The Use of Mental Model-Centered Instruction in Teaching a University Course

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Abstract

Cognitive sciences have repeatedly shown the influence of mental models in the learning process. A mental model is a mental representation that illustrates how reality could be – according to what is stated in the premises of a reasoning problem. This case study examines the use of model-centered instruction in a regular university graduate course. A combination of self-organized discovery and externally guided discovery learning were used to help students to construct their own mental model of a complex intervention process. The results show that all students' mental model clearly gained in complexity along the course of the 14-weeks semester. The models presented also great variety in their structure displaying very different processes: linear, circular, «treelike», chronological, etc. This case study reveals the efficiency of the use of model-centered instruction when the aim is primarily self-organized and guided discovery learning.

1. Introduction

Cognitive sciences have repeatedly shown the influence of mental models in the learning process [1]. A mental model is a mental representation that illustrates in small scale how reality could be. According to Johnson-Laird [2], «there is no complete mental model for any empirical phenomena», assumed that every model is a necessary simplification of the complexity of reality. In order to be useful explanatorily, a mental model has to have a similar relation-structure to the reality it models. Consequently, it is more elaborated than a simulation that merely mimics a phenomenon, and it relies on a structure that describes coherently a process or a procedure related to the phenomenon one attempts to understand.

A mental model is, evidently, an internal process that is not observable directly. It is revealed by an

explanation through one or many languages that uses texts, graphics, images, equations, etc. Concept mapping is one of these languages. Concept maps are graphical tools for organising and representing knowledge [3]. They represent concepts, usually in circles or boxes, and relationships between concepts, indicated by connecting lines and arrows. These maps are categorised, following their structure, as chain or sequential maps, cyclical maps and hierarchical maps.

Concept mapping help in organizing learners' knowledge by integrating information into a progressively more complex conceptual framework [3]. They facilitate the skill of searching for patterns and relationship among concepts, which is frequently solicited when attempting to understand a complex reality.

Once a person has constructed his own representation of his mental model, he has the possibility to constantly refer to it in order to gain better understanding. He can adds or delete informations, as well as modifies its structure

A model-centered learning approach presents learning situations that require construction and manipulation of mental models in order to understand phenomena or complex reality. These learning activities should allow a person to use different sources [4] for the construction of his mental model. He could construct his mental model in an inductive manner, from a set of basic new concepts that interacts with his already possessed analogous mental models. In this case, an adequate learning environment should provide new knowledge while leaving space for the learner to acknowledge his preconceptions of the phenomena and giving him time to identify the analogous mental model he already possesses.

A learner could also use everyday observations of specific aspects of reality, in the real world, that are relevant to the phenomenon. These observations, when done regularly, and analysed adequately, can add new knowledge and concepts to the mental model and help to structure them in a comprehensive way. Finally, a learner can interact with other people by explaining his mental model and comparing it to the models of other learners. This strategy is especially relevant for education and instruction.

2. The Case Study

This paper presents a case study of the use of a model-centered instruction approach in a regular university course. A combination of self-organized discovery and externally guided discovery learning [5] where implemented to help students to construct their own mental model of a complex intervention process, namely, the supervision of a sport club. The graduate course was one of the 5 compulsory courses for the Master degree in sport coaching, given at Université Laval in Quebec, Canada. Six students, 4 men and 2 women, attended the course.

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The students were asked to provide a representation of their understanding of the process of sport supervision in a sport club, 4 times during the 14 weeks-long course: specifically during the 1st, 5th, 9th and 14th week. Because the construction and acknowledgment of their mental model was an explicit learning outcome of the course, each representation was evaluated for 5%, for a total of 20% of the final note.

Representing a complex reality is not an easy task when you are limited by words and texts. Several studies in cognitive science have demonstrated that relations present in mental models are more easily represented spatially [3]. Consequently, the students were asked to use one of the many concept-mapping or mind-mapping softwares existing in the numeric market to draw their representation. Most of them used the free software VUE (Visual Understanding Environment). It allowed them to draw forms around text, to incorporate images when necessary and especially, to connect concepts with arrows and lines. After about two weeks of use of the software, the students gained enough efficiency to be able to represent freely their mental models.

2.1. Preconception and inductive process

As seen in the introduction, studies in cognitive science recommend that model-centered instruction provides opportunities for several sources of information for the construction of models. The contribution of new knowledge that interacts with the learner's already possessed models was thus taken into account in the instruction process. During the 1st class of the course, the students were asked to draw their first representation of «what should be an efficient intervention process for the coaching supervision in a sport club». They were asked to identify the essential components or concepts of this process and to draw a spontaneous representation of it, on paper.

Every person has a preconception of a phenomena or a reality. If asked to do it spontaneously, they can easily refer to the mental models they already possess that are analogous to the phenomena under study and give a comprehensive description of them. In this case study, they drew a simple model that consisted in few boxes and arrows structuring a limited number of concepts they consider important. This learning activity was the start of a learning process that would last 14 weeks: acknowledging their preconception was the first step. The gradual integration of new knowledge to this first representation, mainly by reading and listening to oral presentation of the teacher, was the inductive process that followed. The students had to modify continuously their model, this time by using a concept-mapping software, and to present it for evaluation during the 5th, 9th and 14th week. They used free-style mapping, without constraint on the number of concepts or relationships to add to their model, and without a determined structure. The model-centered instruction used in this course was less aiming at gaining a predetermined understanding of the reality of sport supervision according to theory, than to allow students to acknowledge their own mental-model representation and processes. The evaluation of this part of the course was thus scored accordingly, limited to 20 % of the final note. The understanding of the sport supervision process for the remaining 80% was evaluated with two exams and a written report.

Because the information presented to the students by the teacher was not always directly related to the intervention process of supervising a sport club, the students had to select what contributed to a more efficient process and to integrate this pertinent information to their mental-model. They made these choices in part on the basis of validated facts (theory) that were presented to them by the teacher and in part from their own experiences as sport coaches and athletes. There is of course «central» knowledge, mostly theories and principles, to be retained and the teacher has to make sure it is presented to the students accordingly. But there is also «peripheral» knowledge, which mostly refers to personal experiences, that also contributes to a better understanding.

2.2. The observation and experience of specific aspects of reality

As we all know, observation of specific aspects of a reality can greatly contribute to its understanding. This is why the students were asked to observe the intervention of coaches during short sports clinics, three times during the semester. They were asked to use specific observational grids and to prepare a written report. Several behaviors that were observed and analyzed helped them to gain a better understanding of the role of coaches in the process of sport supervision. Even though the sports clinics were chosen on the basis of their relevance to the sport supervision process by the teacher, the students incorporated only specific knowledge that they felt were contributing to their understanding.

This question of filtering information and retaining only what is considered relevant or meaningful while experiencing or observing a reality is raised by several studies in experiential learning. In this regard, certain authors [6] argue that new experiences are rejected if they produce cognitive dissonance that is unbearable by the learner. On the contrary, knowledge is assimilated if it is meaningful to the learner's «network of knowledge» (another way to name the mental model, in the language of experiential learning). If we apply these experiential learning principles to this case- study, the students

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would filter and assimilate the information that they experience in the sports clinics if they judge it meaningful and they can relate it to their network of knowledge (mental model). That is precisely this judgment process, which is not well known, that was investigated in this case study. By describing what and how students retain information and integrate it to their model, this study will shed some light on this complex judgment process.

2.3. The explanation of mental models and sharing of representations

On the 5th and the 9th week, students were asked to present their model in class and to explain them to the other students. During these presentations, they had the opportunity to increase their understanding of their own model: having to explain something is often the best way to profound comprehension. They had to describe the main elements or concepts contained in their models and by this process, to distinguish what was essential or central, and what was more complementary or peripheral. They had also to explain the relationships between concepts, revealing the structure of the model and its internal process.

These explanations were followed by discussions where everyone could ask clarification questions. This process of exchange and discussion between students on their own representation of mental models is a form of interactive pedagogy frequently used. It allows for the students to acknowledge the differences of the other models and to learn from these other representations.

It was postulate that, by using this kind of interactive instruction, the students would modify their models according to the knowledge they gained from other models.

3. Results and discussion

The results show that all students' mental model clearly gained in complexity and diversity along the course of the 14-weeks semester. The content of the models, in terms of number of pertinent concepts, increased gradually for all students along the semester, but each one had their own limit and it stopped in accordance with their ability to cope with a certain quantity of concepts or the «meaningfulness» of their own mental model. Some students wanted to include a lot of concepts, some preferred to incorporate less. The models presented great variety in their structure. The reality to encompass within the mental model was a complex process of intervention and they constructed a structure using very different processes: sequential, cyclical, and hierarchical. This diversity of representation indicates a strong individuality when it comes to intervene, even though the central concepts to master are more or less the same. Figure 1 shows a representation of a mental model (subject #1) as an example. Concepts are contained in boxes, and arrows identify the relationships between them. Its structure is a blend of sequential and hierarchical processes.

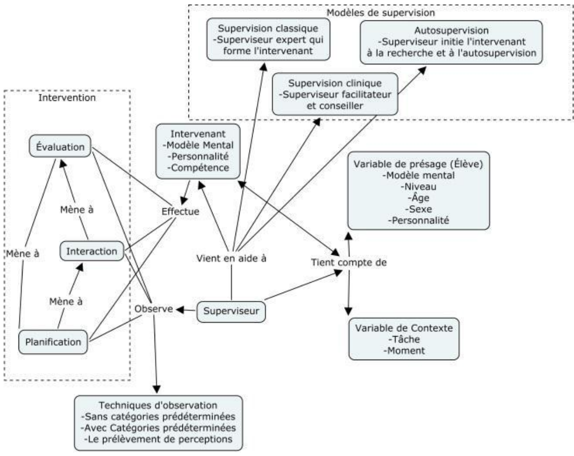

Figure 1. The first representation of the mental model of subject #1

3.1. The progression of content

Table 1 presents the progression along the weeks of the number of concepts that were included in the models. These results do not take into account the first representation that has been done on paper, during the 1st week. This mental model, which was a preconception of the sport supervision process, was in general poorly elaborated and contained a non-significant amount of relevant concepts.

Table 1: Progression of the number of concepts included in the mental models of each students

Week	Students #1	#2	#3	#4	#5	#6
5th	30	71	18	54	45	86
9th	60	101	59	62	51	121
14th	75	132	61	90	55	130
Difference 5th to 9th	+30	+30	+41	+8	+6	+35
Difference 9th to 14th	+15	+31	+2	+28	+4	+9
Difference 5th to 14th	+45	+61	+41	+36	+10	+44

From the 5th week to the 14th week, there was a significant increase (39.5 on average) in the number of concepts contained in the models, for all 6 students. This increase corresponds to the addition of more details and sub categories of existing concepts rather than the addition of whole new concepts. In short, the subjects were revisiting their models, adding more details and precision.

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The increase was more pronounced from the 5th to the 9th week (25 on average), than from the 9th to the 14th week (14.5 on average). This progression is consistent with the common knowledge that a learner will have a tendency to add lesser concepts to his mental model passed a certain point of instruction. This could be explained by his limited capacity of coping with a certain number of concepts [6 Johnson-Laird]. This could also be explained by the natural inclination of beginning by identifying relevant concepts, during the first 9 weeks, then by adding lesser concepts and modifying the structure and the relations between the concepts, during the last 5 weeks.

From the 9th to the 14th week, the subjects added only a small number of relevant concepts to their mental models and they attained a more stable and global conception of the process of sport supervision after around ten weeks of reflection. What was to be changed after that was more subtle.

The total amount of relevant concepts in the last mental model varied from 55 to 132, with an average of 90. This difference is substantial. Three subjects preferred to integrate a limited number of concepts (55, 59, 75) and three subjects chose to integrate more (90, 130,132). This variability in the quantity of concepts is partly explainable by the preference of some subjects to have a mental model that is more global than detailed, and vice versa. One thing is sure; the quality of the mental model cannot be evaluated by the quantity of concepts, once a certain amount of relevant concepts has been integrated. It seems in this case that this amount was around 50 relevant concepts that were identified and communicated by the teacher during the course.

3.2. The nature and type of structure

Several interesting observations can be made on the structure of the models. The first is that once a structure of concepts was chosen, no student changed it radically. Three students selected a hierarchical structure where the concepts are organized in branches that unfold from the center to the outside (for students #1and #6) or from the top to the bottom (for subject #4). Figure 2 presents the last representation of student #1. One can see the progression of content and the evolution of structure from the first representation shown on Figure 1.

The hierarchical structure is particularly useful for separating categories and sub categories of concepts. But it is less suitable for ordering or sequencing concepts. Student #2 and student #5 (Figure 3) used a more sequential structure where the sequence of the operations in the process of sport supervision is emphasized.

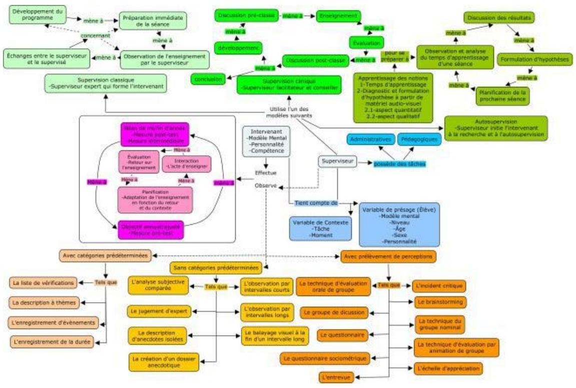

Figure 2. The last treelike representation of the mental model of student #1

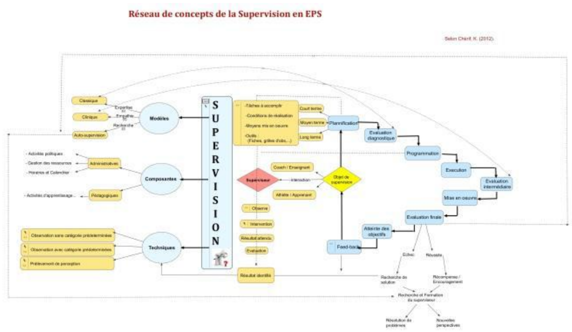

Figure 3. Last sequential representation of the mental model of student # 5

Differently from the understanding of student #4 that was more centred on the distinction between the components of the sport supervision process, regardless of their order, student #5 had an understanding focused on the chronology of the steps to go through in the supervision process. One understanding is not better than the other; they are simply different. These students use different languages to structure their mental models and it has to be recognised and taken into account.

Lastly, student #3 used a cyclical structure (Figure 4) emphasizing several loops of feedback and self-reflection. This structure brings out the importance of going through a process or a cycle many times in order to gain control, mastery or proficiency.

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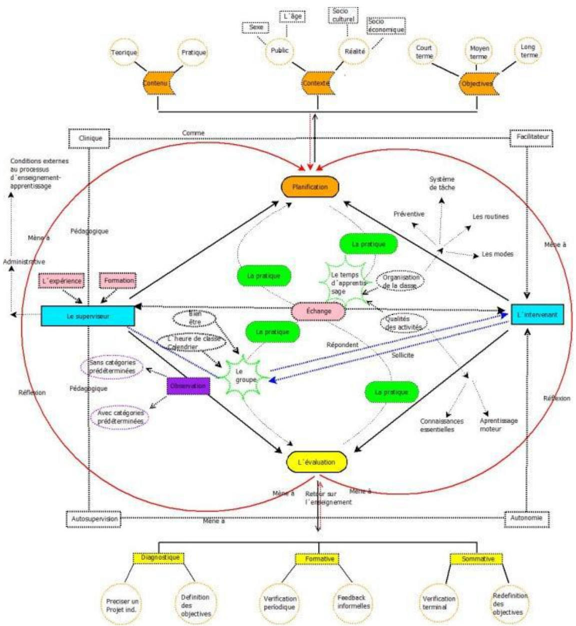

Figure 4. The last cyclical representation of the mental model of student#3

3.3. The evolution of structure

In terms of evolution of the structure of the mental models, all representations progressed significantly during the 14 weeks course. For instance, Figure 5 shows the first representation of student #3, produced during the 5th week.

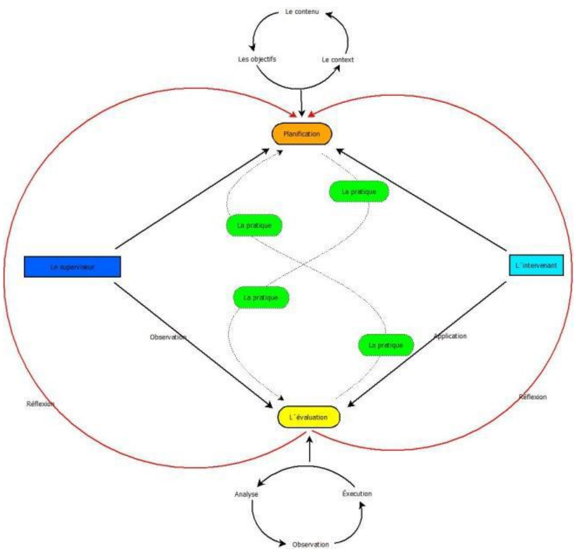

Figure 5. First representation of the mental model of student #3

This first representation presents the circular structure and the main concepts that are fundamental for the student. This «architecture» of the model contains different cycles and loops that will remain, as you can see on the last representation shown on figure 4. The student will modify this structure by adding a sequential part on top that details in three steps the concept of «planification» (planning). She will do the same thing at the bottom by describing the concept «evaluation» in a hierarchical structure of three branches. In the middle of the model, several concepts will complete the loops, detailing the process. The student will also draw a frame where different natures of the sport supervision approaches are identified (clinic, research based, autonomous and facilitated).

Analysis of these two representations reveals a great deal about the thinking process of the student: what she considers essential, what she thinks is complimentary, how she relates concepts. It shows also the evolution of her thoughts and the rapidity of the construction of her understanding of the sport supervision process. Figure 6 shows her second representation, produced during the 9th week.

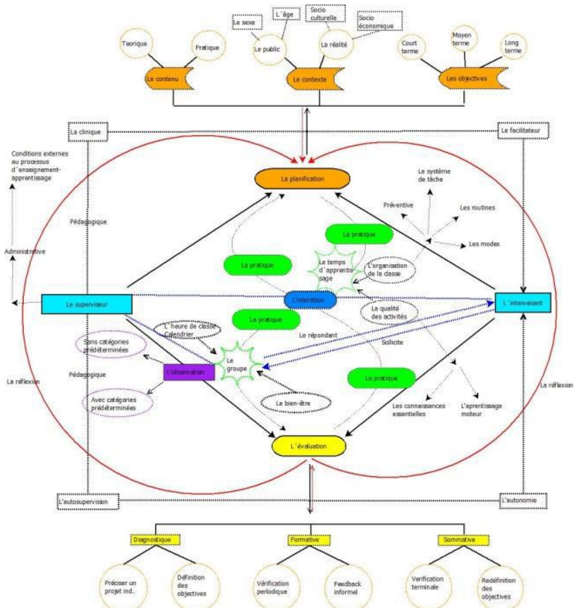

Figure 6. The second representation of the mental model of subject #3

There were a rapid growth of the mental model of subject #3 during the first 9 weeks that lead to the representation shown at figure 6. Far less modification to this representation was made during the last 5 weeks of the semester. When we compare figure 6 to figure 4, we see that subject #3 did not change the structure and only added a small number of concepts to the representation.

This information on the evolution of the mental model is of first importance in order to adapt teaching to the speed and nature of students' understanding. All students do not necessary follow the same pace: some follow a rapid learning curve; others follow a slower but steady curve. For example, unlike subject #3, subjects #2 and #4 continued to add concepts to their representations during the last 5 weeks of the course. Their

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representations showed several differences and additions between the second and the last model (30 more concepts on average). Implications for teaching are numerous. Teachers should respect the student's pace of learning by resisting dictating a uniform pace, usually based on the habit of giving definite information during each class and assuming every student will assimilate it right away and in the same manner.

3.3. The individuality of mental-models

The study of the representations of the mental models of all six students showed a strong individuality in the way the concepts were structured and by the manner that the subjects explained their understanding. Even though the models contain all more or less the same group of relevant concepts, they differ greatly in their structure. This is consistent with studies in cognitive science saying that mental models are strongly linked to the way a person reflects and reasons [7]. For example, Howard Gardner [8], considers the many types of intelligence (linguistic, mathematical, etc.) as different ways of representing knowledge. Symbols and schemas become tools to organize ideas and to communicate them in a very specific and individual way.

The implications in teaching are tremendous. If we want to respect the different ways students represent a reality and explain a phenomenon, we have to use a pedagogy that allows this individuality to be expressed and favours the recognition of specificity of mental models. This is not a simple task for the teacher because he has to accept different representations of a same reality as being equally acceptable. As long as these representations contain the essential concepts referred by theory, are clearly presented and are understandable, they may differ but should be acceptable.

This model-centered pedagogy requires a strong tolerance of ambiguity and uncertainty, from the part of the students and the teacher. The students should accept to evolve in a climate of uncertainty while they construct their own mental model, not knowing «the real truth» and trying to gradually build an understanding of a reality that is complex and ambiguous. They have to refrain from trying to find quick answers to such complexity and they have to adopt an attitude of curiosity and openness to new knowledge. On the other hand, the teacher has to refrain from giving answers to questions that the students are not really asking. They have to avoid to teach the «once and for all truth», from their own perspective, that theories and experiences that their students simply don't have yet. He should rather give a variety of information that suits the different perspectives and experiences of his students, and let them build their own understanding.

4. Conclusion

This case study reveals the efficiency of the use of model-centered instruction, supported by self-organized and guided discovery learning. The students gained a substantial understanding of a complex process of intervention and, above all, they realized the importance of the comprehension of their own representation of this reality.

This model-centered instruction relies on the capacity of students to represent their thoughts using a concept mapping software. The study shows that approximately ten days of adaptation to the software is necessary. The teacher should structure is course to provide sufficient time for presentation of the mental models, at least three times during a semester of 14 weeks. It is also recommended to score this representation process (20% for this case study) on the belief that the recognition of our own mental model is a learning outcome that deserves consideration. The ability of the teacher to use different sources of information for the instruction on the phenomenon or reality to be understood by the students is essential. But it is also crucial that he presents these sources of information through a structured approach using a blend of self-organized and guided learning process. The respect of the individuality of construction of mental model is paramount, but the guiding of students when they need it is also very important [9]. With respect to the construction of mental models, self-organized discovery learning is reasonable only if the learner has previously achieved adequate metacognitive skills to guide the problem-solving process effectively. The learner must have the ability to continuously search for information in the given learning environment in order to complete or stabilize an initial mental model. Graduate students like the ones of this study have probably developed these metacognitive skills during their student's carrier. But it is not necessarily the case for all university students, especially for undergraduate students. Teachers should be aware that students may have problems in this regard and be prepared to react by offering a more guided-discovery learning pedagogy when necessary. This pedagogy can reduce the likelihood that faulty mental models will be constructed in the course of learning. The guidance offered by the teacher took several forms in this study but it mainly consisted of allowing several presentations of the mental models during the course of the semester where the teacher could react and give specific feedback. The presentation of each model in class, by the students, has also a strong effect of guidance because each student could compare his model to other's. This process gives them examples that they can refer to in terms of the number and nature of concepts to include in the model and on the kind of structure that can be used.

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Moreover, the explanation of their mental model that took place during these presentation sessions constituted a strong learning process. Students had to be explicit on their concepts and the structure of their model in order to be understood by the other students. Having to do it orally, in front of the class, is a delicate procedure, but it is very effective. Of course, the fact that these were graduate students that knew each other well and that the group was small facilitated the process. Teachers should not use this kind of oral presentation if they think that the students have not constructed a model that is worth to present.

This study also presents results that are consistent with cognitive theories on learning. It shows that people make sense of a phenomenon by constructing or mapping patterns. This process is dominantly visual and results in schemas made of specific structures and symbols. Thus the mind constructs schematic patterns that represent an understanding of a phenomenon. These patterns are active and evolve as a person comes in contact with new ideas and concepts, listening to lectures, experimenting with new ideas, or sharing thoughts with others.

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