of feedback and quiz together, even in a specific order, made the students experience a discrepancy between their idea of mastery and that of the teacher that is realised in the exam paper (affective dimension), the subsequent (mathematical) discussion allowed the students to become aware of and reflect on their own learning processes (metacognitive dimension) through a cognitive analysis of the questions and answer items proposed (cognitive dimension). An hypothesis following this exploratory study could be that the scheme emerged by the presented scenario which allowed a successful integration of the three dimensions of learning that took place in the orchestration of the three activities feedback, quiz, discussion. This seminal study suggests new research to investigate the emerged hypothesis addressing the development of a renewed orchestration framework, taking into account the pedagogical aim of the teacher in using the digital tools, and a renewed teachers' instrumental genesis for reaching this pedagogical aim. Such a new framework should exploit elements from various theories, in mathematics education and in technology-based education, according to networking of theories (Prediger et al., 2008).

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