Three cases in using concept maps

Daniel, Forgues, architect, Ph. D.
Professor Construction Engineering
École de technologie supérieure
daniel.forgues@etsmtl.ca

Sylvie Doré, Ing., Ph. D.
Professor, Mechanical Engineering
École de technologie supérieure
sylvie.dore@etsmtl.ca

Abstract

Much of traditional teaching in engineering focuses on procedural learning. However, future engineers will face a rapidly evolving and complex environment that will require reflexive learning and cognitive transfer skills which require a deep learning approach as opposed to surface or even strategic learning. Concept maps are powerful tools that encourage deep learning, expand students’ ability to generate and exchange knowledge. This paper presents three cases in which concept maps were used, first to develop students’ ability to analyse and synthesize information from multiple sources and enhance deep learning, second to facilitate the generation and sharing of collective knowledge.

In the first two cases, students were asked to identify and organize key concepts from formal courses, presentations or texts within concept maps. It was found that students not only improved their ability to assimilate content from these sources, but also demonstrated better skills in analysing and communicating information. It was also found that they were more active in class, asked more questions and answered questions more frequently. In the last case, concept maps were used as boundary objects to mediate interactions and structuring collective knowledge in the design process of a sustainable house. The teaching in this last case was based on a socio-constructivist approach of situated learning, in which the students had to co-develop their understanding of sustainable construction within a design laboratory. Concept maps, used in combination with interactive boards and a knowledge portal proved to be quite effective in accelerating individual and collective learning of a complex topic, while also developing communication and transdisciplinary skills.

The three cases demonstrate the power and value of using concept maps in engineering teaching, both from a cognitivist or a socio-constructivist perspective. Concept maps are powerful tools not only to learn how to learn individually and collectively, it increases students ability to structure their though and exchange knowledge.

1 Introduction

Most of engineering teaching engineering is focused on the acquisition of procedural knowledge aimed at solving well defined problems. However, engineers are more and more required to work in multidisciplinary teams on projects increasingly complex and ambiguous. Ambiguity is characterized as a divergent problem, one that cannot have a definite solution. Therefore, there is a need for a new set of tools, firstly to make sense individually or collectively of these ambiguous or ill-defined problems, secondly to adapt procedural knowledge in a reflexive way, through the use of conditional knowledge in order to explore and agree on potential solutions. This paper explores concept maps as a tool for individual and collective learning.

2 Concept maps as tools for learning

In this section, we explore how concept maps can be used to identify structure and link concepts in a form of graphical representation. We present two cases. They both aim at encouraging deep learning. In the first case, concepts maps were used to encourage acquisition of conceptual and conditional knowledge to guide proper application of procedural knowledge. In the second, maps were helpful in associating theoretical concepts to practical applications.

2.1 Principles

Concept maps are graphs where concepts are represented as nodes connected to one another by one or more arrows which represent relationships between concepts. They are considered as a type of graphical organizer and therefore readily appeal to students who
demonstrate a preference for visual learning style. Through making connections explicit, concept mapping help memorization. It is a means of organizing and simplifying ideas as well as revealing holes in student understanding and knowledge.

2.2 Applications

2.2.1 Case 1

One of the challenges facing engineers is efficiently using a growing number of sophisticated tools and methods. This required not only procedural knowledge on how to use them, but conditional knowledge on when to use a given tool or method as well as its limits. Case 1 concerns a second year undergraduate compulsory course in mechanical engineering. Entitled “Computer assisted engineering”, the goal of this course is to gain theoretical and practical knowledge in the use of numerical methods for solving problems represented by linear and non-linear partial differential equations. Students are thus exposed to finite elements, finite differences and a variety of linearization methods. Each week, students are offered three hours of lecture and exercises during which theory is presented and three hours of laboratory during which they learn MATLAB and ANSYS, a finite element software. Theoretical and practical knowledge are integrated in three mini-projects. An example of a finite element project is to design and dimension a lifting device to extract motors from vehicles.

A second strategy was tried the next semester. Every student was asked to produce and hand in an individual map of the material covered the previous week. This strategy was much more efficient. It achieved the goal of maintaining a constant study pace and more students were able to produce meaningful maps as demonstrated by the quantity of concepts presents in the maps as well as the number and quality of links between the concepts. Four weeks into the course, an informal assessment of how students appreciated the course was conducted. They were asked to write down three items they enjoyed about the course and three items they would like see changed. Out of 54 students, 8 students mentioned that they appreciated the concepts maps, 3 that they didn’t mind either way or 6 that they preferred not having this activity. For the rest of the class, it did not appear to be a major issue. Upon discussion, it became apparent that some students had difficulty drawing the maps, possibly because it did not appeal to their learning style. Furthermore, it was deemed not sufficiently strategic for another group, in the sense that they could not see how it helped them obtain better marks at exams and therefore did not judge it was worth the time spent drawing the map.

The third strategy proved the most effective. Students were given the choice between drawing a map, writing a summary or attending a 10 minute quiz given at the beginning of the lecture, all on the material covered the previous week. The results were quite surprising. Out of 33 students, 24 students handed in concept maps, and 2 wrote summaries. All students attended the 10 minute quiz. However, the 7 students who did neither hand in the maps or summary systematically had the worst results (two of them ended up abandoning the course). There were no more complaints about having to hand in a weekly assignment. Student interaction during lectures was improved both in quantity and quality.

Intrinsic motivation is an essential condition for deep learning [1]. When students have a better sense of control over their learning – for example, by having a choice of learning strategies and selecting the one which corresponds most to their learning style – their motivation increases [2]. Furthermore, sense of
competence was increased for the students who handed in maps or summaries by doing well in the quizzes.

2.2.1 Case 2

Case 2 took place in an intensive Master’s degree course, organized in three two-day sessions that examined new trends in managing construction projects. Each two-day session included themes such as: challenges facing the construction industry, problems with traditional tools and principles of project management, issues related to the construction supply chain, implementation of continuous improvement processes, and emerging approaches for design and construction. The course format included analysis and presentation of seminal texts related to each theme combined with presentations from industry leaders regarding their innovative initiatives. The objective was to develop students’ ability in relating theories and concepts found in the literature with the initiatives presented.

The problems encountered with intensive courses are two-folds: students usually have a full time job with little time to reflect and study; the quantity of information conveyed within a two-day session could be overwhelming. It was observed in the first intensive course that students had difficulty identifying and relating core concepts from articles they read with those contained in the presentations they attended and synthesizing them into a coherent understanding of issues and approaches related to each theme.

Concept mapping was introduced as a tool to develop students’ ability to achieve these tasks. Students first got a special training on free software: IHMC’s CmapTool. They were asked to generate maps individually and then as a team for three purposes: for analysis and summary of core articles (individual); for assembling and synthesizing content at the end of each session (individual); and for producing a team project that was addressing one theme (collective). As part of their assignment, they had to assess and comment maps produced by peers.

Using concept maps proved to have multiple benefits both for the professor and the students and quite effective in this course format. The fact that students had, after each session, to wrap up what they learned in a concept map, increased drastically their attention to presentations in order to capture and structure core concepts. It also provided the professor with a quick means to visualize what students understood and missed. The professor could thus provide feedback and focus on blind spots. A surprise was the power of maps for co-learning. Criticizing peer maps and aggregating individual maps into a collective one proved to be remarkably effective in accelerating team efficiency to understand complex issues and lay out possible solutions. This was the trigger to the idea of using concept maps as mediating artefacts in a context of a design laboratory, the object of the third case.

3 Concept maps as boundary objects for sharing and generating knowledge

Projects are getting more and more complex and ill-defined. Complexity is best addressed through multidisciplinary teams. It also requires from professionals reflexive learning skills for making sense and acting on unfamiliar or ill-defined problems. However, teaching in engineering is still focused in large part on learning procedural methods or formulae to solve well-defined problems. Therefore students in engineering are not prepared to be effective team members in a multidisciplinary team.

Design and multidisciplinary teams are powerful ways for resolving complex problems. An emerging approach is to immerse students in a situated learning context within a design laboratory. Students from different disciplines are provided with tools to realize a design project with a relative complexity within a limited timeframe. They learn not by transfer of knowledge from the professor, but by reflective action, interacting with students from various disciplines.

3.1 Principles behind design laboratory

Design laboratory is based on the concept of situated learning, an emerging learning paradigm built on social learning theories (activity theory and situated action). According to these theories, traditional cognitivist approach for teaching design sciences is no more appropriate to prepare future engineers to cope with increasing complexity and pace of changes in their working environment [3]. What [3] qualifies as the “Established Technical Rationality model”, however, is still the one that prevails in the realm of engineering school.

This model is based on this positivist paradigm: professional knowledge is built on a hierarchy in which “general principles” occupy the highest level and concrete “problem solving” the lowest. According to the model, professionals could successfully apply
the general principles to solve any specific problem. It implies that professionals have a systematic knowledge base that is specialized, firmly rooted, scientific and standardized.

There are numerous issues with this model, both for tackling complex problems and for working in multidisciplinary teams. For one, complexity is not characterized with well-bounded problems but by ambiguity and uncertainty [4]. Ambiguity and uncertainty need to be addressed through conversation and sense-making, not through the linear problem-solving taught in engineering school [3]. Secondly, specialized knowledge is a barrier to innovation within multidisciplinary teams [5], [6]. Thirdly, the technical rationality model functions with the premises that design professionals are the ones who should define the problems of the client for which they work. It is considered as a coercitive approach in which engineers use their professional power to persuade and convince clients [7]. It goes against the need for team members, to collectively embrace problem-solving through individual ownership, continuous shared learning, and more importantly, through empathy. Therefore, engineering students, as opposed to students in other disciplines such as architecture, are ill-prepared for addressing complex design problem in a team environment [8].

One solution proposed by researchers [6] [9], is to introduce new boundary objects to destabilize existing practices and push them to radically explore new ways of achieving the expected outcome [9]. Boundary objects are specific mediating artifacts that help represent, learn about, and transform knowledge to resolve existing contradictions at a given border between two or more disciplinary ‘communities’. They act at three levels to help cross borders between specialists and non-experts within an activity: at a syntactic level, to develop a common grammar; semantic for sharing common understanding and pragmatic, and to break the traditional pattern of power and influence found in the traditional design process [6]. We propose that concept maps could be powerful boundary objects for achieving these goals.

3.2 Applications

The department introduced a new undergraduate course in 2009 on sustainable construction. The class was composed of students from mechanical engineering, construction engineering and architecture. One of the course themes was to use an integrated design process (IDP) to conceive a sustainable construction. The course was based on LEED certification, a sustainability rating system, and organized around themes such as green roofs, energy efficiency, and lifecycle analysis. A design workshop was held at the end of the course to test students understanding of the principles of sustainable design and to introduce them to IDP. It was observed that students in engineering were quite effective at dividing tasks among themselves, but quite inefficient in devising a common and innovative solution to meet sustainable project requirements. They were usually the results of the effort of one committed student, not from the team itself.

The course was redesigned around a team-learning format and conducted within a design laboratory. Each team had to design two sustainable houses, the first focused on Passive Haus high performance energy target, the second on LEED Platinum certification. They were requested to work with new, unfamiliar sets of tools: interactive boards, simulation software, and collaboration software.

The traditional approach in architecture in designing a building is to use sketches as boundary objects to discuss various options in devising a solution and then add features to make the design more sustainable. However, an optimized solution requires that sustainability be central to the design process. Concept maps were used in four ways: 1-as an analysis tool for understanding and mapping basic principles regarding the development of sustainable solutions; 2-as a thinking tool, for devising a conceptual model of the design; 3- as a communication tool that facilitated the development of a shared mental model, and 4- as a validation tool for measuring how well the design responded to the model.

Concept maps proved to be especially effective for crossing syntactic and semantic boundaries. Sharing and combining concept maps drastically accelerated the development of a collective understanding of the problem and its possible solutions. It also helped to cross pragmatic boundaries created by specialized tools such as drawings, that are usually mastered by students with an architectural background but not necessarily by engineering students. Concept maps are owned by the collective, they can be used by every the team member as opposed to specialized tools.

4 Discussion

Future engineers are entering an increasingly complex, ever-changing and turbulent world. New tools and skills are required to address upcoming challenges that they will face. They will not only need tools for
solving, but knowledge on how and when to use them efficiently, and also to make sense of unfamiliar situations and increase their ability cope to collectively exchange or generate new knowledge. Concept maps could be considered as a new generation of tools, not only to help students in developing skills in individual and group reflective learning, but also for professors to effectively identify weak spots in students understanding and mastering of a topic. This paper presented experiments using concept maps for two purposes: as tools for learning and boundary objects to improve teamwork. Findings are based on professors’ observations that were corroborated by open discussion with students.

4.1 Findings: maps as tools for learning

In first two cases, a sharp increase in students’ ability to interpret texts and capture core concepts was observed. Students mentioned that concept maps helped them to better make relationships and synthesize the content of thematic for their individual and team assignments. The professor noted an increase in the overall quality of the work and a deepening of learning.

In team assignments, it was always required that individual maps be produced before a team or collective map. This was done for two purposes: first to develop new abilities to individually achieve critical thinking by mapping different perspectives on problems and solutions and collectively by comparing and reviewing each other’s interpretation of a domain; second to ensure that all the students of the team were making a valuable contribution to the project. Individual maps could be easily assessed to measure individual efforts.

4.2 Findings: maps as boundary objects

Concept maps proved to be quite effective as boundary objects to accelerate the development of a common vocabulary and shared meaning. Students attending collaborative design studio for the first time spend a lot of energy to understand each other’s perspective regarding the expected outcome, the process and tasks to achieve it. Without a mediating tool such as concept maps, it was observed that one or two students usually took the leadership role and took control of the decision-making process, or that the project was divided into components that were split between the team members. Either way they didn’t think and make decisions as a team. In this case, students iterations between mapping and designing proved effective in generating new ideas, deepening procedural knowledge and generating conditional knowledge.

5 Conclusion

Concept maps are very flexible tools. They proved useful for individual as well as collective learning; in a classical lecture setting and within a socio-constructivist situated-learning approach. We recognize the limitations of working with small samples. However, we consider the experiences sufficiently significant to warrant further study for which metrics or instruments should be devised for a more robust research protocol.

References


