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Prototyping a *Designerly Learning* in Elementary Classrooms: Building a Frame of Possibilities

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Abstract

During our first six months of fieldwork in an elementary classroom with pupils aged 6-7 years old, we have looked for ways to progressively transform an instructional classroom environment to sustain the development of a *designerly learning* through making activities. In this article, we retrace the evolution of this attempt, along with our motivations, with an instrumental approach, through a description of the activities mediated by the artifacts we have prototyped with the schoolteacher and the pupils. First, we explain what we mean by *designerly learning*, which refers to making activities with a CHAT perspective, extending the focus of making beyond digital literacy and digital fabrication. Then, we describe our prototypes: a series of artifacts, which sets a frame for pupils to engage in classroom's making activities, and for the teacher to facilitate them. Finally, we discuss how such a frame can help scaffold and structure making activities in a classroom context, and therefore might be a prime means to foster a transition toward a *designerly learning* in schools.

Keywords

Mediational means; Instruments; Classroom; Designerly Learning; Making Activities

Introduction

There is a growing interest in making and digital fabrication within the learning sciences communities. Recent research, both theoretical and practical [6], have established the opportunities making offers for general education [3,4,13,37]. But the term “making” lacks of a rooted definition. A recent literature review [26] shows that most studies using the term “making” are referring to the engagement of students in programming activities. However, several voices argue toward a broader understanding of making for learning: they advocate for a holistic and *designerly* approach [6,18,33]. Building on these broader perspectives, we explore how to develop a profound and sustainable change in general education toward an integration of making activities in elementary schools curricula, and we study how the conditions in which making activities occur can act as a lever to foster such change. Working in collaboration with a French school, we have conducted a participative research through design within an elementary classroom, with 26 pupils (6 to 7 years old) and a schoolteacher (56 years old). During the first six months of our study, we have designed new tools that aimed at engaging pupils in a sustainable *designerly learning*, and at transforming the teacher's stance to facilitate such learning.

Drawn upon previous literature, we first detail the concept of “designerly learning”, which refers to pupils’ engagement in making activities. Considering making activities with a CHAT perspective [17,27], we extend the current limitative focus on digital literacy and digital fabrication. We refer to Rabardel’s model of instrument-mediated activities [30] and explain the benefits of adopting such an instrumental approach rooted in activity theory to study making activities. Then, we describe the series of artifacts that we prototyped for this classroom situation, and we explain the instrumental geneses provoked by the introduction of our prototypes, regarding the development of pupils’ making activities, and of our desired learning transition. We analyze how these prototypes ended up composing a complex and subtle system of instruments: a frame that sat new conditions and impacted all the activities within the classroom, and enabled pupils’ deeper explorations, reflective thinking and collaboration. Finally, we propose and discuss an instrumental framework on the conditions of making activities to explore the development of such *designerly learning* in elementary schools.

1. Studying Making activities with an Instrumental Perspective

1.1 Making Activities & Designerly Learning

1.1.1 Situating « Making »

The learning sciences have acknowledged for decades that embodied cognition and situated knowledge foster deep learning [5,12,36], and recent contributions in Child Computer Interaction (CCI) confirm this idea. Students’ access to digital fabrication tools represents another great opportunity toward more active learning, and contributes to the development of more collaborative and hands-on learning experiences [3,13]. Workshops and kits for digital fabrication have been designed and evaluated, demonstrating the beneficial impact of such making activities for learning [6,14,18,29]. Both theoretically and practically [6], researchers have recently once again reaffirm and push further the opportunities that making offers for general education . So, why does it look like these findings have not changed the instructional pedagogy practiced in main public elementary schools? As one can easily imagine, this issue goes beyond the scope of our article. But we would like to contribute with some elements that are worth consideration.

One of the problems we framed is that the term “making” itself lacks a common understanding. Today referring to the Maker Movement, it looks like a newborn concept related to digital tinkering, which deprives it from its historical and conceptual roots. This is confirmed by a recent literature review [REF] showing that most recent studies using the term “making” are referring to the engagement of students in programming activities, involving the use of digital tools, and sometimes craft materials. However, a plea for broader perspectives on making and digital fabrication has proposed to consider the development of a ‘Maker mindset’ [6], or a ‘Bildung’ approach [18]. These refer to the opportunities making offers for personal development and learning through creative processes. Smith et al., also suggest that design thinking could be used in general education to provide students with a better understanding of creative processes [33]. They define design thinking as “the ability to thoughtfully engage in design processes of digital fabrication, knowing how to act and reflect when confronted with ill-defined and complex societal problems”. These voices represent a growing perspective and find multiple echoes in several research communities [15,19,20,34]. But it seems so far that this research has been either focusing on generating models of design processes [33], or on designing tools that can support part of these processes [11,13,22].

1.1.2 A CHAT perspective

We believe that approaching “making” with a cultural-historical activity theory (CHAT) lens [17,27] can be beneficial to draw a third path. This lens asks us to consider the activities learners engage in, in a systemic and intrinsic perspective. So, we would have to look for the learners’ motives while engaged in making activities, as well as the mediational means they use to achieve them [39]. Building

on the work of Petrich, et al. [28], we see environmental conditions of situations (both human and material) as means to be thoroughly designed to mediate learners' making activities: as mediators, these conditions can help learners redefine their inner motives, and achieve their objectives autonomously and responsibly. Situated within a space, a time and a community, these can concern either the means directly manipulated by the learners, as well as the explicit or tacit functioning of the space or community. Designing with care such conditions can enhance learners' conversation with, understanding of, and participation to their environment. As conditions, they do not prescribe any task to achieve but rather exist as potentials, "awaiting" to be used by learners in ways that would seem appropriate for them to fulfill their inner objectives. Therefore, this CHAT lens allows us to operate a shift in the characterization of making activities, where making would not be characterized by outcomes, processes or tools. Rather, making activities can be seen as constructive activities characterized by the thoughtful relationships learners develop with the environmental conditions of their learning situations. This would depend of the degree of agency they have to use and act on these environmental conditions as the right means for their intended end. In other words, learners engage in authentic making activities when they adopt a double focal on the means that mediate their activities: when they simultaneously consider them as tools to shape the world, and as artifacts to be transformed.

1.1.3 Designerly Learning through making activities

We call "designerly ways of learning" (or *designerly learning*) the type of learning that occurs when learner are engaged in authentic making activities. We explicitly refer to Cross' expression, "designerly ways of knowing" [9,10], building on his following statement: "What designers know about especially is the 'artificial world'—the human-made world of artifacts. What they know how to do especially is the proposing of additions to and changes to the artificial world". We understand 'artificial world' in a broad sense as depicted by Vygotski [35], which includes tools and signs. Therefore, *designerly learning* is interested in learners' agency, as participants of the socio-cultural world with a double focal on the mediational means of their activities. It focuses on the conditions of the situations within which learners' activities take place in order to develop this agency. In this perspective, digital fabrication tools and digital literacy can indeed be crucial means of designerly learning environments. But without a careful attention, they will miss to engage learners in authentic making activities. An example of such failure is described by Blikstein [3] with the Key Chain syndrome. Following Moholy-Nagy's "design for life" vision [25], we define design as an attitude, not a profession. Moholy-Nagy argue: "In a healthy society this design for life will encourage every profession and vocation to play its part [...] This implies that it is desirable that everyone should solve his special task with the wide scope of a true "designer" with the new urge to integrated relationships." By engaging learners in participating to their socio-cultural world through authentic making activities, a *designerly learning* fosters such a systemic perspective, where learners create and re-shape relations. Along these lines, Ackermann highlights the importance of experiencing the reconfiguration of relations between tools and people to act on the socio-cultural world: "children will have to embrace the reasons which led so many people before them to give shape to their ideas (by writing them on media that keep records of inscriptions), to use those shapes (as vehicles to get a better sense of their thinkings), and to ease their circulation (by adopting easily decipherable conventions)" [1]. She also characterizes this reflective mediatisation as an "act of design", while highlighting its social dimensions.

Now that we have defined with more details our concept of *designerly learning* with a CHAT perspective on making activities, we would like to precise the framework we will use to study the mediational means of pupils' making activities, and unpack its benefits.

1.2 An instrumental perspective

We refer to the activity theory [17] and more particularly to the instrumental approach [16] to shed

light on the environmental conditions and their capacity to foster learners' making activities. In the activity theory, a subject's activity is understood as a purposeful interaction of the subject within the world. The activity is therefore oriented towards the subject's motives, called the object of her/his activity.

1.2.1 What is an instrument ?

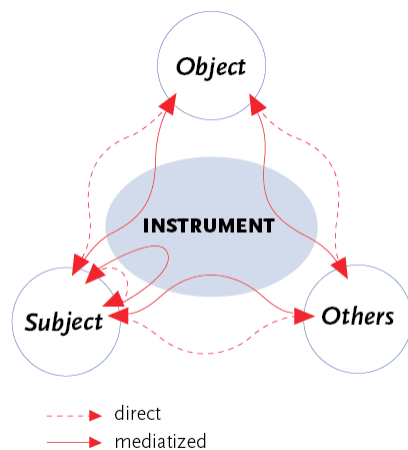


Figure 1. Diagram of instrument-mediated activities (Rabardel) [30]

The instrumental approach considers the mediational means of the activity; i.e, artifacts that are mobilized by the subject in order to realize the object of her/his activity [2,17,30]: they act as mediators of the subject's activity. In Rabardel's quadri-polar model of the instrument-mediated activity (see fig. 1) [30], other people are represented as a pole that interacts with the subject directly or through the instrument. The instrumental mediations can be of different natures: epistemic, pragmatic, interpersonal or reflexive. In this instrumental approach, an artifact is not in itself an instrument. Rabardel reminds us that an instrument is hybrid. It is composed of two components: an artifact component (e.g., a tool), and the subject's scheme of use [30]. Therefore, artifacts are called instrument as the result of the constructive dimension of the subject's activity, and after a design-in-use process [24,38]. This developmental process is sometimes refers to as appropriation [17,21], or instrumental genesis [30]. The instrumental genesis implies a transformation of both components of the instrument due to the subject's activity: the transformation of the artifact (instrumentalization) and the evolution and creation of the schemes of use (instrumentation). Therefore, an instrument genesis transforms the organization of the subject's activity, and this process can go as far as a redefinition of the motives of the subject's activity.

1.2.2 Why using an instrumental approach?

We have showed that the instrumental approach is a theoretical framework that analyzes the mediational means of one's activity with a developmental concern. This is particularly interesting in the case of our research through design study within the classroom to analyze the transformation of pupils' activities, for two reasons:

- In a designerly learning, we argued that learners engage in authentic making activities when they adopt a double focal on the mediational means of their activities (i.e. when they use artifacts as tools to shape the world, and when they reflect and act on artifacts as means to be transformed). As this framework places instruments at its core, it enables the description of the multiple instrumental mediations from a subject's perspective and their dynamics. In our study, it offers a theoretical framework to analyze the dynamics of the teacher and pupils' interactions with the tools that have

been prototyped along the study, in a holistic and systemic perspective. How these tools mediatize pupils' activities? What instrumental geneses occur and how do they transform both the artifacts and the pupils' schemes of use? And more generally, how do these act on pupils' activities within the classroom? What are the tensions and resistances generated by the integration of these prototypes? What do they tell us about the co-activity teacher/pupils?

- Through the concept of instrumental genesis, this framework also offers a renewed perspective on the evolution of the artifacts components, linked to its successive instrumentalizations, in a developmental process. In our study, artifacts were designed as conditions of situations, and evolved as successive versions through the several activities of the different persons in the class. This genetic history of artifacts witnesses a situated "instrumental negotiation" between the subjects of the classroom.

Therefore, this framework helps us studying the two intertwined aspects of our research question: the development of pupils' activities with a focus on the artifacts of the classroom situations, and the design principles of artifacts that can foster a transition toward a designerly learning.

2. Case Study

2.1 A Participative Research through Design

We have conducted a longitudinal participative research through design within a French elementary public school, immersed within a first grade classroom with 26 pupils (first grade – 6 to 7 years old). As prescribed by the French educational program, these first grade pupils were learning the basics of reading, writing and counting. In line with a growing researchers' advocacy [23], we worked in tight collaboration with the schoolteacher to transform his instructional way of teaching toward the development of a *designerly learning*. We had two objectives: first, to study the transformation of pupils' activities (regarding their motives, their instrumental mediations, the social impact within the classroom, etc.); and second, to gather insights for design about material and organizational conditions that can support such transition within the current educational system, in a sustainable and transferrable way. As Collins puts it, we aimed to contribute to "a systematic science of how to design educational environments" [8]. One of our challenges was to address the "doubly artificial" [7] aspect of designing within a school setting. As Cole reminds us, "the school classroom is indeed an aspect of the real world, but it is no less designed and artificial" [7]. We see this "doubly artificial" aspect reflected in the agency pupils have to use and act on the designed environmental conditions, and we see this degree of agency as valuable information to assess the authenticity of the making activities. In a transition of the class activities, as we study here, the teacher's scaffolding activities gives us cues about the progress of this transition.

In the following, we report the first six months of this study. During this period, we came to school two to four days a week. In collaboration with the teacher, iterating in short cycles, we took on a hybrid role that evolved from simple observations to full participation, designing tools and scaffolding learning activities. After each session, we would spend two to three hours debriefing with the schoolteacher, and designing the next experiments for the next day or/and iterating on the tools we designed. Over these six months, we designed several tools: most were co-designed with the teacher, some others were made and brought by us without prior mutual discussion. At the beginning, the teacher would continue to engage pupils in "traditional activities", and we would find peripheral moments together to engage a group of pupils in more hands-on learning activities, mainly through media-making. Rapidly, we found ways, through the design of prototypes, to organize these peripheral activities within the classroom context, and pupils would switch from "traditional activities"—mainly scaffolded by the teacher, to small group workshops—mainly scaffolded by us. These workshops built on the "traditional" activities: pupils were invited to explore ways of transmitting what they have learned, in an open-ended way. Although limited in time, these workshops activities impacted progressively and deeply the more traditional class' activities.

From this participative process through design, we present 14 (fourteen) artifacts. They intend to support the classroom's transformation toward a *designerly learning*. They aim at enabling and organizing the engagement of pupils in autonomous and authentic making activities, and at shifting the teacher's stance. Our aim here is to describe the design principles of these artifacts regarding the desired transition. Therefore, we will not describe or assess pupils' making activities *per se*, but present how these activities were supported and organized within the classroom context. We are interested in:









- The instrumental geneses that occur with these artifacts and how they progressively modify pupils' activities;
- The relations of the artifacts with one another;
- Their role in the development of a *designerly learning*.

2.2 Classification of the artifacts

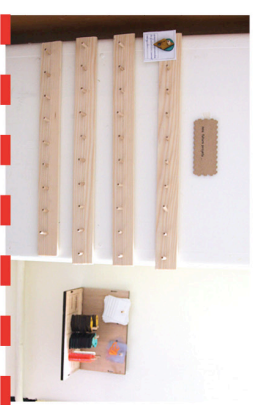
We can categorize the artifacts that we prototyped into four groups, according to their mediational roles in pupil's activities. Note that 1) these category does not acknowledge the chronology of the design process, and 2) most of these artifacts have subsidiary aspects that relate to other categories. The four mediational categories are (see table 1 p.7):

- organization,
- assesement,
- activity tracks,
- and resources management.

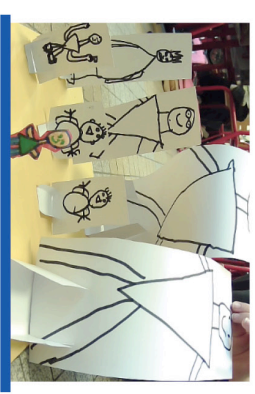
Table 1.
Pictures of some of the prototypes, classified according to their mediational roles.

WHO ?	
	Researcher's designs
	Teacher's & Researcher's Co-designs
	Teacher's designs
	Teacher's & Researcher's Co-designs
	Pupils' designs
	USED ?
	Used
	No Use Observed

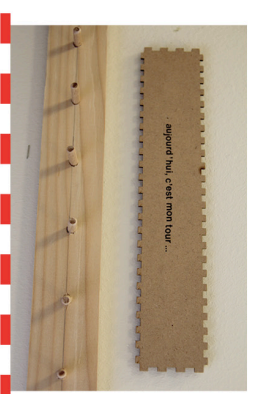
ORGANIZATION



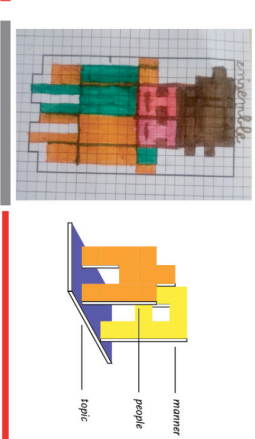
▲ PROJECTS BOARD



▲ PUPILS BOARD

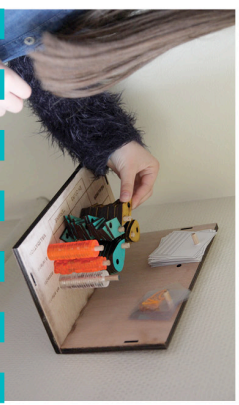


▲ CLASS AGENDA

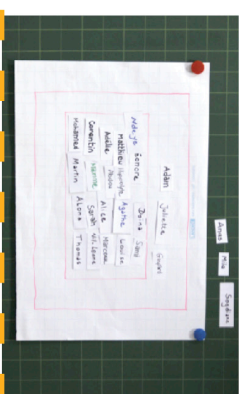


▲ ACTIVITY SIGNS

ASSESSMENT



▲ PROJECTS BOARD

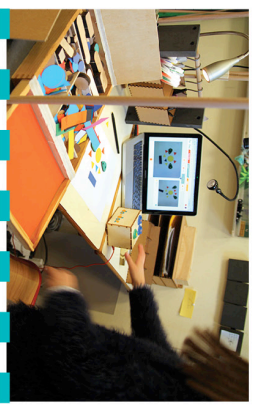


▲ PUPILS BOARD



▲ BALANCE

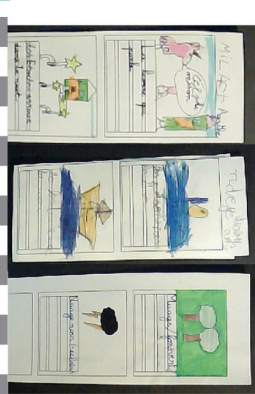
DOCUMENTATION



▲ DIGITAL TRACES



▲ VELCRO BLOCKS



▲ STORY-BOARDS

RESOURCES MANAGEMENT



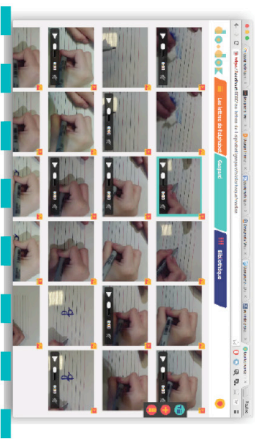
▲ TOOLS & MATERIALS



▲ MOBILE CAMERA SYSTEM



▲ WALLS DISPLAYS



▲ DIGITAL LIBRARY

2.2.1 The Class Organization

In order to enable pupil's autonomy in their making activities, we have experienced the need to establish class rules and to structure pupils' activities over time, projects and people. To support that, we have designed four artifacts:

- **A project board.** On this board, pupils can place a paper with the name of a project they want to do and add little colored wooden pieces to declare the progress of their project (identification of steps, production, validation). Despite our encouragement, pupils did not spontaneously place new projects' ideas on the board, but rather would wait for us (researcher or teacher) to tell them to add a new project on the board. But once the project has started and was visible on the board, pupils would "fill" the progress state autonomously.
- **A class agenda** (daily planner). This wood board displays the projects from the project board, and helps identify the projects that pupils will work on during the day. It also helps prioritize access to the production tools. We observed that the teacher stayed in charge of the daily planning, and pupils placed their project on it when told to do so.
- **A pupils board.** This board identifies pupils' daily roles and mentorship (pupils as resources for others). This instrument was used by the teacher, to daily allocate meta-roles (such as journalist, delegate, provider). We iterated over the design, from nametags on paper (teacher's designs) to characters made out of paper with drawings (pupils' design).
- **Activity signs.** These signs were designed after a collective discussion about the different activities pupils engaged in (brainstorming with the pupils). In this signage system, the activities are represented with three pieces of wood (drawn in a pixel style) assembled as a little sculpture and place on the pupils' table. The first piece of wood indicates the topic of the activity; the second shows the amount of people involved (small group, individual, half the class or the whole class); and the third stands for the way of approaching the topic (manipulations, writing, research, production, etc.) It is an open design for a signage that can evolve according to the new forms of activities that might appear. We have seen the design phase with the pupils, but we have not yet been able to observe its use.

2.2.2 Assessment

The challenge undertaken here is to change pupils' expectations about who can assess their work, and progressively transition to self and peer assessment (instead of teacher/adults assessment). Here, two of the previously described organizational instruments played another major role:

- **The pupils board** can be used to identify pupils' skills, successes, and remaining challenges. The first version of the board with pupils' nametags was actually used by the teacher to place the pupils' names on a diagram: the closer they were to the center, the better they achieved their learning goals, from the teacher's perspective. This was a first step toward making pupils' skills visible to themselves and to the others, which enabled the acknowledgement of other's expertise. Our intention was to go further with the second version of the pupils board and create stamps that could be added to pupils' ID by other pupils to attest their skills.
- **The project board** is used to organize collective critique moments where both the teacher and the pupils comment pupils' projects. The board allows to "note" and to track feedback with additional plastic pieces of different shapes that indicate whether a project has to be reworked or is satisfying. Pupils used the board to remind us to allow time for the class to review their work. They waited excitedly to their presentation to the class and acknowledged the peers' feedback seriously.
- **A balance** (used to teach how to count) would allow to assess group work with plastic pieces. Pupils could use it after small group activities to assess their dynamics as a group by placing the pieces on an axial scale. The balance would reflect how they perceived their collaboration, and enable to discuss and report any problem. (We have not been able to observe its use yet).

2.2.3 Documentation

One difficult but essential component of a designerly learning is to develop a double focal on the mediational means of pupils activities. Therefore, it is important for pupils to document their activity, to reflect on the means they used and how they used them, to achieve their objectives. We encourage this documentation through diverse means:

- **Digital traces** can be captured during their activities via a cross-device platform. This is a way for pupils to keep track of their activities through video, sound, notes of pictures or animations. They can later organize these captures into narratives and share these narratives as ‘process histories’. The capture of traces allows pupils to reflect on their activities at different moments, which enables frequent step-back. Sometimes, a “journalist” was also designated (by the teacher or the researcher) to collect traces for the class during collective activities.
- **Personal and collective journals.** Tracks of pupils’ activities can also be collected on personal diaries (observed, spontaneous) or on a collective notebook (discussed with the teacher, not observed).
- **Woodblocks and storyboards.** Keeping in mind a whole sequence is not an easy thing and often, the beginning of a plan gets lost before reaching the end. To capture this, we introduced two tools: woodblocks with Velcro and storyboard sheets of paper with pre-print squares. Pupils used both at different moments, individually and collectively. Pupils used the Velcro system more spontaneously, which seems to generate more discussions.
- **Collective presentations.** As mentioned, the documentation of pupils’ activities was used to create narratives that were publically presented in front of the class by the pupils. These presentations also invite pupils to find an appropriate way to structure and communicate their whole processes.

2.2.4 Resources

We envision everything in the surrounding environment as a resource to be used and hacked or transformed by the pupils while they engaged in making activities. However, resources organization, accessibility, and hackability have to be facilitated. We have tried to rethink resources management in different ways:

- **Space and furniture.** We made tangible interactive displays with transparent rhodoid sheets that sticks on the wall and can be moved around, and transformed the class’ walls into exhibition walls. Tables are movable and reconfigure the class’ space according to the activities. A clear storage system can be used for the pupils to go autonomously for resources instead of waiting for the teacher to provide things. Pupils came pick what they needed in the storage space without asking, but they would ask us to put a work on the wall. But rearranging the space was something that the teacher would ask that was hard to set, as pupils stayed very attached to their spot.
- **People.** As mentioned earlier, others can represent a good resource and pupils have to acknowledge their classmates as such. The pupil board, in particular, as well as the collective presentations aimed to achieve that.
- **Good practices.** In order to show and share good practices with the whole class, we designed a mobile system to adjust and link a camera or a smartphone to a video-projector. This system is based on the old retro-projection system but instead of showing the teacher’s ‘slides’, it displays the pupils’ way of acting in real time to the whole class. This became a very common thing to do, and pupils would spontaneously propose to show their practices to the class.
- **Tools.** Like in a workshop, tools have to be displayed and accessible. We placed diverse tools and undefined elements (such as tokens, paper forms, stickers, clips...) that can become meaningful while being manipulated, to foster a ‘bricolage’ attitude.
- **Digital library.** In addition to a traditional library corner, we organized all the narratives produced by pupils on a platform that remains accessible at all times and create a class archive that can be consulted inside and outside the classroom.

3. Setting conditions in a systemic perspective

The different prototypes we presented regulate the time, the space and the pupils' activities in the classroom. They embody an open-ended set of rules, for each one in the class to find roles to play, with an understanding of one's possibilities, at a time being. They impacted all activities in the class, and supported the development of new types of activities, both collective or in small groups, such as collective presentations, documentation habits, giving and listening to feedback, brainstorming, bricolage-like activities, etc. As described, these enhanced partly pupils' autonomy and engaged them in deeper explorations, reflective thinking and collaboration. How do these instrument-mediated pupils' activities inform us on the conditions to design to foster a transition toward a *designerly learning*?

3.1 Building a frame

The prototypes evolved from versions of use to new iterations, through design and instrumentalization processes. Each of the four categories of the system took into account and realized the different mediations of the instrumental approach: from the subject with the object of the activity, with the others, and with herself/himself. Organizational instruments allowed pupils to acknowledge and situate their individual activities into a bigger picture of activities. Assessment instruments helped them evaluate their progress on multiple levels, and acknowledge themselves and other's expertise. Documentation instruments supported to record tracks of one's and other's paths, which generated individual and collective memories that the pupils could later refer to. The resources, whether they were material or immaterial, because they were made visible, reachable, and hackable, enabled research-like and creative processes. Pupils generated a great variety of resources throughout these six first months of our intervention.

3.1.1 Relations within the frame

But these artifacts were mutually dependant, and so was their evolution. This longitudinal experience made us aware of how deeply connected these instruments were: a simple change in the design of one of them impacted both pupils' and teacher's activities. In that sense, they compose a "system of instruments" [31], with complex relations between its parts, and which components taken separately do not equal the system as a whole.

For example, using the project's board first made visible the pupil's projects and their progress. But soon, it became important to organize the turn over in the classroom. Later, it helped creating the collective reflective moments, and so finally, it was used to assess and acknowledge pupils' successes and skills. This example shows how the same artifact can be used for different purposes, and how interrelated these mediations are. We also understand how deeply these mediations relate to the others instruments, and form a continuum (the agenda to continue the organization, the digital library to show the narratives, the materials and tools to realize the projects, the story-boards to script the steps, the pupils' board to report skills, etc.).

From this systemic evolution, and following 14 prototypes for 6 months, we saw four interdependent mediational roles emerging progressively (see fig. 2). These represent a frame of conditions to be addressed systemically in order to make possible and organize the desired transition in a classroom setting. We believe this is a valuable frame for designing artifacts that sets the environmental conditions of a *designerly learning* environment. This frame does not prescribe making tasks or processes within the school setting, but rather sets the conditions to design to allow the development of bifocal perspective on mediational means.

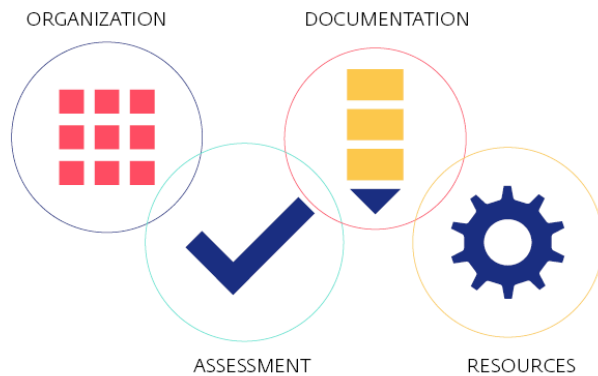


Figure 2. The Frame that emerged from the development of our prototypes within the classroom.

3.1.2 Assessing the development of a *designerly learning*

Coming back to our perspective on designerly learning, making activities are seen as constructive activities characterized by the thoughtful relationships learners develop with the environmental conditions of their learning situations. As a group, we can say that the subjects of the class acted to create new thoughtful relationships with the conditions of their learning situations. Even though, we did not analyze here in detail pupils' activities (scope of another article, in press), the instrumentalization processes (schemes of use with the prototypes) are good indicators that reveal pupils' degree of agency within the "artificial" classroom setting.

Here in this transition process, we perceive tension points, where the teacher still controls and authorizes some of the pupils' activities. For example, this is visible in the use of the first version of the pupils' board, where we see that the teacher is still in charge of assessing the pupils. But, as the frame functions together as a dynamic, the development of collective moments for example, helped to push further the transition toward peer-assessment, and this version of the pupils' board was later discarded. We also note that pupils spontaneously begin to propose new practices (with the camera system, for example) in the class and to inject their own ideas (they brainstormed on the activity sign system). This illustrates that the way the different instruments mediate pupils' activities helps assess the transition progress and makes visible the next steps for improvement. Ideally, these environmental conditions and their instrumental mediations should be continually renegotiated and adapted by all members of the classroom (and even the school) community.

3.2 Limits

At the end of these first six months of intervention, we cannot say that we succeed to complete the transition toward a *designerly learning* in this classroom. Rather, this transition is perceived as a developmental process, and we look for cues and developmental germs. Our prototypes succeeded in this launching or a kickstarter role towards a continuing reflective attitude on the conditions of the classroom environment and their instrumental mediations. We see the frame that emerged from their integration not as a prescriptive framework, but as an incentive toward a shift in our design attitudes: from the design of making activities toward the design of the conditions of making activities. The story of Saint-Exupéry drawing a sheep in *The Little Prince* [32], and ended drawing a box, is in that regard one of the best metaphors of that shift. Our frame is a first systemic approach to help the design of these conditions.

We see a limit in Rabardel instrument-mediated activity model [30], that does not easily allow to extend from the analysis of individual activity to the analysis of co-activities or group activities. We see a great research agenda in extending such model. In our case, the instrumental genesis study would greatly benefit from a finer analysis on the collective aspects of these processes. Combining this with the concept of system of instrument can be a good way to extend it [31].

Conclusion: A frame of possibilities

Engaging pupils—and above all very young children—in authentic making activities is a hard challenge in a classroom setting. Such activities have to be thoroughly structured so that pupils do not get confused or anxious. We consider our system of instruments as a strong frame for freedom, and as a good lever to foster change in general education. Within this frame, anything is allowed. For example, engaging pupils in ill-defined and wicked problems may not be an issue anymore: even though the process is fuzzy and confusing at times, the multiple instrumental mediations proposed by the frame offer pupils with several rebound possibilities, be they social or material. Making activities, whether integrating complex digital technology or not, do not have to deal with setting the whole time-space transformation of the classroom anymore. Thanks to such frame teachers could individualize their teaching, and switch from an instructional stance to a facilitator stance—and even learn with the pupils. Pupils could engage in activities based on their inner motives, and develop a bifocal perspective on the means that mediate their activities. They could also become more creative and adventurous because they are aware and can act on the boundary within which they work together as a group. As for designers, constraints are necessary: they structure—and even enable—design processes.

We see a great research agenda in such instrumental perspective, especially to study the instrumental mediations of digital fabrication tools. In future work, a collective design and research effort should focus on the instruments that compose such frame, taking into account the specificity of each context. Interrelations between instruments could be systematically studied in order to better inform an education transition toward *a designerly learning*.

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