FROM TRIZ TO TECHNICAL CREATIVITY TEACHING

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ABSTRACT
This paper presents a reflection on a teaching module on creative design in mechanics. Primarily based on the teaching of TRIZ tools, it evolved towards technical creativity (creative design) to which TRIZ presents both commonalities and differences. Several issues are discussed.
The first concerns meta-cognition. It plays a specific role in creative design since it is both an objective necessary to adapt and pilot the design process for and a means to learn it.
A second issue concerns the teaching means. We adapted them to the specificities of creative design concepts and tools, whether they are explicit and / or conflicting.
The third issue is the structuring of the learning process. In this module, we try first to give students multiple and varied sources of information on design - sometimes conflicting - including they own preconceptions and the experience they gain through a project. Second, students are encouraged to discuss their design knowledge with their peers and teachers; and a reflection on projects is imposed on them at the end on the module.
Finally, the nature of the relation students have with their teachers and with knowledge is also considered. It affects the teacher's roles and the attitude we show towards our knowledge.

Keywords: TRIZ teaching, technical creativity, meta-cognition, project based learning

1 INTRODUCTION

For engineering design, creativity is recognized as a valuable skill. But its introduction as a learnable objective in design curricula suffers from the common vision of creativity as either an innate characteristic or an inspired process using reasoning modes that can hardly be controlled such as analogy. Instead, engineering design education in France has valued more formal methods such as systematic design [1], and tools such as Value Analysis.
When it appeared by 2000, TRIZ - a Russian acronym for Theory of Inventive Problem Solving TIPS [2, 3] – was seen as a structured and controlled creative method. Its initial objective was to direct creative problem solving by the specification of formal methods. It includes tools for analyzing and solving identified technical problems. It also includes original tools for analyzing the way systems works and how they fail to be "optimal", contributing to problem identification. In practice, TRIZ is also a "world" made of consultants, with large experience gained through many case studies. Their competences go far beyond formalized knowledge and methods. They require building action plans, choosing TRIZ tools and adapting to project constraints and specificities, which is meta-cognition or reflection in / on action. It also requires coordination and knowledge management capabilities. Since it appeared in our country in 1998, its teaching has been included in many schools training engineers (master's degree), in bachelor's degrees, and even in some undergraduate programs since 2010. It is classically seen as a complement to traditional design teaching. Its teaching reflects its position relatively to design: a useful but not integrated method. This situation generates misunderstandings and reticence to use it. Moreover, if the use of some tools can relatively easily be taught, what relates to meta-cognition is very poorly addressed.
To teach TRIZ in design, several stakes have therefore to be addressed. Meta-cognition is the first one. The inclusion of TRIZ inside creative design must also be questioned since, up to now, it is relatively dissociated from existing knowledge on design. As a consequence, the adaptation of teaching means and the design and management of the learning process must be addressed.

2 TRIZ VERSUS INNOVATIVE DESIGN: COMMONALITIES AND SPECIFICITIES

Making differences between TRIZ and innovative design is delicate as it depends largely on the definition one can give to design.

Inspired by the visions of Simon [4] and Schon [5], and Gero's model [6], we have developed a vision of design from a cognitive perspective [7]. Three levels are considered with reference to activity theory [8]. At the lower level, operations are defined. Design is seen as the building of a set of parameters linked by rules, distinguishing means from effects. The use of logical operators is fundamental: deduction and abduction, to which one must add evaluation. At this level, design is considered to be the co evolution between the structure of a product and its "functions": behaviours, functions, needs or affordances [9]. To fulfil functions, designers imagine, define and choose structural features such as matter, shape, dimensions, links between components and bill of materials / choice of components.

At an intermediate level, actions are defined. An action can be made of several operations. Actions can be propositions of novel structural characteristics followed by derivations of actual behaviours, functions and need: This is a design move (action 4 in table 1). Another type of action is the evaluation of the consequences – on the product characteristics, but also on the design process - of such propositions, and decision to (temporarily) accept or reject them (action 5). Regularly, before changing the product definition and after new propositions and evaluations, it is also necessary to observe the entire product in order to identify a set of sub-problems (action 2). This is product analysis. Focalization on a sub-problem and its analysis is another action (action 3). And the definition (beginning of the design process) or redefinition (during the process) of a "frame" is necessary – a set of parameters accepted as a basis of the other actions (action 1).

Lastly, the upper level considers the piloting of the process: how to organize the different actions.

TRIZ concepts and tools can be positioned relatively to design actions. See table 1. TRIZ tools have not been defined here in order to leave place for discussion. Refer to [2, 3].

Table 1. Design actions and relevant TRIZ tools for them

Design action (and next one)	Definition	TRIZ tool
1: (re)Framing (→ 2)	(Re)Definition of product characteristics accepted as a base	
2: Observation 1 (→3 or end of design)	Product analysis, to identify problems / actions to be done	Evolution laws 1 to 3, Concept of evolution, Other evolution laws, 9 windows
3: Focalization (→ 4)	Choice of a problem, and acute analyze of this problem	Technical contradictions, Physical contradictions, IFR, Substance field models
4: Move (→ 5)	Imagine structural parameters and derive behaviours and functions.	39 parameters, TRIZ matrix, principles, principles, Standards, resources…
5: Observation 2 (→ 2 or 4)	Evaluation of consequences of a move, decision to keep it (or not)	

From table 1, TRIZ offers support to the core of design. It provides efficient tools for analyzing a product, analyzing a problem (but not choosing one) and imagining concepts for moves (but not developing a move; especially, representations do not interact directly with TRIZ). The IFR procedure is a good way to prevent students from "always" going to solutions that introduce new objects and new operating principles in a system, thus creating new problems. And the first three laws of evolution are a good complement to technical functional analysis. But TRIZ fails to address decision taking and the strategic orientation a designer gives by framing. Moreover, it appears as a "one shot" and incomplete problem solving process, whereas design activity involves successions of problem solving and problem setting episodes - co evolution of problems and solutions.

This analysis shows that TRIZ tools are relevant for common design activity as well as for hard problem solving. It also shows that these tools must be embedded inside design processes, and not regarded as an objective per se for teaching.

3 MODULE DESCRIPTION

At UTBM since 2004, a joint module mixing TRIZ tools and functional analysis has been taught each year. From the acquired experience, it has evolved towards a module called "Solving problems methods" where TRIZ tools and concepts have progressively been integrated and now forms the core of the module in the production department. A similar module has also been given in the mechanical design department twice. The module comprises lectures (24 hours), tutorials (28 h), and a project during practical work sessions (21 h with a teacher, with small groups of 12 students). The number of students involved in each session is around 48.

In lectures and tutorials, we first present isolated TRIZ tools and then make students apply them, establishing links with design concepts (need, functions, structure, and problems) and more common design tools (Functional Analysis). This is the exact opposite of classical TRIZ teaching which generally presents first the "theory" and its claims. A generic process linking TRIZ tools is presented … in the second half of the module and we contrast it with design activity and creativity models, and socio technical aspects of designing. An initiation to the coordination of design meetings is also given [10]. Design projects involve from 3 to 5 students. Each group of students deals with a different and new technical artifact to improve. A "good" subject is a reasonably simple object with an already identified –but not analyzed – problem, in a known field of technical knowledge: mechanics here.

This module deals with relatively new tools and concepts. And it also offers the opportunity to test teaching methods. For these reasons, we gave it the following features.

- As each project is specific, all the tools are not necessarily used, and piloting the project differs from one group to another. It was therefore necessary to organize the transmission and confrontation of information between groups, in presentations (intermediate and final).
- Learning is presented in the first lecture as a process where the project is seen as a means to learn and not only to implement what has been presented in lectures. The Kolb cycle for experimental learning [11,12] is given, and we insist on the fact that, to be efficient and productive, learning must involve students; that is not only to apply knowledge, but to act, observe, try to abstract, experiment, question the teacher, interact, … as much as possible.
- Reflection on action is not only required, but instrumented and evaluated. Students report facts after each projects work session (tools they used, work done, planned work until next session). Teachers too write their observations on a document (shared among teachers). These data are sent back to students after the last session with a list of questions for reflection on projects. Their answers are included in their final report, mentioned in the final presentation, and evaluated [10]. This process aims to impose meta-cognition as a way for learning.
- We defined a skill reference frame with capability levels related to creative design activity [15]. Differences between groups from the 2 departments (mechanical design and production management) are observed as well as an evolution from one year to another [13].
- In order to improve our teaching continuously, we write down our daily observations and compare them to objectives (detailed for each session). We also ask students detailed evaluations of the parts of the module. Adjustments from one year to another rely on them.

4 REFLECTION

As teachers, we both experiment teaching means and observe their consequences; and we also learn from experience. The module has continuously been improved each year. This situation refers more to action research than to "in vitro" experimentation. Some results can be analyzed with robust methods. This is the case for the analysis of the results of the skill reference frame, already published in [13]. Some are more qualitative, such as the feedbacks comments students give at the end of each session, whose function is, moreover, to adjust the module characteristics from year to year. Other results concern the effects of teaching means (lectures, inductive methods, project, reflection…). In this article, we intend to show a global view of what has been successfully implemented and reflect on it.

4.1 Specific role of meta-cognition in creative design teaching

Meta-cognition is a synonym for reflection in/on action. It is the capability to distance oneself from a current situation (during work or during a confrontation to some knowledge) in order to capture information from this situation, to analyze it and finally to learn from it or to act on it, eventually to observe the consequences of our actions on it.

For design, reflection in / on action has been pointed out by Schon [5] who sees design as a "conversation with the materials of the situation". Following Schon, several works mostly dealing with architectural and form design highlighted the role of the interactions between a designer and his productions, especially his drawings [14]. These works consider the way information is captured and treated: this is visual reasoning. Engineering design must also consider visual reasoning since the representations of designed objects are almost systematically present. Relating to our model of design activity, visual reasoning positively interferes with the lower level: definitions of product features and elementary cognitive operations. Students have to be trained to "see" object with a designer's eye.

Engineering design is also seen and taught as a process supported by methodological tools. It can be specified for routine design, but must always be adapted for innovative design - the solving of wicked problems. Choosing the tool, adapting it, eventually diverting it, selecting the best way to address a given action and orienting the reflection on specific parameters … are indicators of such meta-cognition. This requires knowledge on the functions of the tools, the type of ingoing and outgoing data, their conditions for use, their advantages and limits. This intermediate level meta-cognition is also an objective.

At the upper level, the alternation of problems and solutions, choosing to approach design by functions or by problems, the management of design alternatives, or, relating to our model, the succession of actions including prioritization and focalization, also requires some meta-cognition whose objective is the piloting of the process. The strategic management of design [15] too is an objective.

This makes meta-cognition an objective as well as a tool for design learning, and probably this feature is favouring both.

4.2 Teaching means

When we present the module to students, we explicitly refer to action learning. But most lectures and tutorials on design tools are given before projects.

Creative design has the specificity to rely on a strong part of know-how. It is also a domain where student's pre-conceptions can be strongly established before teaching, and can be diverse. Cognitive conflicts occur. They are means to learn (see later), but their can be more or less easy to cope with, depending on the notion or tool. A reflection on the adaptation of teaching means guides our action as teachers. These means depend on both the formal / informal character of the notion and on the existence of a possible conflict with previous knowledge on design. We classify TRIZ tools and concepts according to these two dimensions. Four parts are made [10].

- In the first one, formal and non conflicting knowledge (for most students, not all) can be taught in a classical way; i.e. lectures then tutorials. What is specific to these notions is that we were first very cautious about them, thinking that they could generate conflicts. But experience showed that they can be delivered to students in this way.
- In the second, for informal knowledge with no conflict, inductive methods can be used. They concern notions that are new, not conceptualized or very little experienced. The main objective here is to name and give meaning to activity features. Some tutorials have been specifically designed, and these notions are regularly highlighted by teachers during projects.
- In the third, informal and possibly conflicting knowledge cannot be taught unless experience has been gained thought projects. For these notions it is no use trying to convince students in lectures. This is especially the case for the effectiveness of TRIZ tools.
- In the fourth part, explicit but conflicting knowledge can be treated by confronting previous knowledge to new data.

4.3 Initiating and assisting the learning process

According to the learning paradigm of Piaget [16], learning occurs via a process of equilibration, involving both assimilation and accommodation. A central notion is the cognitive conflict where student's preconceptions interact with assimilated data and new pieces of knowledge. When the conflict is not bearable, the learner has to adapt his own knowledge structures in order to accommodate the conflict. This is especially necessary when action is requested: making projects is a way to force it. Contrary to teaching/learning by refuting, it does not consider the destruction of previous knowledge but its adaptation. Here, meta-cognition favors equilibration. The different features we gave to the learning module can be seen according to this learning model.

- Previous preconceptions of students are always discussed when they emerge. But there is no specific means to make them explicit. This is a direction for improvement.
- New concepts are introduced by inductive methods. Some are simply named and defined: making the implicit explicit is also teaching. Others are really discovered for most students. For instance, coordination roles and the extent to which one can be attached to a first principle.
- New tools and new procedures interact with previous knowledge; either procedural such as functional analysis, or conceptual since TRIZ tools refer to a specific vision of design.
- Data extracted from projects form a large part of new data. Currently, they are implicit. The list of questions we give students and the specification of the reflective work, are meant to make them more explicit. With this vision, the main objective of projects is not to apply the concepts and tools but to acquire data for reflection. This vision makes action learning a means (among others) for equilibration and not a separate learning paradigm.
- Data coming from related activities are given in lectures and in few tutorials during the second half of the module (i.e. rather simultaneous to the end of projects). Ideal related activities should present both commonalities and differences with creative design. They can also introduce confusions of terms and an objective is to reduce these confusions. For instance, classical creativity is shown as a process having commonalities with a creative problem solving process. Lectures by practitioners relating their own experience show differences in practices. There are highly valuable and appreciated from students.
- The model for design activity we refer to (see section 2) is presented at the end of the module, with other concepts used in design research. This makes a meta-theoretical framework inside which the concepts, the tools and the experience gained through the project can take meaning.
- Finally, the process of accommodation is supported by interactions with teachers and with other students (see later). Requesting a formal reflection on projects too is a way to force it.

4.4 Other favouring learning factors

Cooperative learning insists on the interactions during learning. Without taking it as a paradigm, we see cooperation as a means. It favours meta-cognition which is itself a tool for learning.

Cooperation between students is the norm during project work. But cooperation does not necessarily mean interaction or confrontation. The cognitive conflict is a socio cognitive one. The more acute the conflict is, the more beneficial it is. We do not institute competition between groups, but the presentations made in front of their colleagues are favouring factors for students. We also successfully tried to make students evaluate the work done by others (evaluation here means making constructive criticism and suggestions). This form of interaction has the advantage of making them aware of other student's progress, and favours meta-cognition learning. It will be generalized.

Another important factor is the nature of the relation we build as teachers with students. De facto, we take different roles that must be presented rather explicitly. In projects, we sometimes take a similar role as students, as we discover problems with them: we may be simply experienced colleagues. Another role is to shape situations in order to make students experiment by themselves. In design, framing the system offers large possibilities to adapt the project to learning objectives. Concretely, constraints can be added or relaxed, and we can also orient towards specific sub problems. One must also act as coaches: to discuss with students their strategic choices and results. This is a form of reflection where the capability to hear and reformulate student's beliefs is essential to teachers. This form of interaction will increase in the next sessions. And we are also evaluators of the work done, both technical and reflective.

Finally, the attitude we take regarding the taught concepts, models, theories and tools, and regarding the learning process has also its importance. As design theories are still under consideration, it is important to make students decide which knowledge is steady or not. A selective epistemic rigor is required, especially when we present the meta-theoretical framework. Similarly, we distance ourselves from TRIZ claims, some of them being questionable. Finally, the reflection we conduct on our own teaching is not hidden to students who can easily understand that meta-cognition can also be used for our own activity as teachers.

5 CONCLUSION

Our teaching of technical creativity has progressively been built from a known set of methodological tools. But this is the vision of design activity that frames the module, aiming not only to apply formal tools, but also to start a reflection on the use of the different tools and on the piloting of the design process.

Meta-cognition appears as a core concept for creative design teaching. It is first necessary for design practice. Therefore, it is an objective: a skill for students. According to the vision of design with three levels, meta-cognition affects the way one sees the current definition of the object to be designed, the optimal use and adaptation of methodological tools, and the piloting of the process. Second, meta-cognition is a tool for learning and teaching. It is used for capturing new data from projects which are confronted to existing pre conception of students on design and to other information we give them. It is also mobilized for accommodation where the discussions and confrontations between peers and with the teachers play a central role. Last, meta-cognition is a tool for the continuous improvement of this teaching which is seen as a collective process involving students. It already leads to the adaptation of teaching means to the concepts or tools specificities. It also structures the module architecture and the relations with students.

The main perspective will be a reinforcement of the reflective work we expect from students. We shall also slightly modify the structure of the module in order to propose two cycles of action / reflection instead of the one experienced in projects until now.

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