Technology for Classroom Orchestration

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Technology for classroom orchestration

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Abstract. We use different criteria to judge teaching methods and learning environments as researchers and teachers. As researchers, we tend to rely on learning gains measured in controlled conditions. As teacher, the skilled management of classroom constraints results in the impression that a specific design "works well". We describe fourteen design factors related to the metaphors of classroom orchestration and education ecosystems and illustrate their embodiment in three learning environments. These design factors provide a teacher-centric, integrated view of educational technologies in the classroom. We expand this list of factors to include the main constraints that designers should consider to address the difficult methodological issue of generalizing research results about the effectiveness of methods and designs.

Keywords: educational technologies, classroom orchestration, ecosystem, design based research

1. Are metaphors useful for educational design?

On a regular basis, new metaphors emerge in the field of learning technologies. Are they 'old wine in a new bottle' or do they convey a novel idea? Is 'inquiry-based' learning more than 'learning from simulations'? Is 'educational data mining' different from 'student modelling'? Is 'orchestration' just a new buzzword? It probably is, but nonetheless this chapter argues that the idea of 'orchestration' conveys a new flavour to classroom technologies. However, we cannot evaluate the effectiveness of a design metaphor in terms of learning outcomes. There is no way to establish that "all learning environments whose designers have been inspired by a metaphor X are more effective than those who have not". Design metaphors trigger analogies rather than quantifiable specifications. Hence, a first step to assess their usefulness is to disentangle the elements that can be found in these metaphors and relate them to concrete features of learning environments. This is the goal of this analytical contribution.

In the first section, we explain why the relationship between design and learning should be analyzed in terms of classroom life and not only in terms of learning outcomes. Then, we decompose this relationship by extracting a set of 'design factors', first from the metaphor of 'orchestration' (Section 3) and then from the metaphor of 'educational ecosystem' (Section 4). These factors relate pedagogical and technological design choices with classroom life. In the next 3 sections, we illustrate these factors with three learning environments we have developed and tested in real contexts. Our conclusions revisit orchestration as the management of constraints systems.

This contribution is restricted to the domain of formal education in co-present settings. It does not deny the interest of research on informal learning as well as on distance education but stresses the social responsibility of our research community to contribute to schooling.

2. "It works well (in my class)"

As most scholars in learning sciences, we are not only researchers but also teachers in our own university. Surprisingly, these two roles sometimes co-exist almost independently from each other.

As teachers, we sometimes have the pleasant feeling that the method we are using is "working well". What does it mean? It probably corresponds to situations during which students are engaged in the proposed activities: they attend the course, they pay attention to our talk, they argue with each other at the semantic level, they ask relevant questions, they make smart suggestions,…, in short, they are 'with us'. This "it works well" is just a personal feeling, a subjective opinion, not an objective measure even if it may rely on cognitive cues: the students' answers indicate that they understand, they come with original solutions or new ideas, they deliver satisfactory assignments, they do well at the exam,…. Moreover, "it works well" means that the method is compliant with our constraints: the students' workload is reasonable, our teaching workload is acceptable, there is no main bug in the technology, the teaching material can be reused next year, the students are satisfied (as shown by the course evaluation), as well as the director and the students' parents. As teachers, we have to care about many of these constraints that we do not really conceptualize as researchers: homework, parents, discipline, room size, friendship, security, etc. In summary, there are many conditions for a method to "work well" and we, as teachers, are delighted when these conditions are met.

As researchers, we did not pay that much attention to things that "work well". A first obvious critique is that the teacher's opinion that it "works well" may be unfounded. It may be that students are actually bored while the teacher perceives them as engaged. It may be that students are highly engaged but do not learn much through the activity. For instance, the LOGO environment "worked well" for many years but did not reach its promises in terms of learning outcomes (Pea, 1983; Tetenbaum & Mulkeen, 1984). Similarly, many colleagues stick to lecturing because, from an economical viewpoint, it "works well", that is, it satisfies several of the constraints we will analyze in this chapter. Educational research reached its maturity when it replaced stories about methods that supposedly "work well" by empirical evidence of learning gains (pre-post). The fact that teachers feel their method "works well" is probably a necessary condition for success, at least for sustainability of the method, but certainly not a sufficient condition. The second critique against this idea is that "it works well" refers to a broad beam of interweaved factors that can hardly be disentangled in a formal experiment. Rigorous experiments may not address more than a few independent variables while "it works well" refers to many parameters. While design-based research leads to pedagogical methods that "work well", they still face founded criticisms with regard to the generalisability of their findings.

Can we reconciliate the viewpoint of teachers who need methods that "work well" and the viewpoint of researchers for whom "it works well" can hardly be viewed as a scientific statement? Wouldn't we be extremely happy as researchers to know that the teachers involved in our empirical studies continue to use -on a voluntary basis- the methods we tested in their class? Wouldn't we be upset as teachers to be asked to test methods that don't work well? The gap between the teachers' and researchers' viewpoint is related to the difference of scale in their preoccupation. On the one hand, the researcher has to narrow down his focus to a specific activity or process (e.g. peer tutoring), hopefully isolated from any other source of influence which would be considered as a bias. It is interesting –yet dramatic- to note that the 'teacher effect' is often viewed as an experimental bias (F. Fischer, personal communication)? On the other hand, the teacher has to consider the much broader scope of what's happening inside the class, and to some extent also outside the class. So, there is a huge difference of scope in the concerns of each side. The models we analyze in this chapter are compatible with these two levels since they articulate in a single picture individual cognitive processes, social interactions and the class life. We hence refer to them as *'integrative models'* versus other models that have a more local scope (e.g. the zone of proximal development, the repair theory, …),

Integrative models are not learning theories. They do not predict how learning may result from specific activities. Instead, their strength is to be rather 'agnostic' with regard to learning theories. Theories provide us with a particular lens to grasp the complexity of learning in classrooms, but they are somehow exclusive. Isn't it legitimate to combine them, for instance to reason on the metacognitive skills can be internalized through social interactions (Blaye, 1988)? Isn't it legitimate to design activities that combine self-explanation and socio-cognitive conflict? Teachers don't have to choose between Bloom, Vygostky or Piaget. Researchers don't have to choose either. Students have a single brain; they don't switch between brains when moving from individual to social activities. When two peers perform a classification task, how could we dissociate individual induction from social argumentation? The interest of the models we discuss hereafter is to pay attention to the multiple levels that enter into play when explaining that a method "'works well". It is also their weakness: by addressing many aspects, they remain quite abstract. We hence attempt to extract more specific factors that relate models with design choices. We analyze to general models, orchestration and ecosystems, and then instantiate them with homemade specific models ("SWISH" and "Der Erfahrraum")

3. The "Orchestration" model

Many scholars have used "orchestration" to refer to the design and real-time management of multiple classroom activities, various learning processes and numerous teaching actions (Brophy & Good, 1986; Tomlinson, 1999; DiGiano, & Patton, 2002; Fischer et al., 2005; Gravier et al., 2006; Dillenbourg & Fischer, 2007; von Inqvald, 2009). Intutively, this metaphor is appealing. Music writers and teachers both have to harmonize multiple "voices". They both need a fine-grained control of time. They both translate a global message (emotions, knowledge) into a sequence of atomic actions (notes, interactions). Rothstein-Fisch and Trumbull (2008) explain that they use the word 'orchestration' instead of 'management' because it "*denotes bringing about harmony*" (p. 101). Moon (2001) uses 'orchestration' to refer to "*the process of managing a whole learning group in such a way as to maintain progress towards the learning outcomes and improvement of practice for all*" (p. 120)

Unfortunately, the classroom "orchestration" seems to have a different meaning than its musical counterpart. In music, orchestration refers to writing the score that an orchestra will play. It does not refer to the activity of the conductor when the orchestra is playing. The metaphor is applied in a more orthodox way to computer science where "service orchestration" (Peltz, 2003) refers to the definition of some workflow or architecture that connects different systems (namely web services). Applied to the educational context, the proper meaning of "orchestrating" would correspond to instructional design and not to the real time management of classroom activities.

Nevertheless, metaphors don't have to be perfect to be inspiring. The key difference between music orchestration and classroom orchestrations is that, when orchestrating a classroom, the score has often to be modified on the fly. Could we imagine that orchestra players read their score on a computer display (rather than on paper) and that this score changes dynamically, depending for instance on the audience's emotional state? Good teachers perform "reflection in action" (Schön, 1983), i.e. they are able to change the score as they are playing it. A good learning environment should let good teachers modify the score as often as necessary. The words '*dynamic orchestration*' could convey the combination of design/planning and real time adaptation. Let us stress that 'dynamic' does not mean free improvisation, it is neither plan-free or goal-free, but refers a certain degree of freedom around the instructional plan.

Is that stretching the model of orchestration too far? Metaphors are not correct or incorrect; the question is whether they are useful or not. In HCI, designers have used metaphors such as the desktop, the cockpit, the window, …. Instructional designers also developed metaphors such as 'frames' (Merrill, Li & Jones, 1992), 'anchored' instruction (Bransford et al, 1990), … A metaphor is 'useful' if it helps the designer/teacher to take decisions, namely because it provides a global structure to articulate multiple local decisions. A metaphor creates an *educational flavour* that local design principles do not convey. We analyse now why 'orchestration' does convey flavours that a concept such as 'classroom management' would not convey. We try to operationalize these flavours by extracting a certain number of design factors.

3.1. Teacher-centrism

Orchestra players religiously follow the movements of the conductor. This quasi-mimesis is an exaggeration of the message this model should convey to educationalists but it stresses the importance of the teacher's role. In the last decades, many colleagues have redefined the role of teachers as facilitators (Carey, 1994) along the common place slogan "from a sage on the stage to a guide on the side". Orchestration has a different flavour: teachers are not on the side, they are the conductors, they are driving the whole activity. They are managing in real time the activities that occur at multiple planes. They share their passion for the content. Their body language conveys their interpretation (speed, intensity, …) to the musicians.

Factor 1. **Leadership**. Teachers act as the drivers of the scenario and lead the collective (i.e. class-wide) activities.

Our community has somehow confused constructivism with "teacherless" (Dillenbourg, 2008). Let us state clearly that promoting the role of teachers as orchestrators does not imply that they have to lecture intensively or that they have to make a show. Orchestration would be compatible with "teacher-centric constructivism": it is the students who have to learn through their activity but teachers have the leadership of the whole scenario: lectures may be integrated into constructivist perspective for several purposes.

> *Debriefing* lectures "work very well": these are not simple feedback sessions but lectures that address *new* course contents through the data produced by the students themselves (experiment results, projects, assignments,…). The drawback is that these lectures have to be prepared after receiving the students' contribution which require last minute preparation or even some improvisation.
>
> There is a "time for telling" (Schwartz & Bransford, 1998): lectures "work well" in terms of learning when students have previously acquired some experience of what the lecturer is going to say; when they have the meanings but not the words.
>
> Lectures enable teachers to "qualify" the knowledge for instance to explain to students why an equation is beautiful, why a theory is somehow obsolete, why these results are surprising,… This 'personal touch' or meta-knowledge can hardly be made explicit in instructional material without over-simplification. It's the beauty of human presence to be able to convey these subtle cues.

Providing teachers with a strong leadership implies that they have the power to drive the system and not to be prisoners of an instructional plan. Acknowledging the role of teachers does not simply mean to let them tune some options or parameters but to truely empower them with respect to technology. This implies for instance that teachers are allowed to bypass decisions taken by the system and to flexibly rearrange their own scenario. Of course, we will see that flexibility has some limits described in section 8.1

Factor 2. **Flexibility**. Teachers have the possibility to change the learning scenario on the fly, as far as it makes sense.

As leaders of a class, teachers have the responsibility of what students do in this class. They don't have the same degree of control that the orchestra conductors have over their musicians, but they still have to be 'in control' of their class. A method 'does not work' if students become distracted, if they talk to each other when the teacher speaks to them, if they read their email while they should interact with a simulation. Some methods may reduce the authority of teachers because some students start to do silly things while waiting for late groups, because teachers lose face when encountering technical bugs, etc.

Factor 3. **Control**. Teachers maintain in the classroom the level of interest and concentration necessary for the on-going activities.

A method that "works well" facilitates teachers' task of maintaining interest and concentration among their audience. The class behaviour has not been not a main concern in learning sciences research but it is a major issue for teachers (especially new teachers), directors, parents and even students.

3.2. Cross-plane integration

In computer-supported collaborative learning (CSCL), the idea of "script" emerged as a method that shapes the way collaboration will occur within a team (Dillenbourg, 2002). More precisely, scripts aim at triggering specific types of interactions that are known to generate learning gains such as providing explanation, solving conflicts or mutually regulating each other. For instance, to increase conflicts within a team, some scripts, referred to as micro-scripts, will prompt peers to provide counter-evidence against the claims made by the other (Weinberger, Ertl, Fischer & Mandl, 2005). Another approach is to detect people who have opposite opinions and ask them to perform a task together, or to give peers different documents to read so that they end up with different opinions (Jermann & Dillenbourg, 1999). These so-called "macro-scripts" (Dillenbourg & Hong, 2008) also include individual activities (read, summarize, write,…) and class-wide activities (introductory lectures, vote, debriefing,…) in addition to small group activities. We also refer to them as 'integrative' scripts (Dillenbourg & Jermann, 2007) in the same way we talk here about 'integrative' models.

Factor 4. **Integration** refers to the combination, within a consistent scenario of individual, small group and class-wide activities, as well as activities beyond the class.

Anecdotically, we have used a notation (Figure 1) that is very similar to music scores. Time is represented from left to right. Lines refer to what Vygostky designed as planes: the intra-psychological plane (level 1 in fig 1: individual cognition), the interpsychological plane (level 2: small group interactions) and the social plane (level 3: where culture is located). It is clear that mental activities occur most of the time at the three levels in parallel. The "notes" placed on the score do not represent cognition but concrete activities.

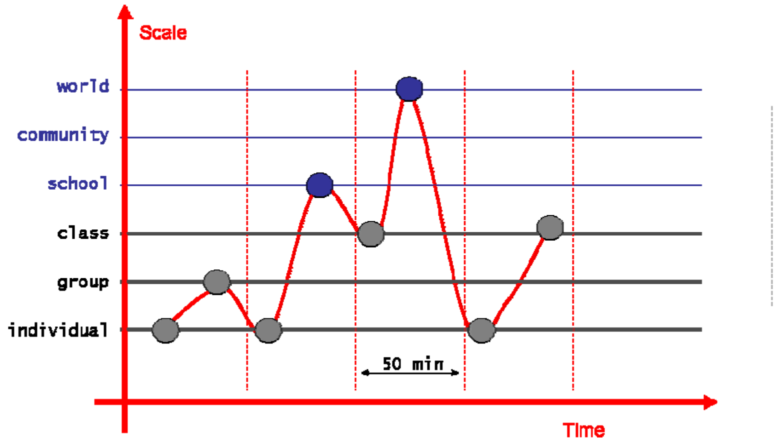

Figure 1: A musical notation for integrated scripts

These levels constitute an arbitrary segmentation of a social scale continuum. However, looking at practices, most classroom activities occur along these 3 levels: solo, class or in between. We added three levels that can be encountered: (level 4) activities with other classes in the school; (level 5) activities with local community (parents, correspondents, local fieldtrips,…) and (level 6) activities with the anonymous world via internet (e.g. on-line newspapers, polls,…). This segmentation is very pragmatic: level 5 adds logistics and security concerns to perform out of school the activities that are performed in the school at level 4.

3.3. *Sequentiality*

A piece of music is more than a set of notes, the sequence makes it all. A method that "works well" is not just a random sequence of activities; there is something in the sequence that turns discrete activities into a consistent whole, there is a scenario.

Orchestration has a flavour of linearity. Some verses or refrain can be moved and repeated but nonetheless, the idea of orchestration refers to some sequentiality. In terms of learning, the order of activities partly determines the cognitive process. Whether a concept definition is introduced before or after the examples will switch between an inductive and a deductive approach. Letting students evaluate their solution before or after providing a feedback changes it all. The order matters. For many years, non-linearity has been perceived as an educational plus, e.g. when moving from linear programmed instruction to branched programmed instruction or when moving from texts to hypertexts. It was a new feature offered by technologies that certainly facilitates adaptation to individual needs. But, despite being the enemy of individualisation, linearity has pedagogical advantages. It may lighten teachers' cognitive load of orchestration by streamlining activities. It simplifies issues of data consistency at the technical level. It also creates a classroom atmosphere by knowing that all students experience the same thing more or less at the same time. Of course, there is design trade-off with factor 2, since flexibility should enable teachers to escape from linearity, but the flavour of linearity is nonethless strong.

Factor 5. **Linearity**. The method is a simple sequence of activities that almost all students will perform at almost the same period. It is easy to explain to the students.

The notion of scenario implies continuity across activities: the groups remain the same, the students keep their roles or rotate in a predictive way, the activities concern the same objects or issues (as in problem-based learning or project-based learning). Technically, this continuity may be implemented as a workflow: the output of an activity is used as input for subsequent activities.

Factor 6. **Continuity**. The successive learning activities are articulated around shared data structures (objects, groups, assignments,…) that circulate via a workflow.

A method that "works well" is not emotionally flat. It includes phases of tension, where energy is accumulated, and phases of relaxation where accumulated energy is exploited. It is difficult to report this from a scientific stance, but the best methods are salty.

Factor 7. **Drama**. The emotional state of students varies across activities, with highest moments that trigger engagement for the rest of the scenario.

3.4. Time Management

One of the main constraints that teachers have to cope with is time. Not only is teaching time limited, but moreover it is segmented into time slices. The flexibility of this segmentation depends on the institutional context. A method will only be described as "working well" if most of the following timing issues can be orchestrated.

A method that "works well" must be reasonable in terms of total time necessary. Time for learning has always been a critique against constructivist approaches and an easy argument in favour of lecturing since the rate of content delivered per minute is high. The time necessary must be proportional to the importance of the domain to be taught within the year curriculum. This importance is measured in terms of credits in higher education or class-contact hours in lower school levels. This means that the time available depends upon the curriculum relevance of the topic (see section 4.2).

Factor 8. **Relevance**. The total time that a method requires to teach X should be proportional to the importance of X as specified in the curriculum

A method that "works well" must be flexible in terms of time segmentation. Should the next activity require a full period or can it be segmented into two periods? Should the teacher stop 15 minutes before the break because it is not worth starting a new activity for 15 minutes? Can students save work-in-progress and reuse it later on?

Factor 2 (again). **Flexibility**. Teachers have the possibility to adapt the next pedagogical activity to fit the time slice available.

The dynamics of a method that "works well", the feeling of drama, require the right intervention at the right time. This is a trivial statement but isn't true that the best joke can be destroyed by a bad timing? This means that some activities must be set up when the students are hot, when the energy is present. This new instance of factor 7 (drama) will be illustrated in section 5.

3.5. Physicality

Finally, conducting an orchestra is rather physical. It is not a virtual action in a virtual space. The conductor is physically engaged. The spatial layout of the room and the location of each musician are very important. The orchestration of classroom activities encompasses the spatial organization of tables, chairs and tools. This layout must facilitate the transition between the different forms of grouping in the scenario and depicted in figure 1. It must enable students to move when they have to move, for instance because they are switching roles within a group or switching between groups as in some Jigsaw scripts (Aronson, 1978). The teacher must be able to pass between groups and to be present across the space. The students' and teachers' location must enable them to see what they are supposed to see.

Factor 9. **Physicality**. Compared to previous models that stressed virtual learning spaces, orchestration refers to the concrete layout of the physical space in the classroom and to the physical movements of the different actors.

The physical layout of an orchestra enables the teacher to perceive the activities of all musicians at any time. On this point, the model does not match very well classroom practices: when the teachers moves between tables (what a conductor does not do), he does only perceive a subset of the students. What the conductor and the teacher have in common here is the need to keep permanently an awareness of the activity performed by each actor. Even a simple lecture requires maintaining an approximate model of the level of attention across the different sectors of the lecture room. A good teacher monitors the state of the class and reacts as soon as soon as something goes wrong. New attention technologies may help some teachers to maintain a global representation of the state of his class, not by doing deep student modeling but by analyzing social signals in real time: what student are looking at, with whom they interact, how they sit on their chair, etc.

Factor 10. **Awareness**. An orchestration technology helps teachers to be aware of the activity state of his students, at a behavioural level.

One interesting problem with the orchestration metaphor is that the conductor has an awareness of all musicians but does not see the audience in his back. Good teachers are known to have 'an eye in their back', but the model only works well if we consider the students as the orchestra players and not as the concert audience.

4. The "Ecosystem" model

It is very tempting to describe education as an ecosystem, as any system with multiple circular causal components (Copeland, 1979, Stoll & Fink, 1996; Dillenbourg, 2008). This metaphor has been applied outside the field of environmental sciences for instance to describe a city or a society as an ecosystem. Authors such as Resnick (2002) or Brown and Adler (2008) use the word ecosystem to refer to the global learning space outside the school, namely the digital sphere. As for 'orchestration', these metaphors are used in a shallow way. Again, is it just a buzzword or is it interesting for a learning technology designer to consider a classroom as an ecosystem? Does it help to understand why some method "works well"? Actually, the notion of ecosystem is quite different from the 'orchestration' since an ecosystem does not include a central orchestrator (unless some divinity is considered as orchestrator). Nonetheless, some authors in natural sciences talk about "orchestrating an ecosystem" such as a Sequoia Forest (Brigg, 2001). The word 'orchestration' is then used in a broad sense as a synonym of 'management'. The ecosystem model has also been applied to business cases. For instance, the study of various communities using the SAP environment is described as the orchestration of an ecosystem (Iansiti & Lakhani, 2009).

4.1. Species

In an ecosystem, one cannot start feeding the rabbits without considering the impact on foxes. As any ecosystem, a classroom shelters the interactions between several animal species: students, teachers, teaching assistants, special support staff, directors, inspectors, parents, … This has trivial implications which are nonetheless worth mentioning.

Methods that 'work well' should not only be designed for learners but also, as mentioned in section 3, for teachers, but also for parents, directors, … For instance, the learning technologies that our community is developing rarely pay attention to the homework and, through it, to the role of parents. Technologies could improve the integration of homework in the flow of learning and enable parents to follow what their children have done. Isn't it strange that, while many scholars on learning technologies are parents, we behave as researchers as if we were not? Some ethical arguments may explain why researchers neglect these possibilities: homework increases the effects of social disparities (Ferguson, Ludwig & Rich; 2001); not all parents have Internet access; parents might interfere too much with the teachers' job, … However, it is a fact that parents and homework are part of the ecosystem.

Factor 4 (again). **Integration** of homework and parents' interaction in the educational workflow.

Each species includes a large variety of animals whose features (size, fitness,..) follow more or less a Gaussian distribution of animals. One may exceptionally find a rabbit that is 1 meter long but not many. A method that "works well" cannot be generalized if it is designed for exceptional teachers. The researcher maybe lucky to find one exceptional teacher, for instance one who cope easily with chaos in the classroom, but this will restrict generalisability fo the results. The very fact that teachers accept to participate into our experiments is an unavoidable bias in the representativity of these volunteers. The trivial implication is that pedagogical methods must be adaptable to differences between teachers. Our point goes further: designing for the ecosystem means that most teachers should be able to apply our method, not only a few of them.

Factor 11. **Design for all**. The method can be conducted by most skilled teachers, not only by exceptional teachers

4.2. Selection

A method that 'works well' in an education ecosystem has to pay respect to the rules that govern life and death within the ecosystem.

Teachers are not free to teach what they want; they have some degree of freedom in primary school, almost no freedom in secondary schools and a bit more at university level. Our community has been quite creative in designing activities that address skills that are not in the curriculum or only in the 'meta' section with transversal skills. An extra-curriculum investment from teachers and students is acceptable for a short duration (the time of an experiment), but such an environment will only be used over long term if is justified by the importance of its learning objectives within the curriculum..

Factor 12. **Curriculum relevance**. How important are these learning objectives within the curriculum of these students?

Whether we like or not, the educational ecosystem is shaped by large scale evaluations such as PISA or TIMSS. Our research community tends to neglect or even disregard these assessments. Instead, we should contribute to the improvement of the quality of these measures. In the meanwhile, these large assessments and more generally all exams are part of the educational ecosystem. A method that 'works well' is a method that does not put teachers, directors or ministers in an undefendable position when the results of evaluations are published. At the university level, we don't have large scale assessments, but the same argument applies: a method will not '"work well", if the students don't perceive this method as really useful for passing the course exam.

Factor 13. **Assessment relevance**. Is the method compatible with the different assessments that students will have to pass?

In theory, curriculum relevance should guarantee the assessment relevance, but in practice there are gaps: the specific way of measuring skills and knowledge may differ from the way they are taught, the national or international assessments may differ from local curricula, etc.

4.3. Legacy

Given the complexity of causal links within an ecosystem, external interventions have to be minimalist. The same applies to the classroom ecosystem. The learning environments we design do not land in an empty world. Every class has its legacy of methods, tools and resources that have been used so far. A new method cannot wash out the past. For instance, a method that "works well" should be compatible with the main book used in the course otherwise teachers would be in the very difficult position of explaining why they do not use the book that has been bought. Another example is that every student or teacher has a legacy of habits with respect to computational tools. If the learning environment proposes a specific email tool or a specific chat tool, it will suffer from a strong competition with the email and chats that students are using, i.e. the ones that already include all their contacts, their histories, their favorite goodies, … The obvious implication is to design a minimalist intervention that respects this legacy, namely to design a learning environment that is limited to the functionalities strictly required by the pedagogical method. This means design should resist to the temptation to provide a fully integrated learning environment (with yet another agenda, yet another forum, etc.).

Factor 14. **Minimalism**. The functionalities offered by the learning environment are only those specific to the learning scenario and that are not provided by the tools (books, software,..) already in use by the students

However, minimalism has drawbacks: an integrated environment enables interconnection between tools, for instance a link between chat utterances and graphical objects on the display (as in ConcertChat, Mühlpfordt and Wessner, 2005) or a link between a forum and a spreadsheet (as in http://www.sense.us). Despite emerging standards and multiple APIs, it remains a technical challenge to provide this kind of interactions between the environment we design and multiple existing tools (e.g. with the 5 most popular chat systems). In other words, there is a trade-off between minimalist intervention and integration, but the ecosystem model is rather on the first end.

4.4. Sustainability

A classroom has limited energy resources as any ecosystem. The energetic efficiency of a pedagogical method is a key factor to claim that it "works well". The energy that students will invest is of course limited; it is actually measured in terms of time (i.e. credits). For instance, it often happens that a very exciting project concentrates all the students' energy on one specific course, leading them to fail other courses. But, most importantly, we refer here to the teachers' energy. A method based on teachers' heroic investment over a few months is not a method that will "work well" for several years. Teachers and their team will do it well the first year, even better the second year and then the investment will inevitably decrease over the following years.

Factor 15. **Sustainability**. The energy required to run the method can be maintained over several years

We should not forget that teaching is a long term repetitive activity: researchers conduct an experiment once or twice but teachers have to repeat it for many years. A method that "works well" must have realistic energy expectations. It may for instance be that groups of 2 are better than groups of 4 for the targeted interaction but they require twice more energy for grading the assignments. Design is always a trade-off.

5. The "SWISH" model and the ManyScripts environment

This section and the two next ones illustrate how the factors mentioned actually shape the design of technologies used in the classroom. We report the local design models used for building these environments, their implementation and how they relate to the 15 factors.

5.1. The 'SWISH' model

A macro-script is a pedagogical method that aims to trigger specific interactions during teamwork (Dillenbourg & Jermann, 2007). Here are two scripts we want to relate to our 15 factors. Their score-like representation is reported in figure 2.

- ArgueGraph (Dillenbourg, 2002) aims to trigger argumentation by forming pairs of students with conflicting opinions. It is run in 5 stages: (1) individuals answer a questionnaire; (2) the system computes their opinion by compiling their answers and locates them on a map that is projected in the classroom and discussed collectively; (3) groups are formed with individuals to maximize their distance on the map; they have to answer the same questionnaire as in the first phase; (4) the teacher gives a debriefing lecture based on the answers provided by individuals and pairs; (5) students have to write a summary of the arguments. Typical ArgueGraph sessions last 3-4 hours depending on the number of questions. Experiments showed that the ArgueGraph conflict mechanism leads students to express more elaborated arguments (Jermann & Dillenbourg, 1999)

- The ConceptGrid script (Dillenbourg & Jermann, 2007) aims to trigger explanations. (1) each team has a set of papers to read and a set of definitions to produce; students distribute their work within teams (2) students individually read the papers they have been assigned to (3) students individually enter the definition of the concepts that they have been assigned (4) teams have to build a grid of concepts in such a way that they are able to explain the relationship between two neighbours on the grid (by entering a short text in the system); (5) the teacher gives a debriefing lecture based on the grids build by students. A typical ConceptGrid sessions lasts 2-3 weeks, including the time for their readings. Experiments showed that ConceptGrid forces students to elaborate upon each other's explanations (Dillenbourg & Hong, 2008).

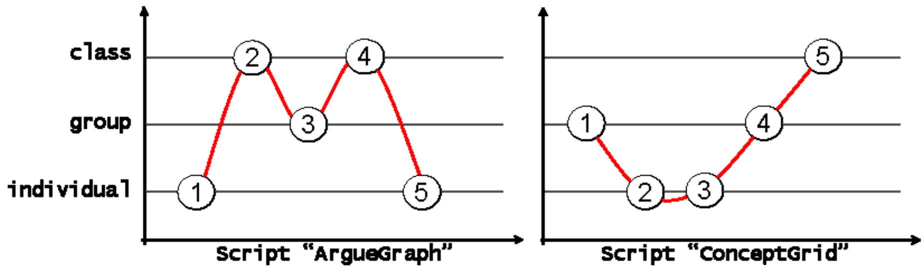

Figure 2. Integration of activities in two macro-scripts

These examples of macro-script rely on the same design principle that makes the team interactions more difficult than if the teacher let them freely collaborate. Collaborative learning is often described as the side effect of the effort engaged to build a shared understanding of the task at hand. This effort is represented as Δ on figure 3: there is a natural divergence in teams at the beginning (Δ1) and the script actually increases this divergence (Δ2) in order to increase the intensity of interactions required to finally minimize this divergence (Δ3). In ArgueGraph, the effort necessary to reach agreement is higher since we pair students who disagree. In ConceptGrid, the effort necessary to build a consistent grid is increased by the fact that no student has enough knowledge to do it; they have to explain it to each other. Both scripts increase the collaborative effort by 'splitting' the team in terms of respectively opinions and knowledge. The nature of this split determines the type of interactions that student will need to engage in to complete the task. Hence, the design principle was termed 'split where interactions should happen' (SWISH). Other examples are provided in Dillenbourg & Hong (2008).

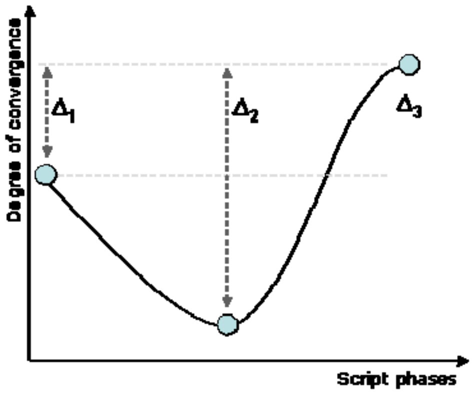

Figure 3. Macro-scripts reduce team convergence to increase the effort to be engaged.

5.2. The ManyScripts environment

The two examples of scripts are available in web-based platform. Teachers can select a script (ArgueGraph, ConceptGrid,..), edit the contents, set up the groups and tune some parameters. Figure 4 presents a snapshot from the ArgueGraph script in the ManyScripts platform: the system synthesizes all the justifications that individuals and pairs have associated to their answers. Teachers use this display during his debriefing lecture (Phase 4)

5.3. Design factors

In both scripts, the teacher has a salient role (Factor 1: Leadership) especially during the debriefing phase. These are not genuine lectures but 'organic' lectures based on what student have produced. The drawback is that these lectures cannot be prepared in advance. We usually had one coffee break between the duo answers and the debriefing phase in ArgueGraph. This semi-improvisation is against factor 10 (DesignforAll) since many teachers don't like to improvise, even if in this case the lecture is facilitated by the environment (figure 4). In ConceptGrid, we usually asked students to complete their grid one or two days before the debriefing lecture, which requires less improvisation but nonetheless heavy work to analyse all grids the night before the course. This stressful preparation work reduces the sustainability (factor 15).

Both scripts illustrate factor 4 (integration) since they integrate individual, small group and class wide activities in a meaningful way. They are linear (factor 3) and based on a workflow that provides continuity (factor 6): for instance, data from individual answers (ArgueGraph , phase 1) are automatically processed to form conflicting pairs (phase 2), individual and pair answers (phase 3) are collected for debriefing (Phase 4).

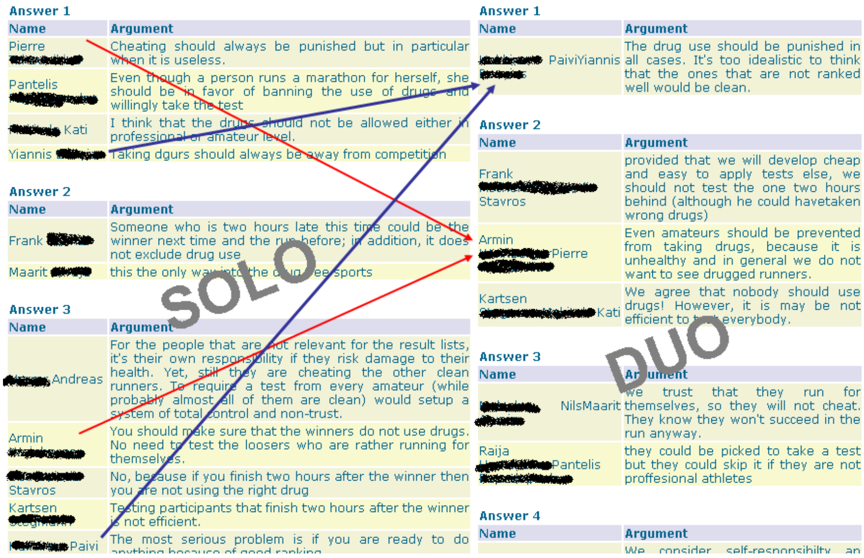

Figure 4: Annotated snapshot of ManyScripts (names are deleted; arrows have been added to indicate how the teacher compares answers)

Drama (factor 7) is embedded in the SWISH model: this model is about increasing and relaxing tensions. However, smaller design elements make the drama higher in ArgueGraph than in ConceptGrid. The conflict phase triggers a degree of engagement that goes beyond the 'didactic contract' (Brousseau, 1998): in many cases, we had to tell students "Stop arguing now with you friend even if you have not convinced him; this is just a didactic game; we have to continue". In ArgueGraph, we also noticed the following phenomenon. When being asked to choose between answers A and B, many students expressed their frustration not to be able to answer some mix of A and B. This frustration pushed them to stand up literally during the debriefing session (phase 4) to defend themselves. They needed to explain that they answered B but actually wanted to answer something slightly different. Their frustration raised their level of participation. Once, we modified the interface of the environment and let the student express subtle choices (e.g. to answer 'in some cases' instead of 'yes' or 'no') and this killed the drama. Finally, we found that the energy generated by this design was very fragile. It depends upon the timing (factor 7) of the script. Once, we did the debriefing activity one week after the argumentation phase instead of right after and all energy had disappeared from this debriefing session.

The time flexibility (factor 2) was crucial in ArgueGraph. We had bad experiences with an early version of the environment in which all students were expected to provide their individual answers before to move to the group formation. The whole class was stuck if one student left the room or lost the Internet connexion. Now, ManyScripts offers the possibility to move on to phase 2 even if all answers from phase 1 have not been provided. In terms of timing, teachers actually make sure that the delay between the first student who completes the questionnaire and the last one is not too high. If many students have to wait for other, it quickly generates all sorts of undesirable behaviour (factor 3: Control).

Since ConceptGrid has a duration of several weeks, we had to implement flexibility (factor 2) in terms of group formation. Once a group of students is formed, what happens if a student drops out the class? If the teacher decides to make groups of 4, what happens if the number of students in the class is not a multiple of 4? ManyScripts implements two functionalities for coping with these accidents (Dillenbourg & Tchounikine, 2007). If a student is missing in a group, the teacher may turn on the 'SPY' feature which enables the group in which role-X is missing to borrow the definitions produced by the students who play role-X in any other group of the class. This makes sure that all students have the same workload (factors 12 and 14). Conversely, if the group has for instance 5 students for 4 roles, the teacher may activate the 'JOKER' function: a 'joker' student may provide a definition that belongs to any other role. These functionalities are not perfect solutions but ways to carry on the script despite an imperfect situation. A method that "works well" should survive to these common accidents in everyday classroom life.

Finally, with respect to factor 13 (assessment relevance), ConceptGrid connects the script to the course exam: the environment includes a button to print all the work produced by a team so they could use it during the exam.

6. The "Erfahrraum" model and the TinkerLamp environment

6.1. The "Erfahrraum" model

The initial vocational education is structured as a dual system in Switzerland and other German-speaking countries: students spend about 4 days per week in a company and one day per week at school. These apprentices are between 16 and 20 years old and represent 69% of the teenagers in the educational system[1]. Vocational education constitutes a specific ecosystem, with its culture, its laws, its actors (e.g. the companies, the corporate associations), quite different from general education. Our main research hypothesis was that technologies may play a specific role in a dual system as a bridge between what apprentices do at their workplace and what they do at school. The model of "Erfahrraum" combines two ideas into a German name that reflects the socio-cultural context in which this model emerged. "Erfahrung" means 'experience'. Learning from experience is of course not a new idea: it is rooted in Dewey's work. Experiential learning is defined by Keeton and Tate (1978) as learning "in which the learner is directly in touch with the realities being studied" (p. 2). A dual training system combines this direct experience with some distanciation, more abstract activities in the classroom. Learning technologies are envisioned as ways to capture the apprentices' experience in order to exploit it during these more abstract activities in the classroom. "Raum" means room, as we insist on the physical orchestration of the room (factor 9).

The model has been implemented by different technologies in three different contexts. In the first context (Gavota et al., 2008), we capture workplace experience of dental assistants by asking them to write down their experience in a wiki-like environment. The school activities, peer commenting and text revision, exploit the diversity of experiences across a class of 20 apprentices: some work in small cabinets with a single dental surgeon, some in large cabinets with several surgeons, some with old fashioned technologies, other with high-tech cabinets, etc. In the second project, (J.-L Gurtner, University of Fribourg) captures workplace experience life in the context of car mechanics and pastry making. They call apprentices on their workplace on the phone and/or ask them to take pictures. Later on, this raw material feeds classroom activities. Finally, we instantiated the Erfahrraum approach in the context of logistics (Jermann, Zufferey and Dillenbourg, 2008). Our observations of logistics apprentices in their warehouse revealed a gap between what apprentices are asked to do in their warehouse and what they are supposed to learn. While the official curriculum specifies that they should acquire logistics skills, the apprentices mainly follow their boss' instructions (move this over there). They are rarely involved in decision making such as flow optimization, warehouse layout or storage management. We refer to this as the 'abstraction gap', i.e. the difference in the degree of abstraction between the tasks they experience and the tasks they should master. In school, the apprentices encounter more abstract logistics problems but the drawback is that they do not connect these tasks to their warehouse experience.

6.2. The TinkerLamp environment

The TinkerLamp is an augmented reality system designed to run tabletop tangible simulations. The simulation which we developed in close collaboration with teachers from a professional school allows logistics apprentices to build a warehouse model by placing small-scale shelves on the table. Besides shelves, users can place tangibles which represent architectural constraints (e.g. pillars to sustain the roof of the warehouse, loading docks, offices and technical service rooms). The building elements for the model are scaled to allow the construction of a realistic warehouse (32 by 24 meters in reality).

The physical small-scale model is augmented through a video projector placed above the table (figure 5). All objects (shelves, pillars, cardboard) are tagged with fiducial markers (similar to a 2 dimensional bar code) which enable a camera to track their position on the table (Fiala, 2005) and

[1] http://www.bfs.admin.ch/bfs/portal/fr/index/themen/15/04/00/blank/uebersicht.html

enable the system to project graphical representations (augmentations) on top and around the objects. The physical layout of the warehouse is used as input to configure a simulation. Projected forklifts represent the movement of goods in and out of the warehouse.

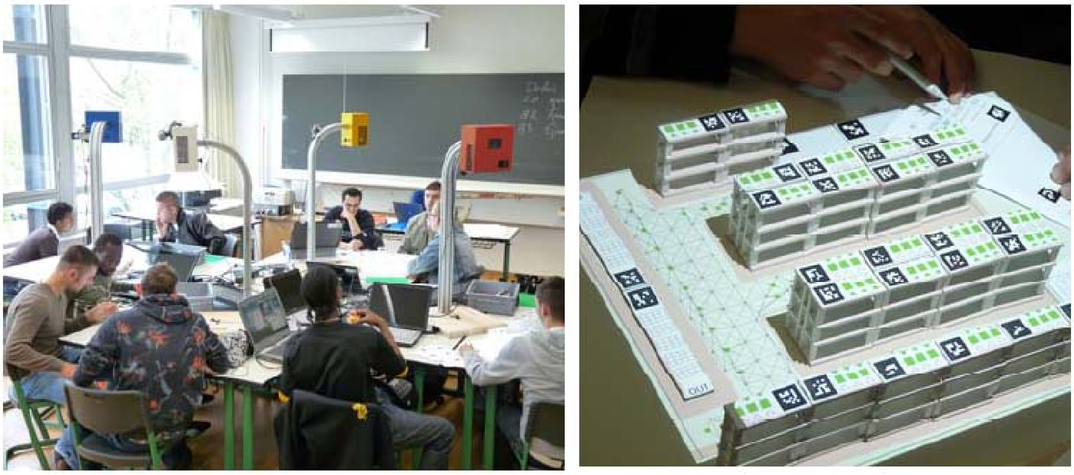

Figure 5: TinkerLamp: a tabletop tangible simulation in the domain of logistics. Left: four TinkerLamps used concurrently in a classroom. Right: a closeup of a small-scale warehouse designed by apprentices. Information is projected on the floor and on top of the shelves.

The simulation is controlled by a paper-based interface called TinkerSheets (figure 6). Small tokens can be placed on a paper form which is recognized by the system and allows users to set parameters like the type of warehouse management, the number and type of forklifts, or the type of augmentation which is displayed. Master sheets allow setting the main parameters relevant for a particular logistic concept and companion sheets either allow setting supplementary parameters or to visualize general simulation output (summarized numbers, graphs, etc).

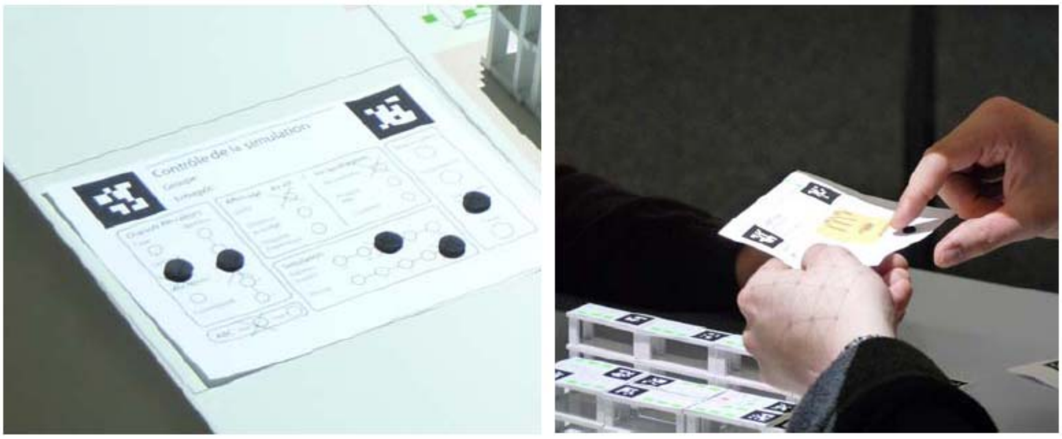

Figure 6: TinkerSheets. Left: a master sheet from the official curriculum is used to parameterize the warehouse simulation. Right: a companion sheet is used by an apprentice to visualize different types of surfaces in the warehouse.

The TinkerLamp is used on a regular basis in 4 different classes in two Swiss schools. Teachers are enthusiastic and describe it as environment that "works well". More formal evaluation have shown the positive effects of the tangibles on learning (Schneider, Jermann, Zufferey, and Dillenbourg, submitted) but the usability of TinkerSheets has not been empirically proven.

6.3. Design Factors

The TinkerSheets offer interesting opportunities with respect to our 15 factors. First, they make curriculum relevance (factor 12) very tangible. The official curriculum – jointly designed by public authorities and the relevant corporate association has the form of a large binder. Teachers may simply take one sheet from this binder and place it under the TinkerLamp in order to set up the activities described in the sheet. In addition, teachers may annotate these sheets with personal comments (e.g. which simulation parameters work better for this activity) that will be very useful for the next year reuse of this activity (Factor 15: sustainability).

These sheets can also be used for designing homework (Factor 4: Integration), for instance by printing a warehouse performance sheet at the end of a warehouse design activity. Teachers may then ask apprentices to perform some analysis at home and to come back for the next week with new simulation parameters. Their homework could typically be assessed by putting the homework sheet under the TinkerLamp and see how the warehouse performs.

The continuity across activities (factor 5) becomes tangible: what connects successive activities is not an invisible workflow, but a concrete sheet of paper that is passed from hand to hand between the different phases of the activity. This "tangible workflow" has advantages: it is simple and concrete, publicly visible, documents can be annotated, shown to echo other…Actually, the virtual workflow still exists since any sheet is associated to a fiducial marker that connects it to a data structure, but this invisible data set has a concrete clone in the physical world.

The physical orchestration (Factor 9) of the activities was initially not trivial. Controlling the simulation required teachers to use finger-driven menus which were not easy to use. This difficulty did not empower teachers as drivers (factor 1). We replaced these menus by TinkerSheets that have a much higher usability. Once they are laid out around the display area, they constitute some kind of cockpit in which is relatively easy to see all available options. Initially, we used a very large version of the TinkerLamp (the TinkerTable, 1.5m X 2m?) which occupied a large space for only 5 students. What would then happen with the students who are not working (factor 3: control)? Working with a subset of the class is acceptable for one experiment but not sustainable on the long term (factor 15). One teacher came with an innovative idea: while one team was working on the table, he projected their work on a screen placed elsewhere and on which he could discuss with the rest of the class what one group was saying. The new tool was then integrated in the 'legacy' environment of a whiteboard and a beamer (factor 14). Later on, we produced a smaller simulation environment (40 X 50 cm) in such a way that 4 groups can work simultaneously in the same class under four different TinkerLamps.

7. The Shelve and Lantern environments

7.1. The Recitation Section Model

Recitation sections are managed in our university in a way similar to many other places: the students receive a set of exercises to be carried out with the help of teaching assistants (TAs), mostly PhD students. The sessions gather between 20 and 60 students in a room with 2 or 3 TAs'. The students work in groups of 2 to 4; some prefer to stay alone. They raise their hand to attract the TA's attention who joins the group and provides help for a few minutes. Occasionally, if several teams face the same difficulty, the TA gives a collective explanation on the blackboard.

7.2. The Lantern Environment

We observed several recitation sessions and noted several regulation problems: students spend a lot of time chasing the TA instead of working on their assignments, TAs do not necessarily come in a 'fair' way (first asker is not first helped), some students ask help from the very beginning of the exercises without even trying seriously to solve it, most students do not complete all exercises while exam items have a level of difficulty similar to the last exercises of the session (factor 12), etc (Alavi, Dillenbourg & Kaplan, 2009). To help the TA to orchestrate the session, we developed two awareness tools. The 'Shelve' is a central display where teams indicate with a remote control device which exercise they do and when they need help. The 'Lantern' is a small device that teams put on their table and which they use to provide the same information either by turning it (to indicate their move through the exercises) or by pushing on its top (to ask TA's help). Both the Lantern and the Shelve display the same information: which team is working on which exercise (each exercise has a different colour), how long they have been working on that exercise (the height of the colour bar), do they need help (it blinks) and for how long (it blinks faster).

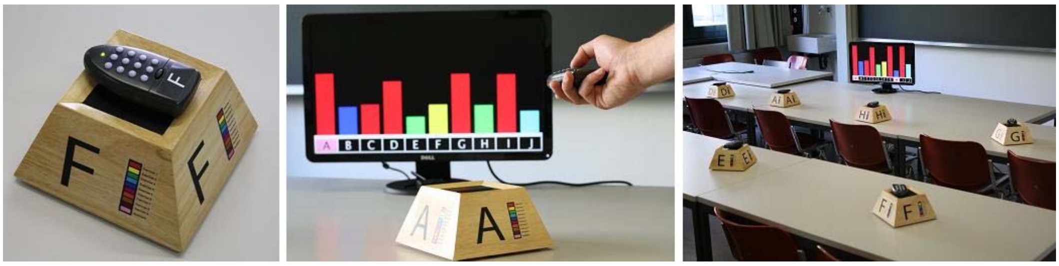

Figure 7. The Shelve environment.

Figure 8. The Lantern (left) and its use during orchestration.

7.3. Design Factors

The Lantern helps tacking the problems of time management (factor 7) and control (factor 2). The main difficulty for the orchestrator is to manage multiple teams of different sizes working at different speeds and requiring different types of help at different times. The experiments (Alavi, Dillenbourg & Kaplan, 2009) showed that students using the Lantern or the Shelve spend less time chasing the TA: once they push their device to ask for help they can concentrate on their exercises. Control (factor 3) is improved because teams do not simply wait doing nothing.

Overall, this environment provides TAs with awareness (factor 10). As we stressed, it does not carry any knowledge diagnosis or any smart computation. If simply provides an overview of who is doing what and who is looking for help help. It also illustrates the physicality of orchestration. The only difference between the Lantern and the Shelve is the spatial layout. Besides the fact that Shelve is centralized and Lantern is geographically distributed, both devices display the same information, in the same way. The Lanterns connects spatially the information displayed (exercise being done, time in exercise, waiting time) with the team being concerned by this information. Yet, this single difference led to different interaction patterns in the class. The central display induced more comparison between groups, independently of their location, while the distributed version led to the emergence of clusters, i.e. sets of 2-3 small groups, located close to each other, and which interact with each other (e.g. a group A helps group B because A sees that B has been waiting for help at an exercise that A has completed (Alavi, Dillenbourg & Kaplan, 2009)

8. Conclusions

8.1. Implications for learning technologies

We presented 3 examples of technologies developed in our lab but many other colleagues have developed environments that are close to the orchestration model and inspired us as the NIMIS classroom (Hoppe et al, 2000), personal response systems, classroom-scenarios based on handhelds (DiGiano, & Patton, 2002; Zurita & Nussbaum, 2004) or even on multiple mice (Infante et al., 2009). Our goal in presenting our examples was to show that the orchestration model, although being somewhat abstract and metaphorical, can be turned into concrete implementation choices. We hereafter list several technological choices that are more or less directly connected to the orchestration model.

1. Orchestration technologies are different from distance education since they are designed for classroom life. They may include on-line activities but the most salient part of the scenario occurs in face-to-face.
2. A part of e-learning technologies are document-centric, while orchestration technologies mostly support activities (e.g. the simulation for TinkerLamp) and overall diverse forms of interactions (as in ArgueGraph or Lantern).
3. Orchestration technologies should have a high usability for the teacher. Of course, the usability also concerns the students but orchestration implies that teachers may easily interact with the technology despite being overloaded by other tasks (managing groups, lecturing, etc.)
4. These technologies make orchestration quite physical, i.e. they have to cope with the spatial organisation of the classroom and other spaces as well as with the location and movements of students and teachers. The development of HCI towards location-aware services is hence pushing learning technologies towards orchestration.
5. These technologies make orchestration very concrete, i.e. something that can be manipulated by the actors (the tangible aspects) and also something that can be perceived by all actors (the ambient dimension). The evolution of HCI towards physical interaction (tangibles, roomware, …) is supporting the pedagogical evolution towards orchestration.
6. Since orchestration technologies have to integrate different activities into a scenario, they need to include some workflow functionality, i.e. the storage and reuse of data between activities. These activities can be performed with heterogeneous software which makes the workflow more complex to implement.
7. Combining the two previous points, when these digital data are represented as physical objects, the workflow management becomes a public task and hence becomes easier. This applies to the TinkerSheets but also to explain why walking to someone with a PDA to share is richer than sending him the data by WiFi (as in Roschelle & Pea, 2002).
8. Implementing flexibility is a complex design issue. A learning environment that would be completely open, where teachers could change everything, would not convey anymore a pedagogical idea. For instance, in ArgueGraph, changing the group formation criteria from "pair students with opposite opinions" to "pair students with similar opinions" is technically easy but pedagogically meaningless. We refer to this as intrinsic constraints, i.e. design choices that correspond to the core idea of the script (Dillenbourg & Tchounikine, 2007). Flexibility can be increased by reducing extrinsic constraints, i.e. design choices implemented for technical reasons (e.g. data consistency problems if one students drops out) or sometimes simply because the designer did not consider leaving this choice open. Designing environments with a clear scenario but which still allow for flexibility remains a challenging trade-off for which new software architectures would be interesting.
9. The integration of a new learning technology in the classroom legacy (factor 14) is important. It takes ages to convince a student who is used to chat on-line with system-X to move to system-Y. There is a need to design our learning environments from the very beginning either as very open systems that can interact with any other web service or simply to consider our learning environment as web services. The advent of 'cloud computing' may push learning technologies towards a better technical integration

8.2. Implications for Design-Based Research

Design-based research (Collins 1992; Sandoval and Bell; 2004) relies on prototyping-testing cycles with the participation of all classroom actors. If this participatory design is carefully conducted, it should produce a method that "'works well". However, the generalisability of the method and hence of the associated learning effects is quite low. It "worked well" in that classroom with these actors, because it matches their constraints, but will it work in a different classroom? Despite our conviction that DBR is the best method for studying classroom orchestration, we must acknowledge that the generalization remains a problem. Conjecture maps help the interpretation of results and their potential generalization. Conjectures embed the relationship between interventions and expected learning outcomes or expected process changes and are hence not very different from experimental hypotheses. One solution we have chosen for the logistics project was to complement the DBR approach by a more formal experiment with a control group. When a method "works well", it means that it is compliant with the many constraints of the context where it has been tested. It's never "it works well universally" but "it worked well in my class this year". Understanding which constraints were satisfied and why the method satisfied them is the condition to generalize the DBR results. This generalisability is not only for the sake of science but also because it is our social duty to come up with methods that "'work well" beyond a single context (even if no method will "work well" universally). We elaborate this in the next section.

8.3. Orchestration as constraints management

Teachers who have to orchestrate the classroom and its technologies actually face a multi-constraints management problem.

1. Curriculum constraints: how relevant is the topic with respect to the learning objectives listed in the curriculum, will these students be motivated by this topic?
2. Assessment constraints: are my learning activities compatible with summative evaluation exams, large scale assessments studies,…?
3. Time constraints: how much time is necessary, how much time is available (see constraint 1) and how much flexibility do we have around these two factors?
4. Energy constraints: how much time and energy must teachers engage to prepare and run this method, how long can they sustain it, …?
5. Space constraints: do I have the space necessary in my classroom do set up these activities, is the classroom layout compatible with the interaction I expect to trigger,…?
6. Safety constraints: Can I keep control of my class? Can I be sued in court because some accident may occur during the field trip? ...

There are of course other constraints such as financial constraints (obviously), cultural constraints (the Tinker lamp simulation fits well the specific culture of warehouse workers), teachers' personality constraints (e.g. risk-aversive versus pioneers), motivational constraints (a method that "works well" should boost the teacher's self-esteem),… Overall, we should mention the prerequisites constraints: no method "works well" if students don't have the pre-requisites. We could build a long list of constraints; these factors have nicely been explored by Bielaczyc (2006). Our point here was to have a shorter list of constraints and to underline which ones are particularly relevant to the concept of orchestration. The six constraint classes mentioned above match the 15 design factors we listed.

8.4. Final word

It is true that "'it works well" is a subjective feeling and not a rigorous statement. However, it is a social reality. No successful empirical study will lead to any generalization if the teachers do not acquire the conviction that "'it works well". It is hence a key item on the agenda of learning sciences to understand what teachers mean by "it works well". It is a key challenge to improve research methods so that they combine this concern with generalisability.

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