Progression in Learning Strategies in Engineering Education. Does Meta-cognition matter?

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INTRODUCTION

Learning cannot be limited to information acquisition and retrieval. Instead, some students show a quite laborious behaviour, obtaining sometimes poor results despite hard work. From a purely cognitive viewpoint, learning is better represented as an activity that gives meaning to new information by putting it in context, making connections and classifications between new and previously learned content, as well as interpretation and self-questioning. Learning is also known to be strongly influenced by other factors, especially affective ones – including motivation. Furthermore it is dependent on conditions such as time and social pressures. It is therefore a complex and situated activity depending on factors other than the quantity of work a student assures. These factors play a fundamental role in constructing knowledge and can themselves be more or less modeled by the learner himself.

A learner has his own way of transforming information into knowledge. The ability to adapt to a given context (institution, teaching mode, personality of the teacher, nature of knowledge, etc.) differs between individuals, as well as the representation of learning and, above all, the ability to reflect on one's own learning process. This reflection on -and awareness of- one's own learning process is a form of "*meta-cognition*" (Flavell 1976, 1979). A student plays a more or less active role regarding his learning activity and learning method. He can select and adapt (where necessary) different learning strategies. Finally, considering possible courses of action leads learners towards "*learning to learn*", that is, according to Nisbet and Shucksmith (1986), "*the most important learning*" (p.vii).

This contribution is an attempt at evaluating the learning strategies that engineering students use and how they change over time. It is based on two basic hypotheses. Firstly, individual's strategies can evolve over time and, second, their progression is characterized by the way that the learner reflects on, plans and adapts his actions. These assumptions focus on the learner and his meta-cognitive competence in achieving control over his learning process. Conscious learners should also be able to expose and self-evaluate their strategies. Based on a survey on the learning strategies adopted by engineering students studying at different levels, this paper will be divided into three sections. We first investigate how to apply meta-cognition to evaluate the progression in the learning strategies. Then, we present the survey, our methodology and the data collection. Lastly, we discuss the results concerning the progression in engineering student's learning strategies and the role of meta-cognition.

1 DEFINITION AND TAXONOMY: RELATIONSHIPS BETWEEN META-COGNITION AND LEARNING STRATEGIES.

This section presents the taxonomy of the learning strategies and proposes to evaluate their progression based on meta-cognition.

1.1. Meta-cognition

Meta-cognition was originally defined by Flavell (1976, 1979). He highlights two inter-related components. First, meta-cognitive knowledge is about the awareness of how factors (i.e., person, task, and strategy) act and interact to influence the outcome of a thinking process such as decision making. Second, meta-cognitive regulation is concerned with the use of control processes (e.g., monitoring, selection, planning, management and evaluating). So, meta-cognition is not only conscious knowledge. It is also intentional, foresighted, purposeful, and directed to accomplishing a goal or an outcome. Moreover, Schraw (1998) describes it as a set of general rather than domain-specific skills.

1.2. Learning strategies

Although scholars do not fully agree about the definition, learning strategies refer to goal-directed activities that facilitate task performance and that are potentially available to conscious awareness. According to Weinstein and Mayer (1986), they are behaviors and thought-processes that a learner engages in during learning and that influence the learner's encoding process. They relate to the fundamental distinction introduced by Marton and Säljö (1976) between deep or surface approaches to learning. For instance, a key distinction can be made between memorization as an end in itself and construction of underlying meanings by creating structural relationships, understanding or transforming relations of significance, spotting gaps, recognizing and formulating important questions.

Learning strategies often are associated with the success of learners: A good learner is supposed to select appropriately and to adapt flexibly his learning strategies to his personal needs and to the requirements of the tasks. What seems to be the pivot of learning strategy is the learner awareness of what he is doing. In other words, a good learner needs to bring his own mental processes under conscious scrutiny and thus control them more effectively.

1.3. Category of learning strategies

Several classifications of learning strategies have been put forth in literature. A first distinction can be made between direct and indirect strategies. Direct strategies transform, in the mind of the learner, the material to be learned into new selfappropriated structures. Indirect strategies act mainly on the learner himself, for example by sustaining motivation or reducing stress. They are commonly separated into affective and support strategies (time and resource management for instance).

Adapting the building-blocks proposed by Larue and Cossette (2005) – based on a synthesis of related literature – we first retained cognitive, affective, management and meta-cognitive strategies, but in our second step, we chose to treat meta-cognition as a separate dimension (see below). The cognitive strategies concern the actions a learner undertakes in order to manage information directly, such as interpretation or generalization. The affective strategies refer to actions engaged to maintain a positive affective climate for learning; and the management ones are related to the management of the resources (time, human resources, methods…).

Finally, the three categories - cognitive, affective and management - were divided into ten strategies, as show on table 1.

Table 1: Strategy domains

Category	Nb	Title	Description
Cognitive	1	Interpretation	To interpret information using other concepts, representations
	2	Reliability	To compare new information with other sources
	3	Structure	To create links (logical, hierarchical, analogical, etc) between new and existing information
	4	Generalization	To apply knowledge or procedures to other cases or domains
Affective	5	Motivation	To work on self motivation
	6	Concentration	To work on concentration
	7	Stress	To work on stress level
Manage-ment	8	Time	To manage time and learning activities
	9	Methods	To create and modulate material methods (space, sorting means, data classification…)
	10	Human resources	To "use" other people (colleagues, teachers…)

1.4. Relationship between meta-cognition and learning strategies

There is still controversy concerning meta-cognitive strategies, being sometimes identified as a separate category, sometimes grouped with other support strategies. Meta-cognition can be defined as a strategy when it is applied to some knowledge. Therefore, it is defined as a thought process about knowledge. But meta-cognition affects all the other strategies (and not only direct ones) in another way: to reflect on the actions a learner undertakes, such as planning, monitoring, regulating, self-evaluation and improvement of learning. A learner can reflect on the way he thinks as well as on his own affective state or on the way he uses his resources. So, we preferred to focus on this dynamic component of learning processes in keeping with a view of meta-cognition as a set of general rather than specific domains (see above) and with Flavell's viewpoint (1979) which stated: "*Cognitive strategies are invoked to make cognitive progress, meta-cognitive strategies to monitor it*" (p.909). Meta-cognition allows some perspective to be taken on the learning activities, to capture elements of information from them (self observation), to analyse them (self questioning), and finally to learn from them or/and to act on them. Thanks to meta-cognition, individual's strategies can evolve over time and their progression is characterized by the way that the learner oversees, reflects on and regulates his learning actions.

With this definition, we used meta-cognition as a scale applied to each learning strategy, from “no real awareness of its existence” (level 1) to "awareness with nearly no action" (level 2), "actions becoming common" (level 3) and finally "ability to implement considered and systematic actions” (level 4). The level (1 to 4) does not directly qualify the actions a student carries out in order to learn, but the thought processes he has on each strategy.

2 DATA COLLECTION

Like all mental processes, meta-cognition is not directly observable in students' activity. However, consciousness is an important characteristic. It states that learners are able to expose and self-evaluate their strategies. So, common methods for capturing meta-cognition can be used, such as self-report methods (Cohen 1987, Wenden 1991), rating scales, diary or questionnaires that ask respondents to describe the way they learn and their use of particular strategies. We chose to conduct a survey in order to get an overview of the learning strategies across different classes from L1 to M2 in engineering education. In this way, a statistical processing of the data is possible.

2.1. Populations

The survey was conducted over six classes whose levels were L1 (group A), L3 (B) and M2 (D, E and F). The total number of students is 224. They belong to three study courses at UTBM and a nearby business and engineering school. B, C and D students are involved in a system and production engineering curriculum in mechanics. Groups B and C are made up of nearly all the students involved in a one-year course. Group D is specific. It is composed of a few volunteers, most of them already known as thoughtful students, questioned just before their final industrial internship. A and E come from the business and engineering school that recruits students from the French scientific baccalaureate (as is the case for UTBM students) and leads them to M2 level in a business degree with competencies in engineering. F students come from multiple and diverse origins in order to qualify for a M2 program in international and industrial project management; Most of them are young engineers with little (or no) professional experience. All were questioned by the middle of the year, between December 2012 and February 2013.

Table 2: Characteristics of groups

Class / group	Number Ni	Level	Curriculum	Specifics
A	36	L1	Marketing / Engineering	
B	61	L3	Production engineering	
C	48	M1	Production engineering	After industrial internship
D	14	M2	Production engineering	Thoughtful students
E	33		Marketing / Engineering	
F	32		Double competence	Heterogeneous population
Total	**224**			

2.2. Questionnaire delivery

For all the groups, we followed the same process for questioning the students in open classes. After a brief introduction on the objectives of the research program and the definition of learning strategy, we questioned each group collectively about the strategies they use. At this stage, strategies are expressed in natural language, collected and displayed. Note that groups B and C were questioned in the same room. Then, the classification into ten strategies was presented and compared with the strategies expressed at the previous stage. If necessary, we answered questions to ensure a good comprehension of the definitions. In the next step, we gave an individual questionnaire composed of assignments, measuring the ten strategies over four levels of progression– according to the meta-cognition scale. Finally, we collected the students' remarks and comments.

The data extracted from each session is therefore made up of a list of strategies expressed in natural language before the introduction of the taxonomy; and the evaluation of the level each student estimates he has for each of the ten strategies of our typology. An answer A to the line of the questionnaire corresponding to strategy k (k varying from 1 to 10) given by student j (varying from 1 to the number of students Ni of his group) from group i (i varying from 1 to 6, corresponding to groups A to F) is noted A_{ijk} .

2.3. Data analysis

The analysis concerns the strategies expressed in natural language and the evaluations each student carries out on his own reflection concerning each strategy (level 1 to 4). For the strategies expressed in natural language, we classified them according to our taxonomy.

From the numerical data produced, an evaluation is made for each student for each category (cognitive, affective, management). The combined average of them is given by averaging A_{ijk} . For each group and each strategy or category, the average strategy ("S" for strategy) is also calculated. A Chi2 test with a 95% threshold is used in order to compare strategies between groups.

3. RESULTS AND DISCUSSION

3.1. Free expression of strategies

We analyzed the number of different strategies each group of students naturally express according to the ten strategies defined above. When questioning each group, we limited our participation to repeating the questions ("Which strategies do you use?" and "Do you know any other strategies?") and to reformulating them; in order to prevent students being influenced. Although this process is subjected to group phenomenon and cannot be reproduced faithfully, some results are encouraging.

Firstly, the students demonstrated an awareness of learning strategies. All ten strategies were identified by nearly all the groups. Secondly, students did not identify any strategy that could not be categorized by one of the ten items of our typology. Thirdly, some differences appeared interesting. Cognitive strategies (74 items) seemed to be easily identified, especially strategy 1 (interpretation – 28 items) and 4 (generalization – 21 items). For strategy 1, half of the answers referred to repetition as memorization process - Group A mentioned no strategy other than repetition. Management strategies (54 items) were also readily expressed, notably strategy 10 (use of other persons – 33 items). Affective strategies (21 items) are less frequently identified. Especially stress management (Strategy 7 – 5 items); and it was never mentioned by any production engineering student.

3.2. Signification of numerical data

With the comparison test (Chi2 test), populations can be separated with confidence. Table 3 gives the results of the Chi2 test with a threshold set at 95 %. Due to the amount of data and to the differences between students in each group, establishing differences by grouping all the strategies is quite easy but not systematic. Such differences between populations when the strategies were grouped by category are less easy to establish. And differences between student groups when strategies were considered individually are rarely sure. The strategies about the knowledge structuring (3), generalization (4) and stress (7) result in no difference whatever the two groups compared. Some show few differences like the management of time (8) and human resources (10). These results are quite surprising since the teaching staff regularly focuses on these points in courses. The strategies that show most differences are motivation (5) and concentration (6), then use of methods (9), interpretation (1) and reliability (2). Such differences reveal progressive learning of these strategies over the course of the curriculum.

Table 3: Results of Chi2 tests

Compare		Strategies										Category			All
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	Cog	Aff	Mgt	
A	B	0	0	0	0	0	0	0	0	0	1	0	0	0	0
A	C	1	1	0	0	0	1	0	0	0	0	1	1	0	1
A	D	0	0	0	0	1	1	0	1	1	0	1	1	1	1
A	E	0	1	0	0	1	1	0	0	0	0	1	1	0	1
A	F	0	1	0	0	1	1	0	0	1	0	1	1	0	1
B	C	1	0	0	0	0	0	0	0	0	1	1	1	1	1
B	D	0	0	0	0	1	1	0	0	1	0	1	1	1	1
B	E	0	0	0	0	0	1	0	0	1	0	0	1	0	1
B	F	0	1	0	0	1	0	0	0	0	0	0	1	0	1
C	D	0	0	0	0	1	0	0	0	1	0	0	1	1	1
C	E	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	F	1	0	0	0	1	0	0	0	0	0	0	0	0	0
D	E	0	0	0	0	0	0	0	0	0	0	1	0	1	1
D	F	1	0	0	0	0	0	0	0	0	0	1	0	1	1
E	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nb of "1"		**4**	**4**	**0**	**0**	**7**	**6**	**0**	**1**	**5**	**2**	**8**	**9**	**6**	**11**

Reading: 1 indicates that the two populations can be considered different for the strategy, group or set of all the strategies with a risk inferior to 5%. 0 indicates that the populations must not be considered different.

Finally, considering the three categories and the whole set of strategies, three sets of groups can be considered different with some certainty. First: the M group (M1 and M2) that are made up of the populations C, E and F. These populations cannot be considered different, except for the strategies of interpretation (1) and motivation (5) between C and F. Second: the L group (L1 and L3) that is made of the populations A and B. They cannot be considered different except for the strategy on human resources (10) and show poorer strategies than M students. Third: D students form a group made of few thoughtful students at M2 level and show the strongest strategies.

3.3. Strategy-development with experience

Figure 1 gives an overview of the strategies deployed by students according to the different populations. The comparisons between groups appear quite coherent.

Globally, strategies grow with experience from L group (A, B) to M group (C, E, F). And not surprisingly, group D achieves the best score for six strategies out of ten. The strategies already identified as those where learning is certain (see above) appear easily in this figure: interpretation (1), reliability (2), motivation (5), concentration (6) and method (9). Despite the absence of certitude (Chi2 tests were not positive), strategies on information structuring (3) and generalization (4) seem to show some learning with experience – This is a suggestion of learning.

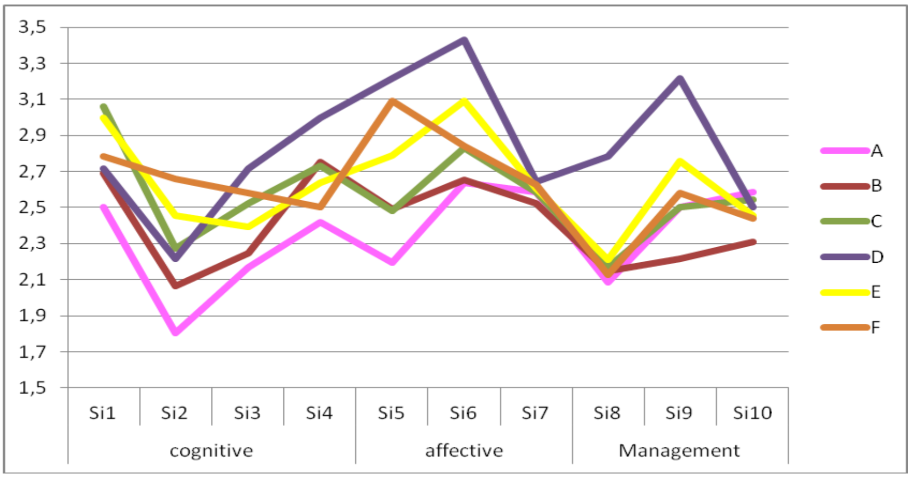

Fig. 1. Average of strategies $S_{ik} = \sum_{j=1}^{j=Ni} A_{ijk} \Big/ N_j$

4. CONCLUSION

In this work, we proposed taxonomy of ten strategies into three categories: cognitive, affective, management. Meta-cognition is analyzed as a transversal category that allows to plan, to monitor and to self-evaluate each learning strategy. It is used as a scale to evaluate the progression in learning strategies.

Students from six classes, ranging from L1 to M2, were first questioned spontaneously on the strategies they use. Then, after the presentation of the taxonomy, they were asked to self evaluate the thought processes they underwent on each strategy.

From the strategies expressed by students in natural language without knowing the taxonomy, we conclude that students are aware of learning strategies. Their learning strategies were discussed with us quite easily, even though affective strategies appear less present in group discussions. Moreover, all the strategies were identified and no new ones appeared, comforting the taxonomy.

From the numerical data, even if the questionnaire is still rough (scale from 1 to 4) and subjected to bias (individual declaration), the statistical analysis of the results can reveal differences between populations of students. There is clear evidence that strategies evolve from L groups to M ones. Learning strategies are learnt and this learning goes on throughout the curriculum to include more reflection on their cognitive, affective and management strategies. And, although limited in size, a group (D) made of M2 students known as being thoughtful indicates further directions for improvement. The learning of learning strategies during the curriculum appears certainly necessary for the ability to interpret, to make information reliable, to achieve self-motivation and concentration and to organize learning methods. Similar learning appears –even if is not certain- for the ability to structure and generalize knowledge. Three strategies show no progression: management of individual stress, management of time and that of human resources.

Considering meta-cognition highlights students as key actors in their learning and more specifically in “learning to learn”. It may become a core competence for the curriculum and for lifelong learning because it leads to learning strategy adaptation and, above all, contributes to improvements due to monitoring and self-evaluation. A challenge for teaching will be to improve the meta-cognition of engineering students. This will be the objective of further work.

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