The many faces of orchestration: Towards a (more) operative definition

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Abstract

The idea of teachers as "orchestrators" of the learning process has been around for many years now, and it is one of the most common metaphors for teacher actions during the enactment of learning activities. In the field of technology-enhanced learning (TEL) and computer-supported collaborative learning (CSCL) there has been a revival of the interest in this metaphor in the recent years, to the point that it has become almost a buzzword. However, very few concrete definitions of it and its constituting elements exist. This document tries to delve towards one definition of orchestration in a CSCL (or in an integrated learning) process. To do so, existing literature on the subject is reviewed, and several concrete research efforts related to orchestration are analyzed. These proto-definitions and research efforts are then compared with authentic examples of integrated learning activities, in order to see how the definitions can be transposed to real, concrete practice and ascertain which factors have a major influence in those concrete examples of orchestration. Finally, an operative definition of orchestration is advanced, as the first step towards providing support to the orchestration of integrated learning scenarios.

1 Introduction

The concept of teaching practice as an activity similar to that of an orchestra conductor is not a new one. Orchestration has long been proposed as a metaphor for classroom interaction, defined as the work of "arranging things to achieve a desired effect" [1]. The parallels are obvious if we consider that teachers have certain pedagogical goals, decide what will be the flow of the class, and also decide when the lesson is over [20, 14]. Thus the assertion of teachers "orchestrating classroom discourse" [18].

This metaphor of orchestration has experienced a revival in the past few years, as researchers in the field of technology-enhanced learning (TEL) and computer-supported collaborative learning (CSCL) realize the difficulties

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that many teachers encounter as they try to incorporate into their practice the results of the advances in those fields. In order to reap the benefits of technology-enhanced and collaborative learning situations, teachers have to cope with coordinating different activities, to be done using different tools (technological or not) by students grouped in a variety of manners [13, 8], sometimes even across different contexts (as it is the case with what is known as *blended learning*). The criticality of this coordination in the enactment of CSCL practice (where collaboration and learning can be made ineffective by poor management of those elements) has shifted the focus of some researchers to the support of teachers and learners as they wade through this myriad of factors in complex CSCL scenarios [21].

In fact, this increase in the interest in orchestration has reached a point where the metaphor has almost become a "buzzword", and it is now thrown around in a variety of situations, ranging from usual teaching practice to something more akin to the orchestration of services in service-oriented architectures (SoA). As an example, the STELLAR Network of Excellence [34] (the biggest European research project on TEL) has posed "orchestrating learning" as one of the main challenges of that area. However, the text of this challenge in the STELLAR website states that "orchestration takes up the challenge of the actual implementation of all the interactions needed for a successful scenario", practically equating orchestration with anything that happens in the enactment of a learning situation. To add to this confusion, there exist a number of research efforts that aim to support orchestration, but fail to define what the exact meaning of orchestration is, or even what it means *for them* (see section 3 for a few examples).

The aim of this document is to take this (rather nebulous) metaphor of orchestration, and try to pin it to *certain authentic teaching practices* in the field of TEL and CSCL, in order to reach a more operative definition of orchestration and its main components. This definition will later guide us in providing support to the orchestration of TEL and CSCL scenarios, provided that those scenarios share common elements with the authentic practices we describe here.

In order to reach this definition, we have reviewed the literature that mentions this concept of orchestration, focusing specially on technology-enhanced learning and computer-supported collaborative learning, which are our main areas of interest, and looking for definitions of this phenomenon. We have also analyzed different examples of research efforts that try to support this process using technology, so that we can extract the (often implicit) definition of orchestration that underlies those efforts. Finally, we have analyzed two existing examples of real TEL/CSCL teaching practice, comparing them to the theoretical definitions of orchestration, in order to see how the metaphor is transposed to tangible teaching practice. With all these analyses we have tried to approach a more operative definition of what is orchestration, what are the main components and factors that effect it,

and what orchestration means in practice, in the settings we have examined.

The document is structured as follows: section 2 reviews the most prominent literature on the phenomenon of orchestration, specially from the point of view of TEL and CSCL; section 3 contains several examples of research that account for different perspectives and approaches to the study of this phenomenon. Later, section 4 contains two examples of authentic CSCL activities observed by the author, and section 5 tries to distill all the previous material into a definition of orchestration to guide our research. Finally, section 6 summarizes the findings of the document, and advances some of the characteristics of an eventual research on supporting orchestration through technology.

2   Orchestration in CSCL literature

As we have seen, the orchestration metaphor has existed in educational literature for a long time. It is one of the many metaphors that draws simlarities between teaching and other forms of human creative behavior (specially, artistic expression): theatre (see, for example, the IMS Learning Design specification [4]), improvisation [32] or, as it is our case, musical orchestration and orchestra direction.

In the field of computer-supported collaborative learning, the most prominent proponents of the orchestration metaphor in the past few years have been Frank Fischer and Pierre Dillenbourg who, in 2006, posed orchestration as *"the process of productively coordinating supportive interventions across multiple learning activities occurring at multiple social levels"* [13]. This first definition was later on expanded by the same authors, who cited some of the main dimensions of this coordination [9]:

- Management of the *cognitive* dimension of the process, coordinating the learning processes taking place at different *social levels* (individual work, group work, whole-class activities).

- Coordination of the *pedagogic* dimension of the process, by *adapting* the *designed* activities to the real occurrences of the classroom.

- A *technological* dimension of orchestration should also be taken into account in CSCL scenarios, coordinating the transactions among the different software components of the scenario.

More recently, the same authors expanded this definition of orchestration, towards the goal of successfully integrating CSCL in a broader learning environment that combines different *activities*, occurring at different *social levels*, *contexts* and *media*. They note that several *kinds of coordination* should take place:

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- Coordination of the *workflow* of activities that occur at the different social levels (e.g. by using macro-scripts).

- Coordination of the different *scaffoldings* used (the teacher, the peers, materials, software) in order to obtain synergies among them.

- Coordination of *regulation* mechanisms in the activity, be them either auto-regulation or external regulation.

- Coordination of individual motivation and social processes.

- *Adaptation* of the activities to classroom occurrences, and fading of any external scripts as they are being internalized by the participants.

- Providing teachers with *monitoring* tools that enable them to monitor the collaboration and *adapt* the environment to this information *flexibly*.

The first of these forms of coordination (coordinating the flow of activities) is the one that has gathered more attention and effort so far in CSCL, even before the rise of the orchestration metaphor, in the concept of *scripting*. The use of scripts in education was originally derived from the "teaching as performance" metaphor [15, 5], which viewed teachers as performers, actors that played a pre-defined script, represented in many cases by the textbook. When applied to collaborative learning, scripts can be defined as methods that structure face-to-face (and computer-mediated) collaborative learning [23, 19]. The use of CSCL scripts, under one form or another, has been established in CSCL literature as a valuable approach, in order to guide and structure complex collaborative scenarios, where a computational representation of the script (e.g. using the IMS-LD specification [4]) can serve to automate the workflow (e.g. by using Virtual Learning Environments with script playing abilities). However, this kind of script automation has been criticized as being potentially inflexible [7, 10], and it is still not widely used in authentic teaching practice.

As we can see, a number of concepts and dimensions have been presented so far, even by the same authors, in a rather disorganized way. If we look at how the STELLAR Network of Excellence depicts orchestration [24], we find even more general definitions (at it was stated in section 1), as well as references to the aforementioned work by Fischer and Dillenbourg. Interestingly, four main research questions around the topic are posed, dealing with the role of teachers in orchestrating learning, the role of assessment and technology in learning, the relationship between high-order skills, knowledge domain and technology, and finally, about the learning trajectories of a person. As the reader may have noticed, at least two of the four research questions appear to be unrelated to what has been presented so far as orchestration. Even if that website is an ongoing effort that has not passed

any editorial filter, the STELLAR website exemplifies perfectly the current state of confusion around the concept of orchestration.

It may also be interesting to note how the metaphor of orchestration has been used in other research areas, the reasons why it was used, and the solutions that the metaphor has prompted in those areas. An exhaustive and deep literature analysis of every field that mentions orchestration exceeds by far the scope of this document, but an example from a field related to computer science is mentioned below:

- In the area of *service-oriented architectures*, orchestration has been used to denote the (often automated) combination of services to create higher level services and processes [26]. This concept is also very related to that of *choreography* (another arts-related metaphor), which in this case refers to the concrete communication protocol (i.e. the messages exchanged) between the different services that are to be orchestrated [12]. It is interesting to note that orchestration "always represents control from one party's perspective" [26]. This is also the case with orchestration in CSCL, which depicts the *teacher's perspective* of the complex teaching/learning process. Choreography, on the other hand, is more collaborative, and allows involved parties to describe their part in the interactions.

After doing this literature analysis, we now have a first approximation to what orchestration is (at least, in the mind of some authors in the field of CSCL). We can also infer, from all the concepts that have been mentioned so far, that orchestration is a *complex process*, with many facets and elements, which are depicted graphically in figure 1.

3 Examples of research under the "orchestration umbrella"

Now that we have a first idea of what orchestration means in the field of CSCL, we will take a look at four different examples of concrete initiatives to support the process of orchestration. We will then attempt to map those efforts to our concept of orchestration, to see what particular definitions of orchestration emerge from them, and use those definitions to confirm or expand our conception of the metaphor.

- One concrete effort to improve the process of orchestration, co-authored by Dillenbourg himself, can be observed in [2]. In this work, Alavi and colleagues take a very concrete kind of learning scenario (recitation sections, where students work individually or in small groups, with teacher assistants helping on demand), and try to improve the orchestration process. Since this kind of scenario cannot have a clear, fixed
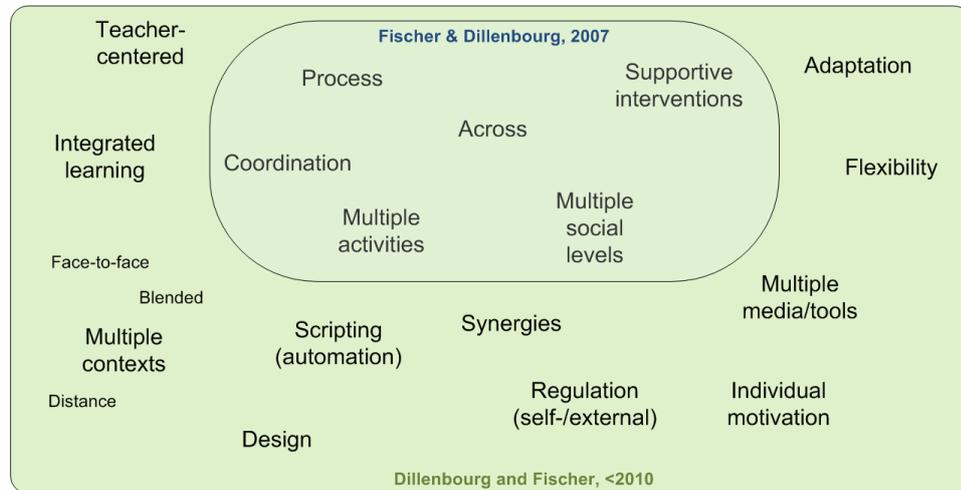
ORCHESTRATION

Figure 1: Concept diagram of orchestration, from the literature review

script, the authors opted for improving the awareness of the progress of each group, through the use of multi-colored lamps. This helps teachers in planning their support and in optimizing their itineraries through the classroom. This work, obviously, uses Fischer and Dillenbourg's conception of orchestration ("managing the flow of activities across different social planes") as the starting point, but it concentrates on enhancing the *awareness* processes of the teacher.

- Another effort that also uses the same concept of orchestration as the starting point is [29] (with additional partial results detailed in [28] and [27]). However, the authors in this case concentrate on very different educational settings: scripted blended learning scenarios (i.e. that combine activities occurring in different contexts, such as face to face and online), using computationally interpretable scripts for automation of the flow of activities. The authors propose a conceptual framework of factors that affect group management of CSCL scripts, aiming to implement flexible solutions for supporting group management in the design and enactment of such scripts. This work does not give a formal definition of orchestration, but its underlying assumption is that *group management* plays an important role in it.

- Niramitranon and colleagues [22] propose what they call a Classroom Orchestration Management Language (COML), a computationally interpretable language to communicate the two main parts of their system for the design and facilitation of one-to-one technology classrooms (i.e. where each student has one computer device). They propose a

prototype for designing and later automating to a certain extent certain aspects of classroom management: a simple taxonomy of tasks, resources from a limited set of resource types, the presentation means of each task, and the actors of the tasks. The prototype for the enactment tool is based around a simple shared whiteboard tool, where information is interchanged in the form of "virtual stickers" [6, 33]. Their work does not include any definitions of what they understand by orchestration, but the underlying idea seems to be that of *scripting* those aspects of *classroom management* (basically, dictating what boards each of the participants see according to the design).

- Finally, Carell and Schaller [3] try to ascertain how Web 2.0 applications (see [25] for a definition and more information) can be orchestrated to support face-to-face TEL situations. They develop a case study in a face-to-face CSCL setting in higher education, where tools such as blogs or wikis were used to support collaborative learning. In their work, the authors do not provide a definition of what they understand as orchestration, and in the conclusions the term "orchestration" is lost, substituted by something more akin to the *usage of multiple tools* (in this case, web 2.0 tools) to perform a set of activities.

As we can see, even if these works share the keyword orchestration, and all pertain to the field of CSCL, very different operative definitions of orchestration emanate from them. We can also try to map these works' conceptions of orchestration to the conceptual map of orchestration from section 2 (see figure 2). As we can see, all of them can be mapped to some of the factors derived from our literature review, and all of them can be seen partial solutions to the complex challenges that orchestration poses for teachers.

4   Two concrete examples of orchestration

Now that we have reviewed several sources of knowledge about the orchestration metaphor in CSCL literature, it is now time for us to see what does this first approximation mean in the context of authentic learning scenarios. To do this, we will analyze two observations made by the author, in rather different contexts, during case studies focusing on the enactment of CSCL activities. One of the activities was performed in a rural primary school (see [30] for more details on the research context), while the other was observed during a postgraduate course on the educational applicability of digital technologies.
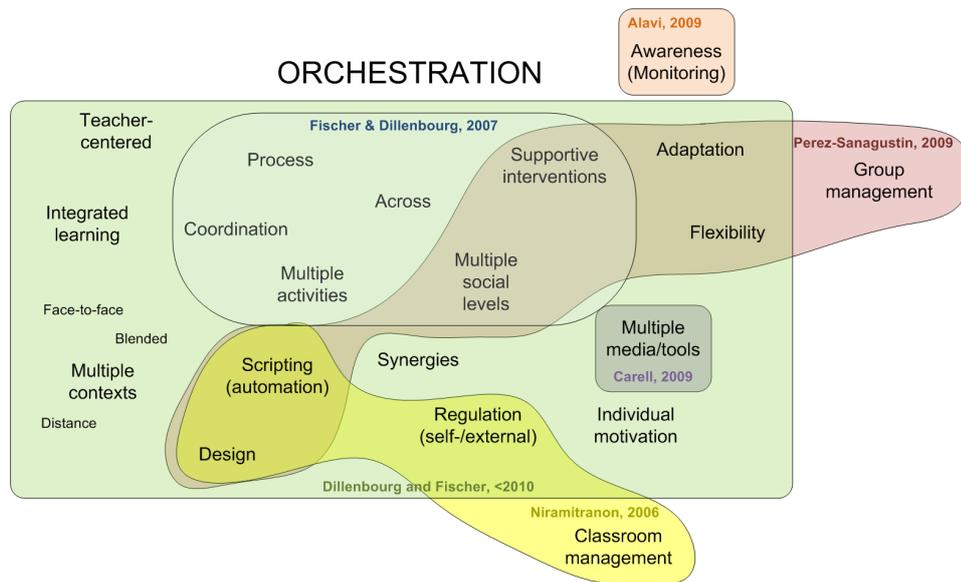
Figure 2: Concept diagram of orchestration, including the mapping of the four research examples analyzed.

4.1 Primary education activity: Coinage system

This activity was performed by a K6-7 teacher in a face-to-face classroom with 18 students, using digital whiteboards, tablet PCs and a small CSCL application called GroupScribbles (basically, an application based on the metaphor of a shared space and stickers, see [33]). The aim of the activity was to guide students (two students for each tablet PC) in learning on the usage of the different coins in the European coinage system. The activity flow consisted of each student taking a different task (to buy one object from a picture in GS showing several priced items), and writing with GS how many coins (and of which values) were necessary to buy the object. Then, the different objects were graphically classified as cheaper or more expensive than a given one. In order for the students to know which task to solve, the tasks were identified with simple arithmetical operations whose results mapped the task to the student's number in the class list. Additionally, paper replicas of coins were handed to the children in order to aid them in solving the main task. When the designed tasks were finished, and since there was still time left, the teacher proposed a brainstorm for new activities to do with the resulting numbers, and then a further classification of numbers was performed.

Analyzing this activity in the light of the proto-definition of orchestration from the two previous sections (represented by the concept clouds, see figures 1 and 2), we can see which aspects of the activity as it was performed, are part of the process of orchestration:

- First, it is important to note how the design of the activity guided the orchestration of the class. This design appears in written form in the teacher's notebook, and it was reified in the GroupScribbles activity that was prepared before the activity enactment.

- The awareness mechanism used in the activity was, naturally, the teacher's own perceptions, which was also helped by GroupScribbles' affordances for assessing the progress of the groups on the fly (through the shared whiteboard). The effort and time dedicated to this assessment was high, and the teacher was continually going from one group to another, solving problems and answering student questions.

- The time and task flows of the activity were managed flexibly as the activity unfolded, including the addition of new tasks on the fly. This flexibility is also linked to the tool's affordance for simple operation that allowed the rapid redesign of the activities, and the low level of automation that the tool provides.

- The coordination of activities was primarily done by social means (spoken word, gestures, etc), with minimal structure and external regulation provided by the technological tool (e.g. a limited set of permissions about who can do what in each shared board). Moreover, the analysis of several activities like this one revealed that this social coordination usually followed a limited set of recurrent routines (such as asking questions randomly to maintain children focused on the correction task, see [31] for more details).

- The usage of technological tools was simple, but certain synergies among different tools (such as spoken word and whiteboard) could be observed, also forming tool usage routines.

- The design was relatively simple in that there were few transitions among social levels or tools. These transitions, however, were dynamic and fast-paced, as it corresponds to most face-to-face scenarios.

- The flow of produced artifacts from one task to another was done manually by the teacher or the students, using the GroupScribbles tool.

4.2 Higher education activity: educational uses of technological tools

This second activity was part of the "technologies in education" subject at the University of Valladolid's master for secondary education teachers . The

activity had both face-to-face and virtual (i.e. distance/asynchronous) components, and was enacted by one teacher and 20+ students[1]. The activity mainly consisted on the students answering (in pairs) an online questionnaire about their knowledge and perceptions about educational uses of different technologies (e.g. blogs, wikis, social networks, VLEs, etc), followed by a face-to-face debate where the different opinions and the reasons behind them were voiced. The main goals of the activity were to learn about educational uses of different technological tools (including advantages, disadvantages and pedagogical implications), and to determine which tools to study more deeply in a later phase in the subject.

As we did with the first activity, the analysis of this activity in the light of the proto-definition of orchestration revealed some interesting aspects of the activity, as it was enacted, related to the process of orchestration:

- The design of the activity (and of the whole subject) was done through a series of wiki pages that detailed the different activities, their phases, and linked to the different resources and produced artifacts of the activities. This was done mainly because of the simplicity and flexibility that wikis pose for editing web content.

- This wiki page with the design was also an important point of reference in the coordination of the activity, both for the teacher and for the students. This wiki page contained links to the resources and the products of the activity, and it served as a reminder and a guide for the coordination of the activities. In this sense, we can say that the wiki was used as a sort of Virtual Learning Environment (VLE) for the subject.

- In this sense, the students voiced their concerns about different elements being used as VLEs in the different subjects (e.g. a Moodle platform, the wiki, ad-hoc web pages, etc), and the confusion that was thus generated.

- The methods for coordinating the phases of the activity were mainly two: spoken word and gestures in the face-to-face parts of the activity, and e-mail communication (with references to the aforementioned wiki and the questionnaire tool) in the asynchronous parts of the activity.

- During the enactment of the activity, changes were needed in the temporal structure, specially in the time limits for each phase. These changes were handled by editing the wiki page with the design and through e-mail communication.

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[1]As we will see later, the the presence of students was irregular, a common attribute of this kind of authentic scenario.

- The transcourse of the debate was greatly impacted by the variable levels of student attendance to the class, which is a common trait of these higher education scenarios. The teacher had to modify on-the-fly the topics of the debate in light of who was present, and the conclusions of the debate (and possibly the knowledge acquired in the activity) reflected this impact.

- The combination and usage of tools was relatively simple, and no technological automation of tasks took place. The teacher, however, expressed that the lack of knowledge about certain technical details of the tools used (e.g. the Excel application that was used for summarizing the results) substracted from the agility of the coordination.

- The flow of data and artifacts among the different phases of the activity was done manually, through links to the different URLs of the resources and artifacts, in the wiki page of the design of the activity.

- During the activity, and in an interview after the enactment, the teacher pointed out certain aspects of the activity that could be improved (a kind of evaluation of the design of the activity), although she pointed out that proper evaluation of the designs was not commonplace.

- The student groupings during the activity were simple (mostly, pair work and whole-class activities), with few transitions between them. However, sometimes the students showed confusion about the different groupings that were being used in different activities. This points towards group management as an important practical issue in collaborative learning, as soon as groupings start to be complex.

- The awareness and assessment of the progress of the activity was done mainly in the face-to-face part of the activity, using purely social mechanisms, moderating the debate to direct the attention of the discussion to the potentially interesting results of the questionnaire.

5 Towards an operative definition of orchestration

With all the information from the literature reviews and the analysis of the two orchestration examples, we will now try to distill a more operative definition of what is *our* concept of orchestration of CSCL activities. To do this, we will gather the concepts and factors that have appeared so far in the document, and we will try to build a conceptual framework of the factors affecting orchestration, and its composing elements. This can be graphically seen in figure 3, where these concepts are categorized. In the figure, we have reorganized the concepts appearing so far, but we have also added new

concepts that are not explicitly mentioned, but are implicit in the works, emanate from the examples of real practice, or have a clear relationship with our understanding of orchestration. Examples include:

- One important missing (or incomplete) element of the definitions of orchestration is the *temporal element*, represented by the question "when does orchestration happen?". Many works assume that orchestration is done during the enactment of the activity, and most of them also assume that the enacted activity has been designed and thus, this design helps in the orchestration of the activity, by providing a structure for the elements that have to be orchestrated. Some works on the evaluation of CSCL activities [17], also hint at the possibility that evaluation has to be integrated in the design and enactment and thus, evaluation may become another element to be orchestrated by the teacher.

- A more fine-grained temporal element can be distilled from the word "across" that appears in Fischer and Dillenbourg's original definition. Orchestration across different activities and contexts seems to imply that orchestration is more critical in the *transitions* between activities, contexts or social planes, but also when the activity occurs in several of these planes *concurrently*. That is not to say that teachers do not orchestrate when they (or they students) are immersed in a single task, but we could assume that in those moments orchestration falls to a more background position. Also, the frequency of these "orchestrationally critical episodes" is an important factor, marking the *tempo* of the orchestration (continuing with the musical analogies).

- Another important gap in the literature about orchestration is exemplified by the question "How is orchestration done?". In fact, this is the question that any work about orchestration aims to answer. Even if no single formula can be given, research work (and real practice) in orchestration seems to polarize around two *ways of orchestrating*: the automated, technologically-mediated orchestration provided by computationally represented scripts (e.g. using IMS-LD specification and players), and the manual, socially-mediated way of orchestrating, where teacher uses spoken word and gestures to manage the flow of the activity (as in the primary school example in section 4). However, this is not a binary distinction, but rather a continuum, a design tension [35], where each researcher or teacher chooses to position.

- Finally, the processes that orchestration is composed of ("What processes does it entail", in the figure), extracted from the literature sources, have been completed with others that have been made apparent by the real practice examples and by obvious relationships with
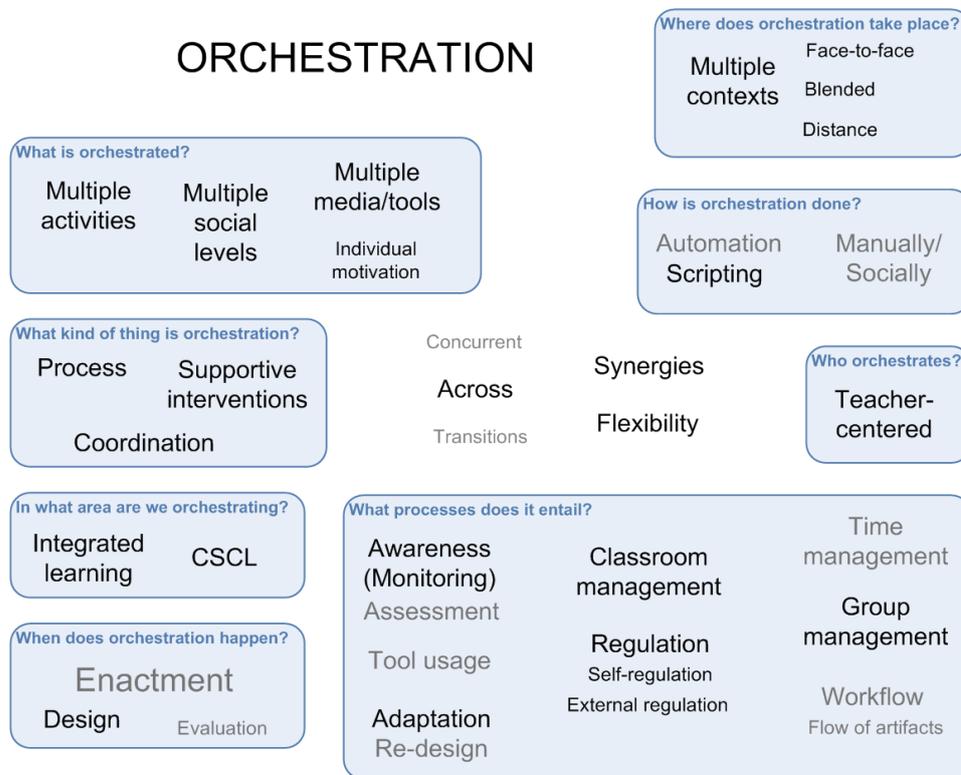
Figure 3: Concept diagram of orchestration, with the elements grouped in categories. Grey concepts are inferences, not appearing explicitly in the literature.

existing concepts: *assessment* of the progress of the class (tied to the awareness mechanisms and leading to the "supportive interventions" mentioned by Dillenbourg and Fischer); *re-design* of the activities, tied to these interventions and to the concepts of "adaptation" and "flexibility"; and *management of tools, timing and the workflows* of the activity, which are not explicitly mentioned as composing processes of orchestration, but are readily apparent when we observe orchestration in practice.

Thus, with all these considerations in mind, and taking Fischer and Dillenbourg's definition as the center of our own definition and categorization, we could define orchestration as:

Orchestration is the complex process of coordinating a teaching/learning situation, from the point of view of the teacher. Orchestration aims to manage (or subtly guide) the different activities occurring at different educational contexts and social levels, using different resources and tools in a synergical way. Orches-

tration is specially critical in the transitions and concurrencies between those elements, and it is often guided by a design (in the form of a script or not), that may be flexibly modified during the enactment (automated or not) of the activity, in response to emergent occurrences.

Moreover, since orchestration is a complex process, we can say that it is composed, at least, of the following simpler processes:

- *Awareness* mechanisms, that the teacher uses to *assess* the progress of the activity and decide on possible interventions.

- *Class management* mechanisms, including social and technological regulation mechanisms, e.g. to enforce that the design of the activity is followed. Examples of these mechanisms include task distribution, group formation or sequencing mechanisms [19].

- *Adaptation* or re-design of the activity, in response to emergent occurrences during the activity (time management, group management, tool usage and management, task/workflow modifications, etc).

6 Conclusions and future work

This document has begun by highlighting the problems that teachers find as they try to integrate new technologies and methods, such as the ones advocated by TEL and CSCL, into their practice. Orchestrating different activities occurring at different social levels and contexts, using different media and tools is crucial for an effective use of these technologies and methods. However, the word "orchestration" is being used in a variety of senses, without a common understanding of what elements it entails. Through a literature analysis, both of theoretical and practical TEL/CSCL literature, and by analyzing two examples of real CSCL practices, we have tried to reach a more operative definition of what orchestration is, and what elements affect this complex process.

This definition of orchestration will guide our next steps in the development of a technological system that support non-expert teachers in the orchestration of CSCL activities, as a PhD thesis work. Since supporting *all* aspects of orchestration would exceed the scope of a single PhD thesis, we are currently aiming to providing support for the *flexible design and re-design* of CSCL activities, as well as to providing orchestration guidance to non-expert teachers through the use of *enactment routines*, both during the design and the enactment of activities.

It is worthwhile mentioning that any efforts towards supporting orchestration (be them either particular or global), should comply with a series of requisites, in order to be effective, as Dillenbourg stated recently [11]:

1. The proposals have to be *teacher-centered*, since orchestration is, by definition, a teacher process.

2. The solutions and research efforts have to be *relevant to the curriculum*, since teachers have little time to spare with experiments that do not advance their curricular goals.

3. The solutions have to take into account events in the different *social planes*, e.g. by providing workflows and scripts to help teachers in the orchestration.

4. The proposals have to take into account the co-existence with *legacy tools* in the classroom, using technology only for its added value.

5. The proposals have to take into account *time management* issues, as teachers need to be able to shorten, interrupt, resume or reschedule activities.

6. The solutions have to be flexible, not only in the time axis, but also in other aspects such as group formation, tool choice, etc.

7. The research efforts have to be *sustainable*, and they have to be designed, not for the motivated or gifted teacher, but rather with the average teacher and the common contexts in mind.

We believe that having a clear conceptual framework of orchestration will not only help us in supporting particular aspects of orchestration. We believe that this sort of framework would also help in developing more global solutions that support all these aspects by integrating particular methods and tools (the Sofocles project [16] could be a step in this direction). We hope that this document can serve as the seed for such a framework.

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