# Instrumented activity and theory of instrument of Pierre Rabardel

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## INTRODUCTION

This chapter starts with the presentation of who Pierre Rabardel is. The rest of the chapter is then devoted to his work and is divided into three parts: in the first part, we outline the theoretical basis of the instrumental approach to psychology used by Rabardel and to which he contributed by developing a generalised instrument theory. The second part presents the concepts that were worked out and developed by Rabardel: the distinction between technical objects, artefacts; the instrument, a mixed entity; the instrumental genesis; the instrumented activity in the instrumented action. The chapter concludes with an example of how the instrument theory is used to analyse a teaching situation focused on designing a product through easily recognisable and analysable lines of action.

## PIERRE RABARDEL, A PSYCHOLOGY RESEARCHER

Pierre Rabardel is a French teacher-researcher specialising in psychology and ergonomics. Today, he is Honorary Professor at the University of Paris 8. He was successively: a university lecturer at the Conservatoire National des Arts et Métiers (CNAM), a research officer at the Institut National de Recherche Pédagogique (INRP), and then a University Professor at the University of Paris 8. During his career, he was in charge of different national and international research teams and several research networks. He founded and led the research team C3U (Conception, Création, Compétences et Usages) that is part of the Psychology Department of the University of Paris 8.

His work covers the relationships between humans and technical objects and technical systems; the instrumental genesis and the cognitive development of subjects. He has been interested in the instrumented activity and in the processes that enable subjects to act and complete a task. He has conducted numerous research studies in professional life and expanded his research to teaching and learning in a school context.

His favorite themes relate to new forms and modalities of application in business; risks and health at work; the increased ability to act; the instrumental approach in ergonomics, psychology and didactics. He has published several books and taken part in many collective works.

## THE INSTRUMENTED ACTIVITY: THEORETICAL FRAMEWORK

### *The anthropocentric approach of technical objects and systems*

Rabardel calls for an anthropocentric approach to technical objects and systems as a complement to purely techno-centric approaches. He considers technological objects and systems as anthropological facts in the sense that man occupies a central place, which determines the relationships to techniques, as defined by Simondon (1958/1969/1989) and Leroi-Gourhan (1971/1985/1991). The omnipresent technical objects and systems generated by technologies constitute a large part of the world in which we live. They are at the heart of our concerns and, hence, cannot be comprehended on the basis of the technologies alone that created them. These technical objects and systems are anthropocentric because they are in response to a human need, designed and made in a human environment. In ordinary life, humans are ubiquitous throughout the life cycle of these products. Therefore, the relationships humans establish with these systems in this life cycle must not be neglected. On the contrary, these relationships must be thought out and conceptualised so that characteristics and properties to serve humans can be understood and organised. But these relationships need also to be understood and conceptualised, since they are at the center of the relationship between cognition and action that contemporary psychology studies.

Technical objects and systems do not involve just technical aspects and should not be considered from a technical point of view only. They must also be examined from the point of view of the people who use them, and be designed as such. This option places human activity at the heart of the analysis, and thus enables the necessary reversal so that it becomes possible to consider things according to humans (Rabardel, 1995). For this author, human, task and artefact form a whole which is driven by the intentional acts of the subject and which is directed towards a result.

### *The social constructivist theoretical definition of the activity*

Rabardel has drawn on the seminal work of Lev Vygotski that preceded activity theory: (Engestrôm, 1990; Léontiev, 1976; Rabardel 1995; Kuutti, 1996; Kaptelinin, 1996; Nardi, 1996; Wertsh, 1997; Wertsh, 1998; Clot, 1999; etc). In this framework, activity is defined as the logical temporal and spatial organisation of the actions and operations that aim at reaching a conscious goal. In other words, activity is an object. The purpose of the activity leads, directs and guides the activity of the subject towards its reason, its completion (Bedny and Meister, 1997). In summary, activity has a social and cultural dimension. It is mediated by artefacts; mediations are, thus, semiotic.

*Social and cultural dimension of the activity*

To explain work as a human activity appropriate for a specific purpose, is not to simply say that it finds its origin in the goals and problems faced by humans. Work, as an activity, results from the use of tools and original ways of thinkink without which the artefact could not have been made (Vygotsky, 1997, p.198). Activity is expressed through goals and through means. Activity is determined by the associated milieu in which the subject acts (Simondon, 2017). The milieu is seen from both a material and social perspective. In this framework, human activity is a complex dialectic process which "is internal to individuals but external in nature" (Seve, 1999, p. 258), the tool being at the heart of the activity. In other words, activity both depends and evolves in the milieu and with the milieu. For Vygotsky subject activity interlace evolution and involution processes, intercrosses internal and external factors, is made of successive adaptations and victories over difficulties (1931/1983; p.136).

*The role of instruments on activity*

In this complex social-constructivist process, the role of psychological and technical instruments (tools, techniques and signs), as part of the socio-cultural heritage, marks the transition from basic activities to higher mental activities. The subject learns, conceptualises within the instrumented action scheme. Two types of instruments coexist in the instrumental act. The psychological instrument differs fundamentally from the technical instrument with regard to its action orientation. The first one addresses mind and behavior, whereas the second one is designed to obtain a certain change in the object itself. The psychological instrument does not cause any change in the object itself; it tends to influence one's own mind (or the minds of others) or behavior. It is not a means of influencing the object. Therefore, in the instrumental act, activity is seen as being directed towards oneself, and not towards the object (Vygotsky, 1931/1978). At the level of the cognitive development of the subject, practice, use of signs and intelligence operate together. The subject learns; the learner is an epistemic subject.

*Instrument - objects under development*

The instrument is an intermediate element that exists between human activity and the purpose of the activity. To take it over, the subject transforms the instrument and makes it evolve. It is an object under development (Leontiev, 1975, 1981; Cole, 1996). When a subject use a technical system, for example a computer system including the 3D printer, the subject develops a new set of competencies.

*Cognitive processes mediated by instruments*

All higher psychological functions are mediated processes, which include, as part of their structure, the use of signs as a fundamental means of orientation and mastery of psychological processes (Vygotsky, 1997). The subject's cognitive process takes place thanks to the semiotic mediations produced in the context of interactive exchanges, through the transformation of the social and communicative function of signs into an individual and intellectual function. In other words, the appropriation of the instruments (technical tools and signs) that marks the transition from basic activities to higher mental activities happens through the transformation of the interpersonal processes into intra-personal processes.

The tool is oriented towards the transformation of objects. It is externally oriented. The sign is a mean of internal activity. It is internally oriented. The tool acts as a sign, and as a sign of action. Tool is sign. It has a dual nature, it is an object involved in action and an action framework. The instrumental approach is semiotic. The link between object and sign is inconceivable without the interpretive mental scheme (which relates to concept, meaning, interpretation grid).

Behind the socio-constructivist vision of the instrumented activity, the instrumental act reveals the complexity of interactions where instruments are at the heart of the cognitive process.

## TOPIC ON, WHICH RABARDEL FOCUSES

Rabardel's theoretical framework mixes the scientific findings of the activity theories. He goes back to the anthropological approach in psychology that recognised the fundamental role of language mediation.

His studies report on the status of the instrument and on the activities it is linked to. They focus on the aspects that appear to be relevant in an instrumental perspective so as to develop a generalised conception of the instrument (Rabardel, 1995). As a central issue of the activity, Rabardel raises the question of the means and associates the instrument with all levels of cognitive functioning. The means are on one hand psychological instruments (as defined by Vygotsky, 1930/1985; 1931/78; 1934/1985). They enable the subject to control and guide its behavior, in other words, they enable the subject to act on itself and others in action. On the other hand, instruments are made up of instruments that have emerged from production technologies and modes that determine action; here, activity is oriented towards the world of objects.

Rabardel's generalised conception of instrument opens up to the fields of work, education and daily life. His conception is based on several fundamental concepts: the artefact and the instrument he links with their functionality, the artefact's instrumental field, mediation, instrumental genesis and social utilisation schemes, situation.

Rabardel's model of instrumented activity breaks with the bipolar models Subject----Object. It provides space for a mediating element: the instrument. (Figure 1)

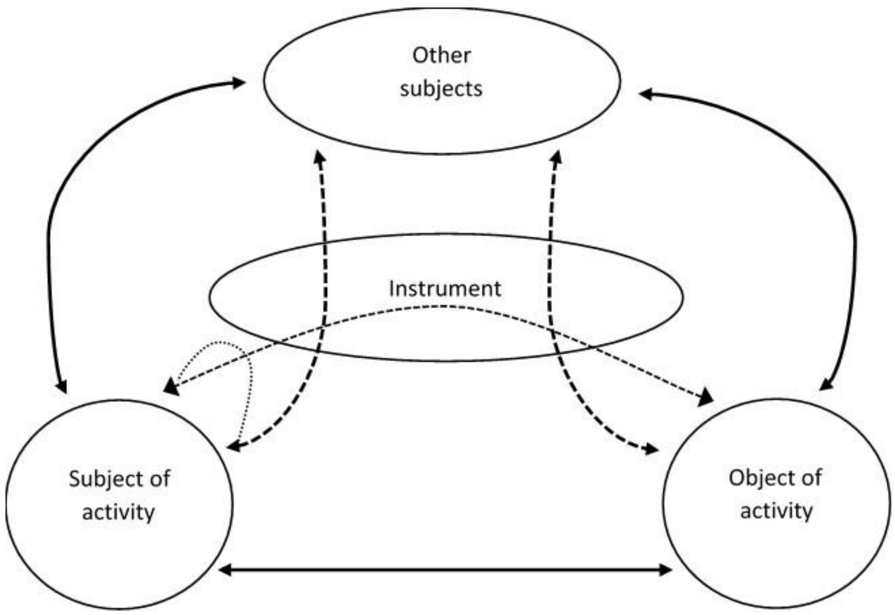


*Figure 1: Rabardel's model of instrumented activity, 1997.*

The arrows represent three types of mediation in the instrumented activity: mediations, which are directed towards the object of the activity (they are object mediations). Mediations are directed towards the other subjects (interpersonal mediations) and towards the subject itself (reflexive mediations).

*Mediation*

The use of artefacts can mediate the relationship of the subject with the object of the activity, with itself and with others. Practice carries three types pf mediation: object mediations are epistemic and pragmatic in nature. They are epistemic when they aim at getting to know the object, whether it is in relation to its intrinsic characteristics or its changes following the subject's actions or the dynamics of situations. They are pragmatic when they aim for the subject's action. Interpersonal mediations relate to activity directed to other subjects. Like object mediations, they are epistemic and pragmatic in nature. Reflexive mediations are the mediations established by the subject with itself in relation to the instrument. The three types of mediation are involved in the activity; however, some types of mediation are more prevalent than others or absent (Rabardel & Bourmaud, 2003; Flocher et Rabardel, 2004; Rabardel, 2005; Rabardel & Pastré, 2005 ;).

*Distinction between artefact and instrument*

The terms “object, artefacts, instruments tools” are used in the scientific literature with different meanings. Rabardel clarifies the meaning of each of these terms (1995, 1997a; 1997b). He makes a distinction between the physical object and the physical object which is used. To distinguish them, he introduces the concept of instrument.
The tool, which is called artefact, is a material and symbolic subject. It is firstly designed and produced by a person or a team of people so as to meet one or several precise goals. The artefact is a term that comes from the anthropological vocabulary. The artefact can be material or symbolic. The subject or other subjects produce it. The artefact when associated with the act that makes it effective, is the instrument. It is one of the instrument’s components. The notion of artefact makes it possible to think out the relationships between the Subject and the physical or semiotic Object. The instrument results from a use. The subject builds the instrument from the artefact when using the artefact during an activity. The instrument is not “given”. It must be built by the subject. The instrument can be enriched according to the way it is used, in the specificity of the situations encountered by the subject in its activities (Rabardel, 1995).

The instrument is a mixed entity linked to both the artefact and the utilisation schemes the subject associates with it. Schemes can result either from the subject’s own construction or from the appropriation of the social utilisation schemes. Regardless of their source, they are considered as utilisation schemes by Rabardel. In other words, the instrument is being built as the artefact is being used. The instrument has two dimensions: an artefactual dimension and a schematic dimension. The artefactual dimension of the instrument consists of constituent functions and constituted functions. The constituent functions, which are initially designed and planned by the tool designer, are changed into other “new” functions. In other words, during the process of using the artefact, sometimes the constituent functions are not used by the subject who makes a particular use of the artefact. The particular use of the artefact means that the subject has created new functions that are called “constituted functions” by Rabardel. The (new) constituted functions are created as the artefact is being used. Both are associated and work together. Both are not neutral and will have an impact on knowledge under construction and its conceptualisation. They depend on the way the user will use an artefact, and on the cognitive structures he will build and develop (utilisation schemes) to carry out a task when using the artefact.

*The instrumental field of an artefact*

The artefact’s instrumental field corresponds to all functional and subjective values that the artefact can have within the activity of an individual (Rabardel, 1999). It gathers the different meanings that an artefact can have for a subject when action is ongoing.

The instrumental field concept allows reporting on the level of re-use of the artefact a posteriori.

*Instrumental genesis*

The search for understanding of the evolution of artefacts according to the user's activity and the emergence of new uses as part of the same instrumental building process has led to the concept of instrumental genesis used by Rabardel.

Instrumental genesis describes a process, which involves both the artefact and the subject. The user develops the instrument from the artefact during the activity in the process. The instrumental development concerns, on one hand, the tasks carried out by the user and the reorganisation of its activity, and on the other hand, the transformations of the artefact and the evolution of the activity which accompanies these transformations (system tailoring) (Cook & al., 1996; Cook, Harrison, R., Lehman, M. M., & al., 2006). The instrumental genesis process corresponds to a type of activity carried out by the subjects placed in a position of action vis-à-vis the artefacts. The generated activity is sufficiently constant and generalised to allow the subject to start anticipating the evolution of the artefact. The process described has to be analysed from an ergonomic point of view (analysis of the contexts and situations, of the potential events and schemes that are available or that can be built). It also has to be analysed from a psychological perspective by referring to the subject who pursues goals in the action.

The process of instrumental genesis has two dimensions (as the instrument). It comes from both the artefact and the utilisation schemes. Both dimensions can be distinguished and are often joint: the instrumentalisation directed towards the artefact and the instrumentalisation related to the subject itself.

During the instrumental genesis, a dual movement happens between the artefact and the subject:

- Instrumentalisation (movement from the subject towards the artefact): the user adapts the tools to his/her needs; thanks to his/her knowledge, he/she will be able to select and use the function she/she needs for the ongoing action. This process is based on the characteristics and intrinsic properties of the artefact. It can be defined as a process for the enhancement of the artefact's properties by the subject. New functions can emerge that are not necessarily anticipated by the artefacts' designers (catacresis: for example, using a wrench as a hammer).
- Instrumentation (movement from the artefact towards the subject): the constraints and potential of the artefact influence and condition the action of the individual (its representations, its gesture, its procedures, etc.). The user changes its activity, its action and utilisation schemes so as to use the tool's functionalities. Schemes are constructed by the subject based on his/her experience, and allow him/her to act on the reality. The gradual discovery made by the subject of the intrinsic properties of the artefact is associated with the accommodation of its schemes and with changes of meaning of the instrument resulting from the association of the artefact with new schemes. We observe that schemes do not have only a private dimension, but they also have a social dimension as they partly result from a collective process. The study of the schemes helps explain the processes underpinning the activity, in particular the subject's conceptualisation of reality.

Both the modifications of the artefact and of the subjects allow the instrumental genesis. The instrumental genesis addresses on one hand the subject that changes during the instrumentation process, and on the other hand, the artefact that changes during the instrumentalisation process.

The constituted instrument is linked to the unique circumstances of the situation and to the conditions faced by the subject.

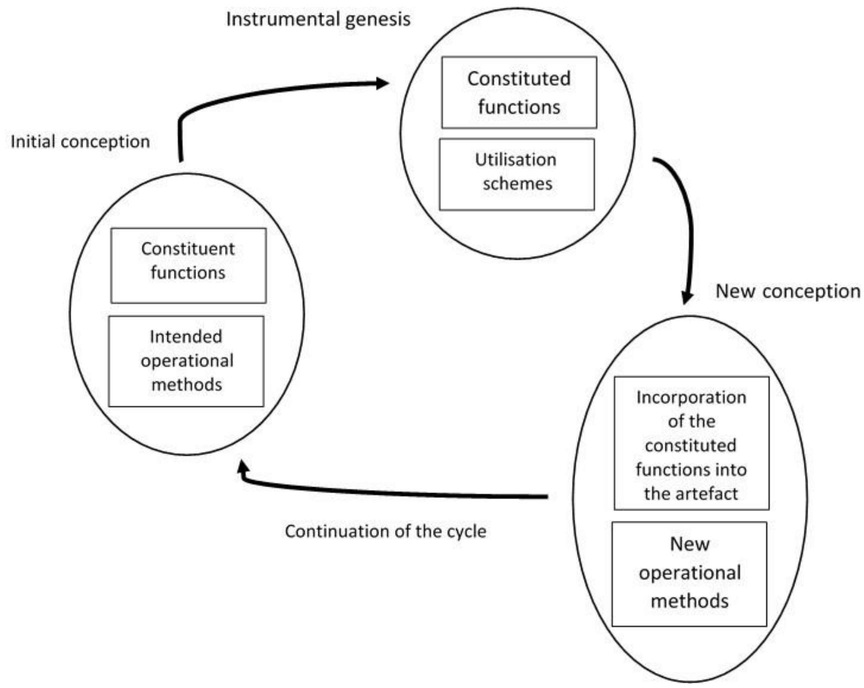


*Figure 2. Instrumental genesis process, Rabardel, 1995.*

The instrumental genesis process is of varying durations. In this process, several types of schemes appear. Social utilisation schemes are at the same time "organising" the activity in the sense of Vergnaud (1991; 1996), but also "acting as a structure" that has a history, that changes as it adapts to situations (past, lived experience) so as to interpret new data (Béguin & Rabardel, 2000). These utilisation schemes refer to the interaction of the subject with the artefact. They have a private dimension that is proper to each subject, as well as a social dimension that has developed between the subjects. Instrumented action schemes are directed towards the object of the activity. To reach the objectives pursued, these schemes refer to utilisation schemes. They carry the activity's meaning. Schemes for collective action that have been instrumented in reference to the use of artefacts by several subjects', function simultaneously or jointly.

*Situation, types of situation, organisation plan of the activity*

Action is oriented towards a goal. Reaching this goal depends on social circumstances and material resources (Suchman, 1987). The activity mediated by the instruments is always situated. It depends on the situations. The situation defines the context of the action. It is organised according to the main type of activity which depends on the subject's action, in other words, which depends on the way the subject's activity is organised. The families of activity gather types of situations having the same general aim. The families of activity are organised on higher levels than the types of situations. Areas of activity are organised around the characteristics of the environment or according to other factors (Rabardel & Bourmaud, 2003) and constitute activity organisation plans.

## THE 'PRACTICAL' USE IN TECHNOLOGY EDUCATION

Rabardel's instrumental approach is very often used for research in France. It is used less frequently in other countries. This is due to the fact that not many people read publications written in French. In technology, this approach is justified by the fact that the tools on which it is based are the components of the learning environment (Andreucci *et al*, 1996). The approach provides a certain number of analytical tools which allow one to study the activity of the actors (teachers and students) who are placed in a project situation (design of objects and technical systems, analysis of technical systems, use of technical systems) that are characteristic of technological education. These tools support the study of the construction of complex knowledge, for example, the conceptualisation of materiality from a technological perspective. This is a concept too often studied from the perspective of the physical sciences and chemistry (Chatoney, 2003). They may also support the activity of students placed in project situations which require the use of: calculators (Trouche 2005); Tableur (Haspekian 2005); educative resources' (Contamine, George & Hotte, 2003); dynamic environments' (Zanarelli, 2003) or CTBT (Brandt-Pomares & Boilevin, 2009; Laisney & Brandt-Pomares, 2015).

As a further example, we will examine the design activity as the object of an actual learning-teaching situation in France. It concerns students aged 14-15 years old. This study, which is based on a research project aimed at studying the role that 3D printers have on the students' abilities to develop solutions in a school context (that is to say in the presence of other subjects; students and teacher). This research project was conducted in 5 schools in the South of France and involved a sample of 270 students and 5 teachers. We will limit our discussion to the development of solutions, as proposed by the teacher, to design a protective cover for a smartphone and on the role of the material artefacts provided, in order to achieve the task. We will examine the situation using the concept of an instrumental approach, which will demonstrate how Rabardel's theoretical framework assists us to understand the reality and to identify the structure of the instrumented activity.

To understand the instrumented activity, we will use different tools to analyse the task. Preliminary analyses of the task and of the activity will enable us to identify the knowledge that is needed for the task, and then to define the space for possible solutions. The analysis of the outcomes reveals the way pupils seek solutions. They allow us to know more clearly, how the introduction of a 3D printer influences the creative process that students utilise in order to design objects. The analysis of the instrumented activity was carried out on the basis of the relevant areas identified by Rabardel: (subjects, object of the activity, artefact, mediation, structure of the activity), which highlight the interactions between subject-object-technology, which in turn, allow the subjects (teachers and students) to act, learn and conceptualise.

*The task: Developing solutions*

Developing solutions to problems is an activity that is very common in technology education. It happens at all teaching levels according to curriculum and institutional requirements. In middle school, where students are aged 14-15 years old, the requirements state that students should develop creative, aesthetic, functional, technical, scientific and technological design skills.

The task, as discussed above, consists of designing a protective cover for a smartphone using a 3D printer. The students were provided with some initial specifications for the protective cover, traditional drawing tools (paper/pencil), a CAD program (SolidWorks© or Google Sketch Up©) and a 3D printer.

The teacher's guidance is necessary in the beginning to provide the specification for individual students to produce pencil sketches for the design of a smartphone cover. After collective discussion the students choose the most appropriate solutions. The students then transfer the selected drawing onto the CAD program.

The computer model produced by students is then discussed and altered if necessary before printing on the 3D printer. Each stage is a determinant of the task. All the feedback between subjects (individual and collective) and objects (their designs) informs the next stage and leads to the emergence of a solution.

In this situation, students have to choose the form, the dimensions, the structure and the used materials available at school. To achieve and finalise the task, they must use knowledge related to the physical characteristics of the materials and their forming processes, as well as procedural knowledge related to the use of traditional drawing tools and CAD tools. They must think out, invent and propose solutions using the representation resources and tools that are available to them. They must also take into account the constraints of the technical guidelines; knowing that there is, in principle, no formal specified procedure, that could give a universal solution to this type of design problem, and allow its actual conception.

*Subject and object of the activity*

Subjects involved in the development of the protection covers for a smartphone were, in the first place, the individual students who looked for solutions, in the second place, the teacher who accompanied the student's and in the third place, the other students who were present and who actively took part in the activity that was sometimes undertaken as an individual activity and sometimes as, a collective activity.

The instrumental approach invites us to distinguish between the subjects of the activity and the object of the activity in the project. Table 1 below details this:

*Table 1. Object of the activity depending on the subject*

| | Phase 1 | Phase 2 | Phase 3 | Phase 4 |
|---|---|---|---|---|
| Object of the student's activity | Getting familiar with specification and drawing protection covers | | Drawing one's model using CAD software and saving it | |
| Object of the students' activity | | Reviewing sketches, reformulating specification Drawing further protection covers | | Making the last adjustments on the existing graphical model, printing, making adjustments, printing |
| Object of the teacher's activity | Encouraging students to develop graphical tools | Reviewing sketches, encouraging students to reformulate specification Encouraging students to develop further graphical tools | Encouraging students to use available CAD tools, to save regularly the modelling traces, to make adjustments on their models | Encouraging the student to print his/her model Encouraging the students to make adjustments on their graphical tools |

The students must "effectively" seek a solution to the problem raised by the teacher. Effectiveness is not automatic. Some may wait for the solution to be found by another student; some may completely disengage from what goes on in the classroom; or prepare for another class.

The teacher accompanies the students' research work. To do this he let students act freely, either he guides them to the solution. The object of his activity is not given. Now it's necessary to question and observe the subjects to understand the nature of their activity. Indeed, a similar type of action may be undertaken by the objects of a different activity. Therefore, the object of an activity that the technology teacher teaches, and the way that an artefact is designed to middle-school students, can vary according to the teacher, the students and the situation itself. The first goal of the teacher may be to find ways to have the students come to a solution and achieve a material result (a printed protection cover for example) for each student or group of students. However, this does not exclude other objects of the activity, such as developing the creativity of the students by letting them: test solutions that in principle won't work but that will participate to the research process, and perhaps not produce an outcome with all students. This list is open and must be instantiated, through obtaining the point of view of the subject of the activity.

*Artefacts and mediation*

The written, graphic or material outcomes of the activity of the students (workbook, documents, drafts, notes, sketches, object…) are artefacts that are easily identifiable in the teaching-learning situation. These artefacts mediate between what preceded and what will follow, and transform the students' activity. Students' feelings, ideas, thoughts are being expressed in these artefacts. In this case, the outcomes of the activity are graphic (manual sketches), digital (3D models) and material (printed protection cover).

To study the variety of the students' work, we distinguish three notional fields defined by Rabardel & Vérillon (1987) and Rabardel (1989): geometry, technology and code. Geometry allows thinking out the forms of the represented protective cover for a smartphone; technology allows thinking out the characteristics of the material (in this case plastic), the movements related to the constituent parts, their structure and the functions of the forms; and finally, code interacts with the two previous notional fields by combining both the significant and the signified. From this perspective, all written and digital traces as well as prototypes made using the 3D printer will be collected and analysed.

Table 2 shows the indicators that have been taken into account for analysing solutions with regard to the notional fields related to two functions of the specification (for instance).

*Table 2. Solutions' analysis indicators*

| Function (CDC) | Notional fields | Form | Structure | Materials |
|---|---|---|---|---|
| Protecting the smartphone from shocks of normal use | Geometry | | | Maximum thickness |
| | Technology | Breakable areas of the Smartphone that need to be protected<br>Shock absorption<br>Attached to the Smartphone | Shock absorption<br>Number of parts<br>Mobility of pieces | Mechanical properties<br>Shock absorption (ABS) |
| | Code | 2D/3D graphical representation | | Texture |
| Adapting to smartphone | Geometry | Complying with the Smartphone's dimensions | | |

| | | | | |
|---|---|---|---|---|
| without damaging it | Technology | Get in place and easily remove from the smartphone | Number of pieces<br>Mobility of pieces | Mechanical properties (flexibility, roughness) |
| | Code | 2D/3D graphical representation | 2D/3D graphical representation | Texture |

The analysis of the traces of the students' activity shows that the "swift transition" from the 3D digital model to the material manufactured object supports the modelling phase, the integration of the technical guidelines' constraints and contributes to seeking solutions on a wider and more varied scale than when using manual sketches.

The table below shows the number of solutions developed by the students, according to the tools used and the different phases of the design process, from the first sketches to the 3D printings and potential redesigning.

*Table 3. Solutions developed by students*

| Sketched solutions | Modelled solutions | Printed solution | Redesigned solutions |
|---|---|---|---|
| 250 | 120 | 51 | 2 |

The tables 4, 5 and 6 below present the results obtained from the analysis of the intermediary graphs produced by the students during the process of seeking a solution. They allow comparing the solutions developed using sketches (phases 1 and 2) and the 3D modeler (phases 2 and 3) which correspond to the exploration, generation and modelling phases.

In terms of «form» (Table 4), there is no significant difference regarding technology. However, one can see strong differences regarding geometry and code, which can be attributed to the specificities of the tools used, as for example, the small proportion of quoted sketches (6%) whereas the establishment of digital models requires oversizing.

*Table 4. Results in terms of "form".*

| Form | Sketches (n = 250) | 3D Models (n = 120) |
|---|---|---|
| Geometry | | |
| Lack of quotation | 57 % | 0 % |
| Partial quotation | 37 % | 0 % |
| Full quotation | 6 % | 100 % |

| | | |
|---|---|---|
| Compliance with the smartphone's dimensions | 85 % | 78 % |
| Compliance with the 3D printer's dimensions | 90 % | 78 % |
| Technology | | |
| Full protection of the Smartphone | 88 % | 96 % |
| Protection of the breakable parts | 12 % | 4 % |
| Volume optimisation | 11 % | 7 % |
| "Innovation" | 21 % | 11 % |
| Code | | |
| 2D | 46 % | 0 % |
| 3D | 54 % | 100 % |
| Textual information | 36 % | 0 % |

Regarding "structure", (Table 5), there are significant differences between the outlined solutions and the modelled solutions, in terms of both geometry and technology. The range of solutions developed by the students is wider, which enables the student to explore on a wider scale, the space of the problem raised. When using the 3D modeler, solutions focus exclusively on a unique piece with an envelope-shaped structure. These results confirm the results of Laisney & Brandt Pomares (2015). Thus, one can see a greater variability of solutions when students use traditional drawing tools (manual sketches) than when they use a 3D modeler.

*Table 5. Results in terms of "structure"*

| Structure | Sketches (n = 250) | 3D Models (n = 120) |
|---|---|---|
| Geometry | | |
| "Clutch bag" | 12 % | 0 % |
| "Envelope" | 76 % | 100 % |
| "Skeleton" | 8 % | 0 % |
| "Valve" | 4 % | 0 % |
| Technology | | |

| | | |
|---|---|---|
| 1 piece | 94 % | 78 % |
| 2 pieces | 5 % | 0 % |
| 3 pieces | 1 % | 0 % |
| Pieces mobility | 4 % | 0 % |
| Shock absorption | 4 % | 4 % |
| Complementary functions | 24 % | 11 % |
| Code | | |
| 2D | 46 % | 0 % |
| 3D | 54 % | 100 % |
| Textual information | 26 % | 0 % |

In terms of "materials" (Table 6), here again the observed differences concern the specificities of the tools that promote the integration and the definition of the used materials or not. 95 % of sketches do not define the nature of the materials, even if the represented solutions use different pieces requiring physical or mechanical properties adapted to their functions. Using the modeller allows students to represent more easily the materials thanks to the tools "colour" or "texture".

*Table 6. Results in terms of "materials".*

| Materials | Sketches (n = 250) | 3D models (n = 120) |
|---|---|---|
| Geometry | | |
| Absence of definition | 95 % | 33 % |
| Defined materials | 5 % | 66 % |
| Technology | | |
| 1 material | 88 % | 100 % |
| 2 materials | 12 % | 0 % |
| "Innovative" materials | 3 % | 0 % |
| Code | | |
| Absence | 95 % | 33 % |

| | | |
|---|---|---|
| Colour | 2 % | 44 % |
| Texture | 3 % | 23 % |

In terms of forms and structures, one observes a wider variability of solutions developed during the exploration phase using sketches and a smaller variability of prebuilt solutions. Indeed, many sketched solutions are dropped during the modelling phase. The choice of materials is not discussed as it is forced due to the 3D printing process, which imposes fewer constraints and does not require as much knowledge of the manufacture and choice of materials as traditional processes using machine tools. This can have the benefit of making it easier for students to explore all the possible solutions to the problem raised: students seem to have more freedom in the exploration phase (fewer constraints linked to the forms and materials).
However, students face difficulties during the modelling phase. These difficulties that have already been mentioned in our previous study (Laisney & Brandt-Pomares, 2015) are due to the fact that students are dealing with a double challenge. This challenge consists, on one hand, in using a complex software that they may not necessarily know very well, and on the other hand, in solving the design problem. At last, students rarely benefit from the back and forth movement that 3D printers are supposed to make possible given that the teacher does not favor this practice, which is expensive in terms of organisation. In consequence, there is little or no redesign after 3D printing, which does not encourage the process of seeking a solution.

*The productive activity: completing the activity*
From the artefacts' side: traditional drawing tools and the 3D pattern making software (Google SketchUp) are artefacts that have been identified initially. Each student represents (draws) a possible solution to the problem raised, with a possible variability. The software is a necessary artefact for modelling and then piloting the 3D printer, whereas the use of traditional drawing tools (free hand drawing with paper pencil) is variable. Observations may reveal that students are more comfortable drawing by hand, producing sketches using a paper pencil. After that, when they need to model it on the screen using a software, one notes that some of them do completely drop traditional drawing and others adjust their drawing as they conduct modelling. The utilisation patterns of a pencil to draw on paper have been constructed and used by students before attending primary school, and are not the same patterns as those that allow screen modelling and that are still in construction and require to be instrumented. Some students' drop traditional drawing in favor of software, others do not manage to model their sketches and get back to traditional drawing, and at last, others use both representation tools to develop their solutions.

*The constructive activity: developing the subjects' activity*
From the teacher's side: one notes that the use of 3D printers radically transforms the teacher's activity, in comparison with the use of numerically controlled

machines. Even if, in both cases, these hardware devices are connected to a computer network which ensures continuity of digital information from sketches to final manufacture (production tools), the 3D printer and its short prototyping process allow considering further uses. It contributes to improving the design process (search for solutions) as it allows more frequent back and forth movements between the digital model and the material model (printed object), which fosters validation of an object's form or function.

From the student's side: one notes that 3D printer allows a "swift transition" from virtual (digital model) to real (printed object), which helps students to conceptualise shape and structure constraints, and beyond this, to consider the transformation of the digital model with the aim of redesigning the object and deepening his/her search for solutions. Thus, this new artefact transforms the activity of searching for solutions carried out by the student who does not use it only as a means of production but also as a "quick" testing tool that is under construction in an iterative process.

This example reveals that when artefacts change or, as we have just seen, when introducing new artefacts, the subject's activity evolves, changes and causes an invariant modification of the activity. The subject's productive activity changes (instrumentalisation process) but this assumes a constructive activity (instrumentation process) through real instrumental genesis.

## CONCLUSION

This chapter gives us the opportunity to present the theoretical and methodological contributions of Rabardel's instrumental approach and to illustrate its use in school context. Interest is twofold. On one hand, it focuses on relevant aspects with a view to instrumental study of the link that exists between a subject and an object through a technology that places practical intelligence on the same level as other forms of intelligence. On the other hand, Rabardel provides a series of tools to analyse this link, notably in school context in which, as we know, activity is directed towards a purpose and determined learning goal. In a specific context in which activity is strongly instrumented and focused notably on issues relating to knowledge mediation and knowledge construction by students, this allows for cognitive development and capacity for student to act.

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