Concept Mapping: an Innovative Tool for Curriculum Development

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INTRODUCTION

In the last decennium learning outcomes became a key factor in curriculum development and quality assurance in higher education in Europe causing an increased interest in methodologies for specifying programme outcomes. At the Faculty of Engineering Science, KU Leuven, the ACQA (Academic Competences and Quality Assurance) framework [1] was adopted and implemented. Competence profiles based on ACQA criteria were compiled for all engineering programmes and actively used in curriculum development, quality assurance and accreditation procedures [2].

Despite the proven value of the use of programme outcomes and competence profiles in curriculum development, educational developers at the Faculty of Engineering Science felt a need for additional tools to guide curriculum analysis and design.

At KU Leuven, starting lecturers are invited for educational training by the Educational Development Unit. In these sessions they are asked and coached to design a concept map for their course(s). The concept map is then used for the further definition of course content, course goals, methods and evaluation. In general, both lecturers and trainers are very positive about this use of concept maps at course level. These positive experiences with concept mapping as a tool for course design were inspiring to elaborate these principles to a curriculum level.

In this paper, the focus will be mainly on the use of concept mapping as an organizational tool on the programme level (i.e. level of degree programme). At first, literature concerning the use of concept mapping in engineering or science disciplines will be discussed, as well as literature cases from medical and accounting education. Thereafter, the use of diverse formats of concept mapping at the Faculty of Engineering Science will be described and discussed in the context of educational support in curriculum development.

1 CONCEPT MAPPING?

1.1 What?

Concept mapping is a tool for visualizing interrelationships between concepts in an integrated, hierarchical manner.. A concept map illustrates the dynamic network of these relationships and emphasizes important domains or themes. *Fig. 1* represents a concept map on concept mapping. In higher education concept maps have already been used to organize, plan and display information for complete programmes, modules and topics [3,4,5,6].

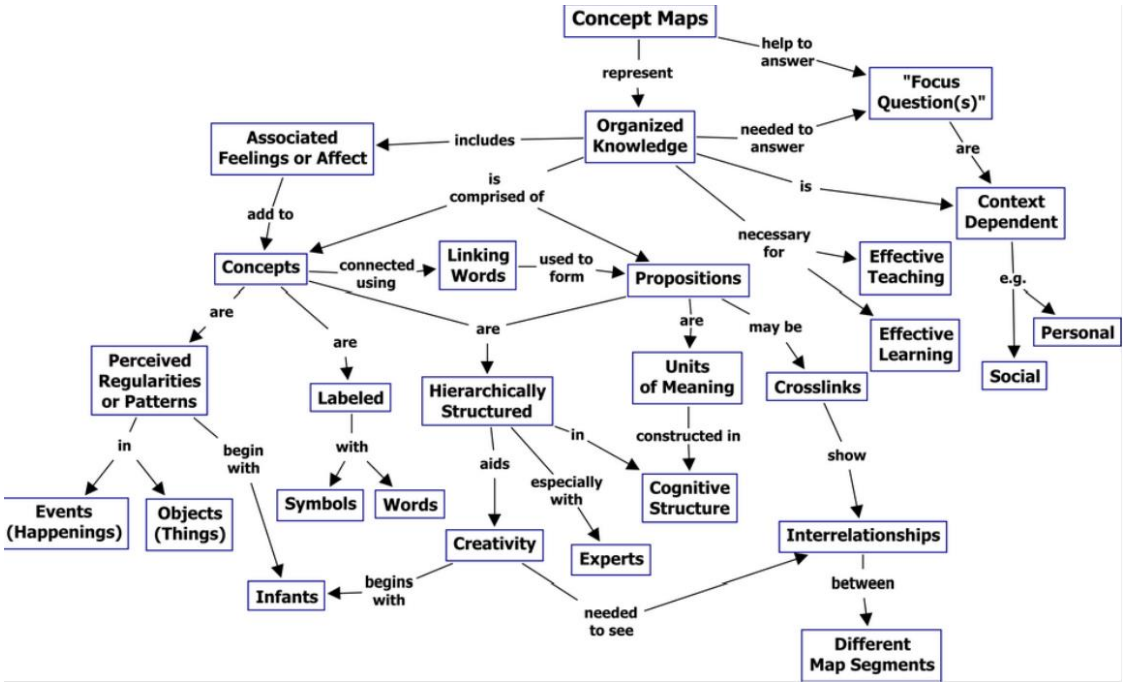

Fig.1: Concept map on concept mapping (www.ihmc.us)

1.2 Why at programme level?

Building and using a concept map representing the entire programme is beneficial for three different stakeholders involved in the programme.

Firstly, providing a concept map of the programme to students is ideal for achieving the perception of the 'big picture' of the curriculum [6]. As Cornwell (1996) describes: "Often students do not understand the purpose of the courses in the freshman year and how they relate to and help advance their desire to be an engineer. They are also typically unfamiliar with the details of the curriculum of their desired major. By giving freshmen this concept map and explaining it to them it is hoped that motivation will be provided for the basic math and science courses taken by these students and it will reduce attrition since the students can see how the material in these courses fits into the entire curriculum and is critical for subsequent courses [7]." In their study Morsi et al. (2007) presented a concept map of the curriculum along with flowcharts to Electronics Engineering students to increase their awareness of curriculum elements in their programme of study. Evaluation results indicated that after this presentation students had a greater understanding of the importance of prerequisites and the importance of taking classes in a specific sequence. Students also felt that understanding how classes are "tied" together will motivate them to perform better in these classes. Students even indicated that a concept map should be presented to all students in a first semester introductory engineering class [6].

Secondly, concept mapping at programme level has also proven to be a helpful tool for curriculum developers. A concept map is a guide for sequencing of topics in the curriculum [8]. As Novak and Gowin already knew (1984): "While curriculum concept maps do not specify the sequence in which topics must be taught, they do highlight a series of 'valid sequences' and provide a useful vehicle to help educators (re)consider the sequencing of topics." [3] The use of concept maps also allows to identify missing linkages, inconsistencies, false assumptions and previously unrecognized relationships [6]. In addition, concept maps provide a useful way of involving relevant stakeholders in curriculum development, such as fellow educators, students, professional bodies and employers [5]. As McDaniel (2005) states: "The curriculum map serves as a framework for communicating the essence of the curriculum at varying levels, for addressing stakeholders' queries, for incorporating new competencies into existing courses, and for designing new academic programs." [9] Moreover concept mapping allows stakeholders with varying backgrounds to share their visions and values and thus promotes working at the conceptual level before starting the detailed planning [10]. Finally a concept map of the programme is useful for curriculum developers to evaluate the entire curriculum and to check its coherence [7].

Thirdly, concept mapping at programme level is a valuable tool for faculty to guide their course design and revision in relation to the bigger picture. The concept map of the programme helps them in determining course prerequisites, sequence and flow [6]. By using mapping themselves as a way to organize overall themes of courses and lessons, faculty can articulate the intended programme outcomes more effectively, they can decide what material needs to be emphasized to scaffold learning and tie assessment plans to the overall structure of the course [9]. When faculty revise courses and lessons, the concept map can reveal which concepts need to be removed and which need additional emphasis [9].

1.3 How?

A standard method for the construction of a concept map involves defining the topic, identifying and listing the most important concepts that are associated with that topic, ordering the concepts from top to bottom in the mapping field, and adding and labelling linking phrases. Once the preliminary map has been built, cross-links are identified and added, and a review of the map for completeness and correctness is performed [4].

Although concept maps are generally represented hierarchically [11], with the most general concepts at the top and more specific concepts arranged below, variations can take the form of chain, spider, network or cyclic formats. Evidently, the concept map format depends on the content and the individual using the tool [9].

2 CONCEPT MAPS AT THE FACULTY OF ENGINEERING SCIENCE

At the Faculty of Engineering Science, concept mapping has been implemented by three different engineering programmes: the Master of Civil Engineering, the Master of Materials Engineering and the Master of Biomedical Engineering. For each programme, the setup of the concept mapping was induced by diverse reasons. *Table 1* gives a short overview of context, setup and results.

Table 1: Implementation of concept mapping at the Faculty of Engineering Science.

Programme	Civil Engineering	Materials Engineering	Biomedical Engineering
Context	Reflection on the curriculum as a whole	Detection of gaps and overlap	Reflection on the interdisciplinary character of the programme
Actors	Programme director Educational developers Lecturers	Programme director Educational developers Core group Lecturers Students	Programme director Educational developers Lecturers
Setup	Two-day conclave Mapping in small groups Discussion in plenum	Iterative meetings core group Assignments for teachers	Half-day meeting Assignments for teachers
Output	Consolidated concept maps Actions points	Quantitative analysis of concepts Overlaps and gaps eliminated	Process supported by all lecturers

2.1 Context

The *Master of Civil Engineering* wanted to critically reflect on the content and structure of their bachelor and master programme as a whole; the replacement of some lecturers was an extra impulse for the reflection exercise. As mentioned above, a concept map of an entire curriculum is useful to evaluate the entire curriculum and to see how all of the courses fit together into a unified and hopefully cohesive whole rather than a collection of unrelated courses [7].

The *Master of Biomedical Engineering* wanted to specifically reflect on the interdisciplinary character and design of their curriculum with engineering and medicine being the two main pillars. Their main goal was to enhance the integration of both disciplines within the curriculum. Hearings with students on feasibility of the programme also pointed out that the use of a wider variety of case studies would be an added value.

The intentions of the *Master of Materials Engineering* were strongly content focused. They wanted to define overlap and gaps within the programme with special attention to the presence and development of sustainability.

2.2 Setup

In the setup of the concept mapping exercises several parameters such as context, (amount of) participants, timeframe and final objectives were taken into account.

Master of Civil Engineering: for the master of Civil Engineering, concept maps were made during a two-day conclave by all key lecturers of the programme. Students were not yet involved. The setup of this two-day programme was well prepared by the programme director and educational developers of the faculty and central educational services. Starting from a broad perspective with a profiling exercise the setup of the two-day conclave gradually worked to a very content focused approach. The first morning lecturers discussed their vision on the substantive focus of the programme, the uniqueness of the programme, the need for specialization or broadening and stakeholders' input on the programme. In the afternoon, main (potential) conceptual branches of the curriculum were defined in plenum, taking into account the discussions of the morning session. In small groups, these branches were developed in concept maps, using post-its on large posters. To support the process some guiding questions were formulated: "Which concepts a graduate engineer should be familiar with? What are the basic, broadening and deepening concepts?" All posters were presented and discussed in plenum with the other participants. To conclude the conclave, the potential impact of the development of all individual branches on the curriculum was discussed.

Master of Biomedical Engineering: recently, the programme reformulated the programme outcomes and composed its competence profile based on the ACQA framework [1,2]. To activate the discussion on the enhancement of the integration of both pillars of the programme, educational developers planned a concept mapping exercise to be executed in a half-day meeting with all key lecturers of the programme. During the planned afternoon, lecturers did not start concept mapping, but decided to discuss themselves the upset of a more tailor made concept mapping exercise. Their discussion was supported by examples of exercises where concept mapping proved to be a useful tool for interdisciplinary curriculum design [9]. Edmondson (1995) for example explains the use of concept maps in redesigning an interdisciplinary veterinary curriculum. Maps were used at several levels, including curriculum, foundation courses, lectures, labs and individual case studies. During the process the faculty reconceptualised the subject matter in a way that avoided redundancy across various fields. They found concept maps to be effective tools for mapping the content in a way that allows faculty from various disciplines to reach consensus on how to design interdisciplinary courses [5]. The afternoon session concluded into the concrete plan to map all crucial concepts for the programme by all lecturers. Another important outcome of the afternoon was to pay special attention to the use of various interdisciplinary case studies within the programme.

Master of Materials Engineering: the concept mapping was part of a series of activities concerning the curriculum. Learning outcomes were reformulated, a curriculum mapping was executed and a competence profile was composed based on the ACQA framework [1,2]. As after all the work done, still some content focused questions were left, the programme decided to develop concept maps. The sequence and setup of all concept mapping activities was determined by a core group of lecturers supported by an educational developer, though the process of developing

the concept maps actively involved all lecturers. At first, lecturers were asked to brainstorm for all relevant concepts students should acquire, both present or absent in the present curriculum. After structuring of the concepts by the core group, all lecturers were asked to rate the concepts for their current presence in the curriculum. For each course of the curriculum, 10 point could be divided over the different concepts. Based on the mapping, total scores were calculated for all concepts. Quantitative analysis and a first interpretation of the map was done by the core group. At all times of the process, also student delegates were asked to actively participate.

2.3 Experiences, results and future plans

Master of Civil Engineering: the setting of a two-day conclave gave all participants a chance to get familiar with the process of concept mapping. The approach of working in small groups of lecturers was well received. Van Neste-Kenny (1998) already described the need of learning participants how to do concept mapping and the importance of working in small groups: too many participants produce too much data for inclusion [10]. Although the conclave had been intensively prepared, participants sensed the activities of the two-day conclave as a natural flow. The use of the post-it based posters supported the subgroups to explain their concept map to the other participants, but also allowed a lot of flexibility in the following discussions as post-its can easily be replaced. The two-day conclave delivered very concrete action points which will be worked on in small task forces. These actions points vary from fine-tuning a specific concept map to critically analysing the content and setup of a specific course. Further discussions on the impact of the individual branches on the entire curriculum are planned in the near future.

Master of Biomedical Engineering: the development of the concept mapping is still in progress. Key lecturers were very pleased with the afternoon meeting. They described the discussion on the setup of the concept mapping to be a significant value to the process. Literature confirms the importance of the understanding of the setup and expertise by the participants to be successful in concept mapping [10]. The approach to complete the concept mapping process in the near future is quite similar to the one described for an interdisciplinary problem-based veterinary curriculum [5] where nested maps were developed in collaboration with all lecturers. In this case, concept mapping was used as a way of developing representations of the entire veterinary curriculum, the planned courses within the curriculum, and case-based exercises within the courses. The process involved four different steps: the production of a series of hierarchical nested maps by a core group; goals and broad conceptual themes derived by all lecturers; refining of the themes and development of concept maps of portions of the curriculum by subcommittees and finally the creation of additional concept maps for particular lecturers, labs and case-based exercises by groups of lecturers. For the Master of Biomedical Engineering the following steps are planned for the near future: listing of concepts for the entire curriculum; refining of the themes and development of concept maps of parts of the curriculum and finally the creation of additional maps for case-based exercises to meet the demand of the students to a wider variety and deeper elaboration of case studies.

Master of Materials Engineering: the quantitative approach of the concept map was well suited for the target group. Although lecturers critically analysed the content of the curriculum, they still felt comfortable. Quantitative analysis is not new in the

development of concept maps. Toral et al. (2007) even describe the use of multivariate statistics (cluster analysis) in the concept mapping process for an Electronic Engineering programme. The fact that a statistical approach avoids that some opinions could prevail against other is a main advantage of the method used [12].

Based on the quantitative analysis, gaps and overlap of conceptual themes were detected and some new conceptual needs within the programme were formulated. Also the weight of certain concepts in the programme has been adapted, e.g. to upgrade the importance of the concept sustainability, a course Sustainable Materials Management has been created.

3 CONCLUSIONS

At the Faculty of Engineering, KU Leuven, a well-balanced variety of support strategies for curriculum development are in use: optimizing learning outcomes using the ACQA framework; curriculum mapping; developing competence profiles and bench marking; fine-tuning of learning paths across the curriculum; aligning learning and evaluation methods. Besides the proven efficacy of these instruments, we believe concept mapping to be a strong instrument as this method fits in very well with the expert-thinking approach of our lecturers. Although, one should be aware that concept mapping will not be the ideal instrument in all cases; a well-balanced consideration of goals, context, stakeholders involved and time frame available will define the choice of an instrument for a specific curriculum development exercise.
The recent experiences at the Faculty of Engineering Science with concept mapping also confirm some findings in literature: it is important for participants to well understand the setup of the concept mapping exercise and to have some expertise or training in concept mapping; working in small groups is seen as positive and the upset should be adapted to the specific demands and characteristics of the group. Creating a solid support base among the participants is crucial to be successful in concept mapping. Involving participants in the design of the mapping and the further monitoring and analysis strengthens their sense of ownership.
Lessons learned from the three case studies described in this paper will be implemented in qualitative scenarios to be developed for the other engineering programmes at the faculty. Concept maps described in this paper are mainly situated at programme level and are executed by (key) lecturers of the programme. In the future, educational developers of the faculty also want to stimulate the use of the concept mapping method at individual course level, executed by individual lecturers. They also believe that the involvement of other stakeholders is crucial for an optimal use of the concept mapping method. Adapted communication strategies on the development, significance and interpretation of concept maps according to the different stakeholders need to be developed.

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REFERENCES

[1] Meijers, A, Van Overveld, C and Perennet, J (2005), Criteria for Academic Bachelor and Master Criteria, Technische Universiteit Eindhoven, Eindhoven.

[2] Londers, E, Berbers, Y, Buyse, MP, De Proft, M and Froyen, L (2011), ACQA: An instrument for accreditation and quality assurance in engineering curricula, Proceedings of the SEFI 2011 Conference, Lissabon.

[3] Novak, JD and Gowin, DB (1984), Learning how to learn, Cambridge University Press, New York.

[4] Canas, A, Coffey, J, Carnot, M, Feltovich, P, Hoffman, R and Feltovich, J (2003), A summary of literature pertaining to the use of concept mapping techniques and technologies for education and performance support, The Institute for Human and Machine Cognition, Retrieved November 18, 2004, from http://www.ihmc.us

[5] Edmondson, KM (1995), Concept mapping for the development of medical curricula, *Journal of Research in Science teaching*, Vol. 32, No. 7, pp. 777-193.

[6] Morsi, R, Ibrahim, W and Illiams, F (2007), Concept maps: Development and validation of engineering curricula, Proceedings of the 37th Annual Frontiers in Education Conference-Global Engineering: Knowledge without Borders, Opportunities without Passports, Anaheim, California, pp. T3H18-T3H23.

[7] Cornwell, PJ (1996), Concept Maps in the Mechanical Engineering Curriculum, Proceedings of the ASEE Annual Conference, Washington DC.

[8] Simon, J (2010), Curriculum changes using concept maps, *Accounting Education*, Vol. 19, No. 3, pp. 301-307.

[9] MCDaniël, E, Roth, B and Millar, M (2005), Concept mapping as a tool for curriculum design, Proceedings of Issues in Informing Science and Information Technology Education Joint Conference, Flagstaff, Arizona, pp. 505-513.

[10] Van Neste-Kenny, J, Cragg, CE and Foulds, B (1998), Using concept maps and visual representations for collaborative curriculum development, *Nurse Educator*, Vol. 23, pp. 21-25.

[11] Novak, JD (1998), Learning, creating and using knowledge: Concept maps as facilitative tools in schools and corporations, Lawrence Erlbaum Associates. Mahweh, New York.

[12] Toral, SL, Martinez-Torres, MR, Barrero, F, Gallardo, S and Duran, MJ (2007). An electronic engineering curriculum design based on concept-mapping techniques, *International Journal of Technology and Design Education*, Vol. 17, No. 3, p.341.