A COHERENT AND DISCRIMINATING SKILLS STANDARD FOR INNOVATIVE DESIGN

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ABSTRACT
We introduced a skills and capabilities standard into two teaching modules of two departments at UTBM university. Four skills were defined from knowledge of the design activity, from which 32 capabilities were derived. The modules deal mainly with functional analysis and TRIZ tools for technical problems solving, but the relative proportion of TRIZ differ, as well as student's backgrounds in design.
Students were asked to evaluate each of their own capabilities. This set of capabilities was easy to understand by students.
The scattering seems contained, and comparisons between the series of data show differences between capabilities, skills, populations of students, and modules contents. The results show that a learning session can make students more aware of their (average) initial level and also reveal overestimated as well as non recognised initial capabilities. Moreover, the differences we observed can be explained by the modules or students features such as students' backgrounds or amount of teaching relating to a given skill.
This skills and capabilities standard therefore appears stable, coherent and discriminating, and its use in academic and industrial context can be programmed.

Keywords: skills standard, skills repository, innovative design, technical creativity, capabilities.

INTRODUCTION

Because of its strategic stakes, innovative design is considered as more and more important for many industrial companies. In order to improve the performances of an existing product, or/and to create a new one, engineers have now to be able to imagine futures needs, functions, services, and the technologies able to fulfil them. But innovative design is a rather complex activity, difficult to observe and to describe. One can easily recognise the fact that it requires specific skills, but identifying and describing them is not so easy although they are important and useful to run and manage the activity, to build and pilot training courses, and to evaluate individual abilities.

This paper reports the building up of a skills standard in innovative design and its first uses.
In the first part, some characteristics of innovative design processes will be recalled. Then, an activity model will be exposed, and from it, specific design skills shall be delimited.
In the second part, we shall give the method we used to build the skills standards as well as the skills definitions and the list of capabilities.
Finally, we describe the first applications of that standard, used as a self-evaluation tool for students in mechanics and manufacturing engineering courses. The objective is not to directly use the standard in order to get results and discuss them, but, beforehand, to evaluate the ability of the standard to measure and reveal differences between populations: stability and sensitivity.

1. INNOVATIVE DESIGN REQUIRES SPECIFIC SKILLS

1.1 Some innovative design specific characteristics

Discourses about innovative design are multiple and diverse. We will give here some of its important features, founded on literature survey, on our research based on the observations of design sessions, and on our experience in teaching and practicing.

- **Importance of representations**: designing involve reasoning on a product that does not still exist and still not defined. Part of the activity consists in the building of relevant representations describing different and complementary aspects of a product, all evolving. Among them, structural representations in the form of drawings (schematic or technical), CAD or physical models are naturally present. But other representations support the expression of behaviours, functions or product use (need): simulation results, functional or flows models, use scenario … The first function of all those texts, graphs, mock-up or tables is to support the reflexion on the product [1]. In collective situations, additional functions appear such as information sharing, ideas communication, or personal involvements …

- **Importance of creativity**: Determining the product behaviour requires classical engineering knowledge, essentially based on deduction. But the ability to propose and build solutions also depends on other reasoning modes like teleological, abductive, and analogical reasoning. These modes are more difficult to learn and assist.
- **Co-evolution**: innovative design problems are "ill defined" [2, 3], and sometimes qualified as "wicked": it is not possible to have a correct formulation of the problem(s) without engaging in some sort of solution hypothesis [4]. During the design process, "unexpected discoveries" are common [5], typically new criteria: they will complete, modify, or even erase the current formulation of the problem. Also, new (sub) problems emerge. Design research recognizes that solution(s) and problem(s) co-evolve during the design process [6, 7]. A consequence is that the formulation of need, functions, and requirements… must be considered as a part of the final deliverables rather than as given data or intermediate milestones. Innovative design deliverables are made of both descriptions of the proposed product (its structure) and the needs it corresponds to. These two descriptions are linked by the analysis of the product behaviour and by functional analysis.
- **Design process piloting:** the evolution of problem and solution, and the use of multiple reasoning modes, give the design process an opportunistic character; more exactly, the problem definition has to be constantly refined by designers. This requires the designer to determine objectives, intermediate milestones, and to evaluate permanently the current situation in order to transform it. From a technical point of view, this is first an analysis of the current definition of the product aspects. Actions are then programmed, and the product definition is transformed: a new observation is required in order to evaluate the effect of the transformations, and to determine the new actions to be done. This is an iterative procedure, where each action depends on the other ones (path dependency, but also teleology). We chose to group these possible actions in three categories: product analysis, interpretation and focalisation, and transformation; each one requires specific skills.
- **Reflective practice**: in a previous paper [8], we defined reflective practice as "the attitude adopted by an individual in order to take an external and critical look at his/her activity (in progress or completed). It allows him to analyze the contextual and generic elements of a situation, to gain a critical distance in relationship to the schemas being used, to capitalize". This reflection is necessary to consciously program future actions. We consider that it must be mobilized for all the aspects of the design situation. These can be technical (co-evolution), relative to the use of methodological tools and product representations, to the piloting of the project and to social communication. This reflection is not of same nature to pilot the activity or to carry out elementary actions.
- **A collective activity**: in engineering design, technical creativity is both individual and collective work. Each participant must therefore have elementary relationship know-how (express an idea, listen to others …) and the leading of meetings can be supported by animation techniques (be attentive to each participant, allow each one to address and act, reformulate ideas …); this social part of the activity relies on communication know-how of both the meeting participants and leader.

1.2 An activity model.

As other researchers [9], we try to understand design in the form of a model [10]. The model is made of a product view, and of an activity one.

In the right part of the product model (Figure 1), the product is represented by propositions and links between propositions in the form of deductions (use of rules). In the left part, target parameters are defined, and linked via abduction. Evaluations result from the comparison between effective parameters and target ones. This view represents parameters, propositions, and operations.

The process view represents observations and actions (Figure 2). The core of design activity is a set of actions such as: observation of the entire product, focalization on sub problems, movement (tentative to transform the product definition on order to propose a solution for a sub problem- a movement can be made with multiple operations and iterations) and observation of the consequences of the movement. The end of the activity cannot be normally decided unless no sub problem remains. The beginning is called "framing".

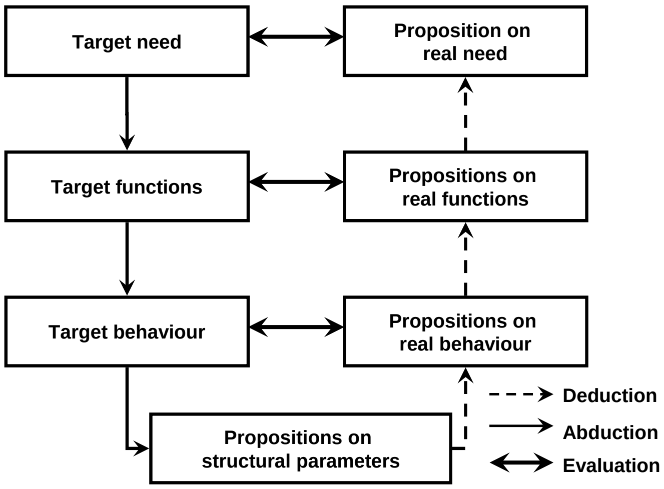

Figure 1: product model

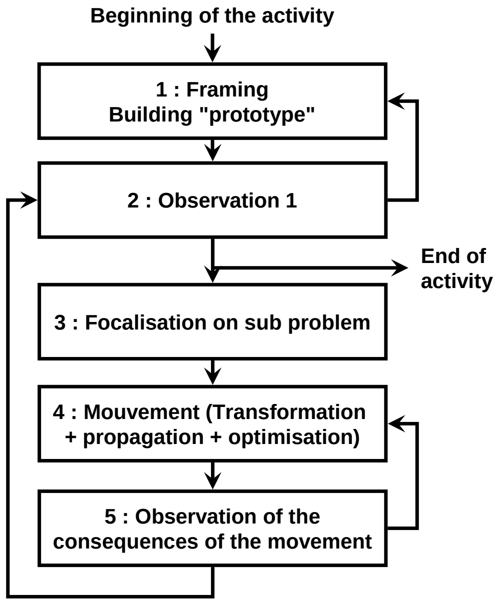

Figure 2: Activity model

1.3 Design skills delimitation.

We consider that being able to realize and organize a design activity requires some precise skills, which we propose to present in four layers:

A. **Basic scientific and technical skills**, as required from any engineer in a given technical field. For instance, an engineer in mechanics has to be able to analyze a mechanical system, understand the way it works, model it, calculate displacements or stresses, create the components of a system of well known lay-out.

B. **Methodological skills**: being able to use methodological tools such as functional analysis, value analysis, project planning. In this layer, this can consist in applying relatively standard procedures, not radically different from the ones used in regular design projects.

C. **Reflective practice**: as soon as a design problem is wicked, it requires the designer to modify, invent, and improve his own process. This includes for instance the ability to choose the right tool at the right time instead of using it systematically. It also includes the ability to modify a tool according to the current situation, in order to maximise its added value (from the design process point of view, i.e. relatively to the goal to be reached) compared to the resources (people, time) it needs to be set up. For instance, it is often not useful to develop an exhaustive functional analysis after each iteration, or to systematically reframe the problem. It is up to the designer to decide how much time it is worth spending on a given task, depending on its expected value and on the process constraints. That's why being able to use a method is not enough: a deep knowledge of every step of the methods is required in order to be able, for instance, to decide to use short cuts as soon as possible.

D. **Team and project management**. Since design is almost always a collaborative activity, the designer will have to assume – at least occasionally – some functions of project leader or team manager. Before all, he has to put up with all situations needing elementary communication abilities: listen, reformulate, explain, manage a meeting …

From the activity model and the specificities of design activity underlined above, one can see that design skills include scientific and technical skills, but go far beyond them. Skills associated to the use of methodologies and "reflection in action" (meta-cognition), including process management, are specific to design activity. They are the skills we address in this paper.

2. THE SKILLS STANDARD

2.1 Structure

In a previous work based on a master degree in innovative design [11], we presented the methodology used to derive skills from the definition of the standard.
We consider two main levels:

- **A skill** is a global ability to act in a real situation; it should be linked to an activity, then a job description [12]. But it is too large and complex to be easily evaluated;
- **A capability** is an elementary item; it cannot be easily split up. It is easier to evaluate than a skill. A skill can be split up into several capabilities.

When building the standard frame, definitions of skills derive from the activity: the activity model presented above was a prerequisite for skills definitions. Similarly, the definitions of capabilities derive from skills.

According to their definition, capabilities are assessable. Each capability can be written in the form "be able to", and without any conjunction (especially "and"). As innovative design activity is largely instrumented, many capabilities relate to choosing, using, and modifying techniques and methodological tools. As innovative design is reflective, we wanted self evaluation to be possible. Capabilities level definition range from "no action" to "automatic", based on cognitive scheme. "The cognitive scheme (…) has the advantage to make easier action by automating it (…) [13].
The levels are:

- CL1: I'm not able to act.
- CL2: I'm able to act in common situation.
- CL3: I'm able to act in 80% of situations, even unusual.
- CL4: I'm able to act automatically.

Only experience enables to gain the level 4 and we cannot require it in academic training. But living repeated real or realistic situations (internship, projects) can help to gain this level.

Around 60 capacities were defined in the first version of the standard. Among them more than 20 were concerning general communication abilities needed for the D layer (team and project management). In order to transpose this standard to engineering design modules, we excluded this D layer (it is not explicitly addressed in the corresponding modules). We also choose to simplify the standard and reduce the number of capabilities to 32.

2.2 Skills and capabilities standard contents

2.2.1 Skills

Four main skills have been defined, as follows:

- S1: to analyze a product in order to understand the reasons why it has been so-designed, and to criticize it. It consists in having a static "designer's sight" on an existing object, to answer the following questions: "what?" (What is this object, what it is made of?), "what for?" (What are the needs it is designed for, and the functions it has to complete?), "how?" (How does it work and match the required performances?). This needs using some tools of functional and technical analysis in order to describe several points of views.
- S2: to build and decide one's aim and action map. From the previous analyses (on the current reality), the work consists in defining the future reality to be built, i.e. in detecting the main performances to be improved and problems to be solved (framing, prioritizing, defining goals and focusing on them).
- S3: to imagine and built some solutions, then evaluate them, decide to save or modify them.
- S4: to manage the design process and the project. Aside the operational level of the tasks previously described, the designer sight must include the possible consequences of the current activity in order to anticipate them, and to take in account the "good" and "bad" unexpected events.

2.2.2 Capabilities

The following capabilities have been defined. All are to be read "Being able to …".

1. Identify a technical system (A set of means structured towards a goal) and its frontiers.
2. Analyze the needs of that technical system: what are the expected services, what are their causes and goals.
3. Describe a use scenario of the system.
4. Adapt the need description (i.e. means and detail level) as just required by the work in progress.
5. Describe the lower and upper systemic levels, and their evolutions, using TRIZ multi-screen representation.
6. Identify the life cycle main phases and the system functions, described as flows of material, energy or information between the system and its environment.
7. Adapt the functions description (i.e. exhaustiveness, means and detail level) as required by the work in progress.
8. Express the expected performances by defining elements needed to evaluate the functional flows (physical measurable quantity, measuring procedure, expected levels).
9. Adapt the performances description (detail level) as required by the work in progress.
10. Identify the system main internal components and their relations (contacts, flows, actions); describe and represent them using a functional analysis flow diagram, or a TRIZ substances-field model.
11. Identify the main structural parameters influencing the system behaviour (physical quantities, shapes, sizes, material, product architecture…).
12. Adapt the system structural description as required by the work in progress: detail level, most-adapted means (free-hand drawing, CAD, mock-up…).
13. Explain and argue the main characteristics of the system: parameters, specificities and advantages, expected and observed behaviours, in relation with its functions and uses.
14. Compare the current system or technical solution with other ones (in terms of functions, performances, technical strategy); choose a technical concept.
15. Describe the product future needs by formulating hypothesis about its expected evolution (for instance by completing the TRIZ multi-screen analysis).
16. Determine the criteria able to qualify the future system as well as tests able to validate them; formulate functional requirements.
17. Identify potential points of fixation (psychological inertia with TRIZ terms), or items of poor adequacy between the needs and the chosen technical strategy to fulfill them.
18. Detect and describe dissatisfactions on an existing system.
19. Prioritize the problems, and make decisions in order to focus on the most important improvement(s).
20. Define the new objective to be reached (for instance in terms of TRIZ Ideal Final Result).
21. Make explicit the problems and express them with TRIZ models.
22. Adapt the use of TRIZ problem modelling tools as just required by the work in progress.
23. Propose concrete concepts of solution; describe them as precisely as required to make it possible to other people to understand the way they operate and estimate their ability to work.
24. Choose among the creativity tools the one that best fits the work in progress; transform it if necessary in order to adapt it to the distinctive characteristics of the situation.
25. Build a technical definition of a solution as accurately as required to make it possible to evaluate its ability to work and its performances; choose the best adapted representation, according to the other people and to the project needs.
26. Postpone one's personal judgment on an idea, solution or concept.
27. Cut off oneself from the technical solution currently in development, and imagine radically different solutions (avoiding the fixation phenomenon).
28. Manage the time and the other resources of the project; anticipate.
29. Detect the elements needed to progress: information to get, actions to launch.

30. Identify some design iteration as soon as they occur (since they might reveal a co-evolution of problem and solution).
31. Manage the action towards convergence or divergence according to the project current needs. Alternate those two modes of thinking.
32. Take into account the unexpected discoveries.

2.2.3 Relations between skills and capabilities

The splitting of skills into capabilities was:

- Skill S1 → Capabilities 1 to 16
- Skill S2 → Capabilities 17 to 20
- Skill S3 → Capabilities 21 to 27
- Skill S4 → Capabilities 28 to 32

Note: For the evaluation of a skill, relations between those two levels are more complex than a simple "tree structure". They can be described in a skills-capabilities matrix, detailing which capabilities (and at which level) are required to get a skill at a given level.

3. THE SKILLS STANDARD FIRST USES

3.1 Modules.

Since its definition [11], the skills standard has been used in 2 teaching modules of 2 departments in UTBM university. The modules are based mainly on Functional Analysis and on TRIZ methodology for technical solving problems [14, 15]. TRIZ is not regarded as a method or theory. Rather, it is presented as a set of methodological tools, complementary to other more common design tools. Design activity is better described with concepts coming and adapted from modern literature on designing, - see above. These concepts are outlined in introduction and final lectures. The two modules present commonalities, but also differences.

Both are given to students in mechanics at the end of their curriculum, just before their final industrial placement. The duration is the same for each and so for the ECTS credit (6). The teachers are also the same.

In the production department, the teaching of TRIZ tools is combined with that of functional analysis in a same module. This "Innovative product-process design" module will be named here "Module A". Some students discover functional analysis. Most of them have already heard about it - but only heard. And a few of them have learned it before entering UTBM university– i.e. "a long time ago". This initial knowledge is therefore only partial and bases must be strengthened. This is the reason why Functional Analysis makes (a little more than) half of the lectures, tutorials, and projects during practical work sessions – and TRIZ only the other small half. There are other lectures and tutorials including: the introduction and module debriefings, exercises without method (in order to discover some "intuitive design" traps), and industrial lectures. Last, most of the students of that department followed a teaching in project management.

In the Mechanical Design Department, the other module "Technical Creativity" – named here module B – is proposed to students that have already been taught classical design tools and processes, including bases in external Functional Analysis for all, a complete and strong teaching in external and internal functional analysis and Value Analysis for 2/3 of them, and several design projects: the design of the whole product and its development has already been treated in previous modules. And now, specific situations where a problem has to be solved must be addressed. The teaching of TRIZ makes the core of this module: more than half of the lectures, more than 2/3 of the tutorials, and all the project practical work sessions. Other lectures and tutorials include the same complements as for module A, to which we add creativity techniques, questions concerning design knowledge (including the Delta Design role play), and a sensitization to animation roles. In module B, we also ask students to make a specific work based on reflection on their design projects. Reflection is explicitly given as a way to learn –see [16] for the module description and the way reflection is guided.

Contrasted to module A, module B spends much more time to TRIZ teaching. Even if Functional Analysis is often used during the beginning of the design projects and also discussed (reflection), it is not explicitly taught. See table 1.

Table 1. Modules features (L = Lecture, T = Tutorial, PW = Practical Work, including project and cases studies). The repartition in time is approximate since, in a same teaching sequence, several techniques can be combined. For instance, a creativity session including questions on TRIZ, industrial lectures on the use of methodological tools, the naming of concepts prepared by exercises without method, links made between the tools, digressions, recall of concepts…

Module features	Module A	Module B
Department	Production	Engineering design
Teaching volume	L24, T28, PW21	L24, T28, PW21
Functional Analysis	L11, T12, PW12	0
TRIZ	L08, T12, PW09	L13, T20, PW21
Others	L05, T04	L09, T08
Questionnaire given	Spring 2010, end of session	Autumn 2009, Autumn 2010; beginning and end of session
Series of data	2A10, and 3A10	1B09, 2B09, 3B09, 1B10, 2B10, and 3B10

3.2 Questionnaire delivering and data.

The questionnaire was given to students in the form of a table. Each student was asked to self evaluate his own level for each of the 32 items according to the capabilities levels CL1 to CL4. See table 2.

Table 2: data series collected

Time at which the students have to answer	At the **beginning** of the module	At the **end** of the module	
Question the students have to answer to	What is your level **now**?	What was your level at the **beginning** of the module?	What is your level **now**?
Data series of module A	No data	2A yy 2A10 : 39 students	3A yy 3A10 : 39 students
Data series of module B	1B yy 1B09 : 40 students 1B10 : 53 students	2B yy 2B09 : 42 students 2B10 : 45 students	3B yy 3B09 : 42 students 3B10 : 45 students

(yy : year → 2B09 : series 2, module B, 2009)

The difference between series 1 and 2 [see figures 3 and 4 below] qualifies the difference in the perception of the evaluation of a same knowledge at a given time, for evaluations made before a teaching session, and after it. It can give information on the stability of a self evaluation along time.
The difference between series 2 and 3 [see figures 5 and 6 below] qualifies the perception of the gain made during the teaching session.
Series 3 qualifies the perception of the obtained levels at the end of the sessions. For instance, it could be used to look for correlations with the academic grades granted by the teachers according to their own evaluation system.
Comparisons between semester autumn 2010 and semester autumn 2009 of a same module B (series 1B10 / 1B09, 2B10 / 2B09 and 3B10/ 3B09) could reveal evolutions of the population in a same department.
Comparisons between module A and B can also be done.

For autumn 2009, module B (45 students), 40 questionnaires were collected for series 1, and 42 for series 2 and 3 – 37 concern the same students for comparing series 1B09 to series 2B09. For autumn 2010 (63 students), the numbers are respectively 53, 45 and 44. For module A, spring 2010 (56 students), 39 questionnaires were collected at the end of the session. Students had very few difficulties to self evaluate according to the given capabilities definitions – except few questions on the significations of some terms.

Figures 3 to 6 show some of these results.

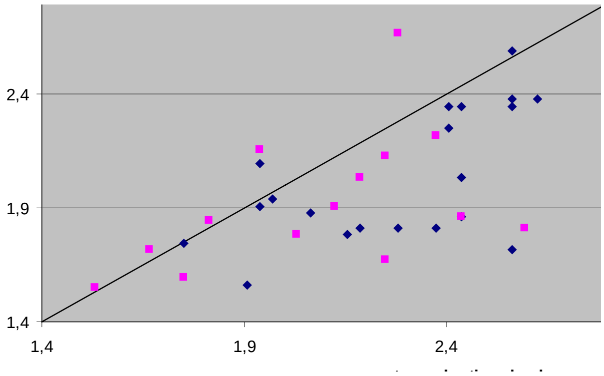

Figure 3: Series 2B09 versus series 1B09. One dot = one student

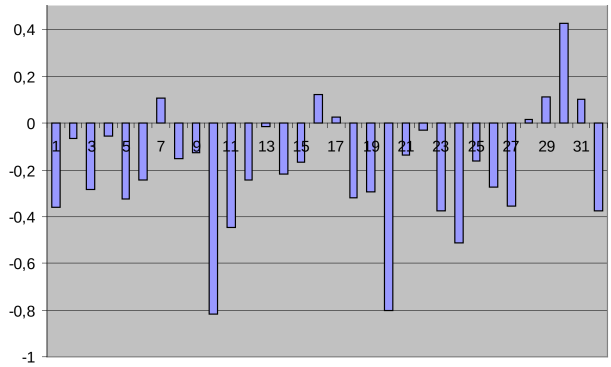

Figure 4: average difference (all the students) between 2B09 and 1B09 versus capability number

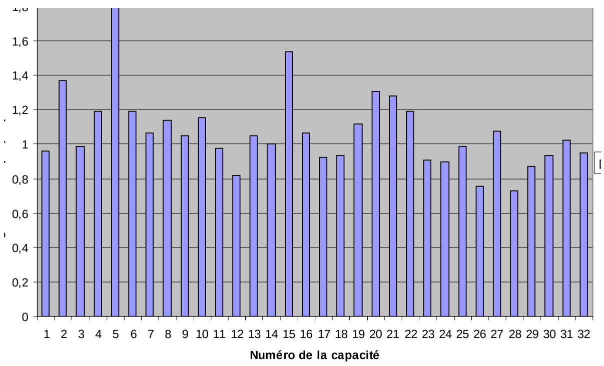

Figure 5: average difference between 3A10 and 2A10 versus capability number

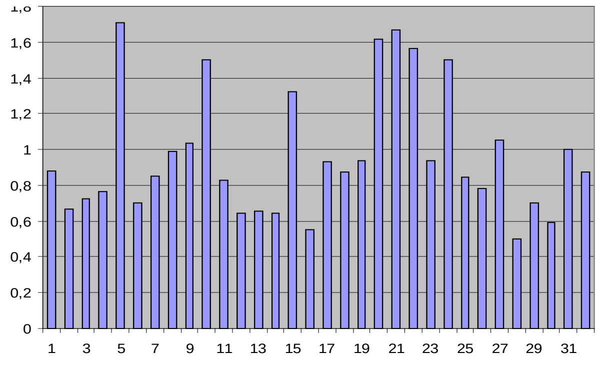

Figure 6: average difference between 3B09 and 2B09 versus capability number

Statistical tests have been systematically done in order to evaluate the significances of the differences between series of values, i.e. when comparing a same capability (or a same difference) made either by different groups of students, or at different dates (after / before). When comparing a same capability, modalities can be CL1, CL2, CL3, or CL4. When comparing differences, modalities can be 0 (no difference), 1, 2, or 3. The classical Chi square (χ^2) test has been used with a threshold p= 0.95. Table 3 gives the results.

Table 1: Results of the (χ^2) tests on all the capabilities.

	Data 1	Data 2	χ^2 tests results : are data 1 different to data 2 with p = 0.95 ?
1	1B09	1B10	No difference, except for capabilities 20 and 30
2	2B09	2B10	No difference, except for capability 14
3	3B09	3B10	No difference, except for capability 15
4	3B09-2B09	3B10-2B10	No difference
5	2B09	2A10	Differences for 1, 2, 6, 7, 8, 9, 12, 13, 14, 16, 21, 23, 25, 28, 29, 30, 32
6	2B10	2A10	Differences for 1, 2, 3, 4, 6, 7, 8, 9, 12, 13, 14, 16, 23, 25
7	3B09	3A10	Differences for 1, 9, 10, 16, 21, 22, 23, 24
8	3B10	3A10	Differences for 1, 9, 10, 15, 16
9	3B09-2B09	3A10-2A10	Differences for 2, 16, 24, 30
10	3B10-2B10	3A10-2A10	Differences for 2, 4, 8, 14, 16, 19, 22, 24
11	1B09	2B09	Differences for 1, 10, 11, 20, 24, 26, 27, 30, 32
12	1B10	2B10	Differences for 3, 5, 6, 10, 11, 15, 18, 19, 20, 21, 22, 23, 24, 27, 32
13	2B09	3B09	All capabilities differ

14	2B10	3B10	All capabilities differ, except 28
15	2A10	3A10	All capabilities differ

In table 4, we also report the average values (all students in a session, all the capabilities referring to a given skill), and standard deviations of groups of capabilities corresponding to the skills S1 to S2 (see 2.3.3), in order to compare module A to module B. The standard deviations range from 0.32 to 0.5: they are quite similar from one series to another one and correspond appreciatively to 1/8 of the total range (range of 3: from CL1 to CL4). When comparing module A to module B, we estimated a strong difference when the difference between the A value and the B value was higher than 0.75 * the standard deviation; and only a significant difference for 0.5* the standard deviation.

Table 4: Average values (AV) and standard deviations (SD). ** Strong differences between module A and B. * Significant differences. (See in the text.)

		S1		S2		S3		S4	
		Av.	SD	Av.	SD	Av.	SD	Av.	SD
Module B, Autumn 2009	2B	2.14	0.4	1.9	0.5	1.75	0.44	2.13	0.47
	3B	3.03	0.32	2.97	0.42	2.89	0.42	2.83	0.41
	3B-2B	0.91	0.32	1.1	0.27	1.19	0.38	0.72	0.45
Module A Spring 2010	2A	1.61**	0.39	1.65*	0.38	1.45*	0.33	1.75*	0.47
	3A	2.76**	0.36	2.74*	0.39	2.47*	0.37	2.65	0.49
	3A-2A	1.15*	0.37	1.07	0.48	1.01	0.33	0.9	0.45

3.2 Analysis:

3.2.1 Beforehand precaution.

The absence (or quasi absence – see lines 1 to 4 in table 3) of differences between two consecutive sessions of a same module (B09, B10), is encouraging. It shows a relative stability of the test. Nevertheless, some precautions must be taken.

First, the correlation between the grades students get by the teachers' evaluations (of the project work, report, presentation, reflective work, final exam) and their own self evaluation with the standards sheets, appeared not good. There are students with a high grade and a low self evaluation, and students with a low grade and a high self evaluation. For a given population, the collected data show that other factors influence the self evaluation. The self esteem is probably the first of these factors. For this reason, data obtained by this questionnaire cannot be used for individual evaluations – or cannot be used as a unique source of information.

Second, the comparison between series 1 and 2 for a same population shows that the evaluation of a level depends on time, or more precisely on the learning experience. Figure 3 shows that, except for a small number of them, students evaluating the level they have / had before the teaching module give a lower rate after the session than the one they gave before it. The teaching session has probably the effects of making some concepts more explicit, and of showing that capabilities can be less easy to obtain than a trainee can first imagine. An average decrease of around -0.2 is observed, but it depends on the capability (figure 4). Some capabilities show a significant decrease. Especially capability 10 and 20, which, for this population of students, correspond to the ability to use specific tools, part of these tools have already been taught before the session but other ones are discovered during the session. The discovery of new tools to analyze a system could explain the data. Other significant decreases in capabilities can also be explained by the nature of the teaching which gives complements, but also tries to make students more reflective; for instance, capabilities 1 and 5 question the limits and definition of a system and 11 relates to the notion of physical contradiction in TRIZ. To choose a creativity tool (capability 24), or to fight the attachment to the first principle (27) appear not so easy after the session. And unexpected discoveries (32) are really explained in the module. The fact that more significant differences appear in line 12 compared to line 11 could find reasons in a slight evolution in the student's population for this module: opened for one course of study inside the mechanical department in autumn 2009, and for two in autumn 2010. Few students are concerned, but this can affect the statistical analysis.

Some few capabilities rates increase: 7, 16, 29, 30, and 31 but the increase is not significant (except 30 for B09). This could reveal the recognition of tacit capabilities [17] that were present, but not named explicitly, and precised during the session.

3.2.2 Students levels.

Comparing populations B09 to A10 shows differences.

At the beginning of their session (lines 5 and 6), students in module A discover design whereas students in module B have largely been taught to it, and have some experience in design projects. The difference is particularly important for Skill S1 (Functional Analysis), with significant differences for capabilities 1, 2, 6, 7, 8, 9, 12, 13, 14, 16. This is coherent with the initial experiences of the trainees. For both modules, skill S3 has the lower rate. It corresponds to the ability to imagine solution, partly with the assistance of TRIZ tools; but only partly: capabilities 23 and 25 are already familiar to B students.

At the end of the sessions (lines 7 and 8), the levels are still different, especially for skill S1, capabilities 1, 9, 10, and 16. And, this is now coherent with the difference in the total time invested for each skill (before and during the session). "A" students at the end of the sessions did not have as much teaching and training as "B" students in Functional Analysis during their entire curriculum.

The progressions also differ, especially for capabilities 2, 16, and 24. Again, this is certainly due to the fact that most of A students discover the domain.

3.2.3 Capabilities progressions.

All the capabilities in the studied sessions show a progression. Of course, this is encouraging, even if there is a possible artefact due to the fact that, at the end of the session, students can be tempted to amplify the progression – this is also the recognition that they have learned something. The average progression seems similar for both modules: around + 1. But it does not really show significant differences between the skills, the capabilities, or between the populations of students. For skill S1, the progression for A students appears higher than for B students (but no significance); this is coherent with the contents of the modules. Nevertheless, we can notice an increase in skill S1 (functional Analysis) for B students, who might have progressed by the discovery of TRIZ functional tools but also by experiencing and reflecting. The capabilities related to TRIZ show the highest progressions: 5, 15, 21, and 22, but also 10 and 20 (see above), and 24 for session B which includes a lecture on creativity. And there are some capabilities that could be studied in detail in order to improve next sessions.

4. CONCLUSION

Innovative design is a complex activity, its description is difficult. Nevertheless, some of its main features such as co-evolution, creativity, use of representations, necessity to pilot the process with some reflection in action, as well as an activity model, have formed the bases for the building of a skills standard. Four skills are defined: to analyze a product, to build and decide one's aim and action map, to imagine and build solutions, and to manage the design process. From these four skills, a set of 32 capabilities has been built.

This set of capabilities has been proposed to students in a self evaluation process. They were asked to evaluate their levels (from "I am not able to act" to "I am able to act automatically") at the beginning of a learning session (evaluated before and after the session) and at its end.

The main and single question relating to a self evaluation of capabilities by students is the signification of the levels and the confidence one could have in the data. After analyzing the data, there are some indicators for a good confidence concerning the use of this standard. These indicators are

- The fact that the questionnaire can be given with –nearly- no additional explanation. It seems expressed in terms that can be easily understood.
- A relatively low value of the standard deviation compared to the total range.
- A steady behaviour between two consecutive sessions of a same module.
- The fact that results can show differences that are significant between the series of data, and between the groups of students. Knowledge can be extracted from the data.
- The fact that students identify, once the session is over, some difficulties they didn't imagine before. This is the first step in learning: become aware of…

- The coherence of the differences between the series of data and the contents of the teaching: The skills levels before the sessions appear coherent with the previous teaching students had. The final levels vary according to the overall teaching in each skill and the progressions depend on the amount of time students can learn and experience by themselves.

Therefore, such a standard system of evaluation of capabilities and skills appears quite steady, and allows revealing differences between populations of trainees; according to their past knowledge and to the learning session they follow. Moreover, it can – by itself – enrich the learning process by making the required skills explicit.
The applications of this standard can therefore be imagined with relative confidence in both academic and industrial contexts. The next application will be the continuous improving of our teaching at UTBM University.

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