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Using mind maps for the measurement and improvement of learning quality

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Graphic organisers, specifically concept maps, have been used to measure learning quality in higher education. This paper examines the use of an alternate graphic organiser to assess and improve learning quality. Mind maps interactively created within groups of learners, in support of specific constructivist learning practices, are assessed here. Results indicate that the mind map is an appropriate alternative to the concept map for observing constructivist learning within a technical discipline. Further, the practice of collective mind map creation, using an initial spoke structure, positively impacts learning quality within a community of learners.

Key words: graphic organisers, constructivism, engineering.

Introduction

Professional accreditation within electrical and computer engineering may be achieved with reference to requirements specified by either the US-based Institute of Electrical and Electronics Engineers (IEEE), or the UK-based Institution of engineering and Technology (IET). Both bodies emphasise that not only must students acquire a corpus of facts and skills, but that they must also be competent in the real world application of those skills and both bodies recommend the use of constructivist learning practices to enable students to achieve these goals.

> Problem solving and critical thinking skills...are essential to the study of computer engineering.
>
> (IEEE Joint Task Force on Computing Curricula, 2004, p.iv)

> [Graduates should display the] ability to apply and integrate knowledge and understanding of other engineering disciplines to support study of their own engineering discipline.
>
> (IET Degree Accreditation Committee, 2006, p.12)

This paper examines the use of a specific graphic organiser to assess and improve learning quality in an undergraduate electrical and computer engineering programme. Learning quality may be defined as meaningful change in the learners' cognitive model that occurs during exposure to learning practices and curriculum content. Measuring, and improving, learning quality therefore facilitates professional accreditation, within engineering programmes. Firstly, constructivist theories related to three specific constructivist learning practices are reviewed. Next, the ability of graphic organisers to both facilitate these learning practices and allow the observation of learning quality is discussed. This is followed by a brief summary of objective indicators, as reported in the literature, which can be generated from graphic organisers. The context of the investigation and the associated research questions, precede the details of the method used regarding the use of mind maps in the delivery of four offerings of elective final year courses. The paper concludes with a discussion of the findings and the implications for future teaching and learning practice.

Constructivism as the pedagogical basis of learning practices

Constructivism is a theory of learning; the underlying premise is that knowledge cannot be transferred, rather learners must internally construct knowledge and meaning from facts and experiences (Atherton, 2011). Learning practices (and the corresponding constructivist theories of learning) endorsed by both professional engineering bodies include:

peer group/co-operative learning - social constructivism
scaffolding - socio- cultural constructivism
peer-supported resource creation - social constructionism

Social constructivism is a theory which proposes that social interaction is one mechanism that facilitates an individual's internal construction of meaning. Aufschnaiter (2003) observed second year undergraduate physics students co-operatively working on a laboratory task. Three types of dialogue were identified in that context: self-explanation, interaction with others and explanations to others. The work emphasises that the nature of the interaction between peers is less critical than the fact that interaction takes place. Further more meaningful interactions take place when the task and apparatus are familiar.

Socio-cultural constructivism is drawn from the concept of the Zone of Proximal Development as proposed by Vygotsky, which suggests that engaging with tasks that can be accomplished with some (but not too much) help is an effective means of developing the learner's internal cognitive structure. It suggests that students will learn more from interaction with peers who are slightly more competent. It also informs the nature of the teacher-learner interaction, where the teacher provides scaffolding by guiding the learner through the learning process. This is often supported by the use of learning scaffolds, tailored resources such as detailed routines or expert models. Bliss, Askew, and Macrae (1996), in attempting to observe examples of scaffolding in primary school mathematics and science classrooms, noted that facilitator-guided oral interaction associated with scaffolding is not easily implemented, and requires intention in the creation and use of associated scaffolds.

Social constructionism is a theory of learning that states that students learn by individually and collaboratively creating, and reflecting about, artefacts intended for use by their peers. Moguel, Tchounikine and Tricot (2012) describe the collaborative solution of problems by 16-17 years olds learning mathematics and physics using a computer based simulation. Students individually perform experiments using the simulation, and reflect collaboratively on the accumulated result. Moguel et al (2012) identify two non-exclusive approaches to facilitating appropriate interaction during creation of, and reflection upon, peer-supported resources: monitoring with appropriate intervention and scripted activities. Web and computer based tools are particularly useful in organising learners during these processes - allowing users to create digital artefacts and collaborate using synchronous and asynchronous channels, and allowing teachers to intervene where needed. Activities can also be structured using publicly available Web 2.0 services such as Facebook (Hurt, Moss, Larson, Lovelace, & Prevost, 2012). Alternatively, learning management systems support several activities, which can be structured to encourage discourse and interaction within the community of learners (Dougiamas & Taylor, 2001).

While the three constructivist learning practices (co-operative learning, learning scaffolds, and peer-supported resource creation) are advocated by both engineering professional bodies, as with all constructivist practice, they do require additional (often unaccustomed) work by learners, and may not guarantee content coverage. Chang (2008) highlighted concerns, expressed by learners, regarding the degree of learning comprehension and the breadth of information given when exposed to constructivist practices in an undergraduate physics course. Hurt et al. (2012) suggests that effectively addressing these concerns requires appropriate objective indicators of learning. The graphic organiser, as a tool that supports constructivist learning practices, is described next.

Graphic organisers and constructivist learning practice

Graphic organisers are tools and techniques that allow the user to visually depict the organisation of information (Novak & Canas, 2008). Concept maps are hierarchical graph structures including nodes that express concepts, and linking arrows labelled with the relationship between the concepts. Concepts and relationships typically come from a known, finite set. Novak and Canas (2008) in reviewing strategic uses of the concept map, makes the following suggestions for strategically supporting the three constructivist learning practices discussed in this paper:

> *peer group/co-operative learning*
> The concept map can be constructed by students working in couples or small groups (p.18)…The concept map can also be a class effort…where all students…participate in the construction of the map (p.19)
>
> *scaffolding*
> For difficult topics… concept maps serve as a guide or scaffold or aid to learning (p.20)…[with] a series of concept maps in a discipline, starting with the most general, most inclusive ideas (p.22)
>
> *peer-supported resource creation*
> the storing of concept maps [on the server]…encourages collaboration among users constructing the maps…having learners comment on each other's concept maps…is an effective form of peer-review and collaboration (p.16)
>
> Novak and Canas (2008)

The use of these concept map based strategies, in professional and/or academic contexts, has been reported in the literature. Johnson and O'Connor (2008) report on the co-operative construction of concept maps to facilitate team performance of a shared task. Amadieu, van Gog, Paas, Tricot and Marine (2009) report on the use of two different concept map topologies (hierarchical and network) as a learning scaffold for the presentation of technical content to adult learners. Kandiko, Kinchin and Hay (2008) report on the use of the concept map examine transformation over extended interaction between research student and supervisor. Further, the research shows that the effectiveness of concept map based learning strategies is not impacted by learning style (Kostovich, Poradzisz, Wood & O'Brien, 2007), or learner prior knowledge (van Gog, Kester, Nievelstein, Giesbers & Paas, 2009).

The concept map is not the only graphic organiser that can be used to support learning and constructivist learning practice. Davies (2011) specifically identifies argument maps, concept maps, and mind maps as graphic organisers that, while similar, are appropriate for observing different learning quality outcomes.

> **Mind mapping** allows students to imagine and explore associations between concepts; **concept mapping** allows students to understand the relationships between concepts and hence understand those concepts themselves and the domain to which they belong; **argument mapping** allows students to display inferential connections between propositions and contentions, and to evaluate them in terms of validity of argument structure and the soundness of argument premises.
>
> (Davies, 2011, online, *original emphasis*)

Given the topological similarities between the visual representations of the three 'maps', Davies (2011) recommends that an integrated mapping tool should allow the learner to transparently switch between the techniques. Such a tool would facilitate moving between associative, relational and inferential thinking in a constructivist framework.

Novak and Canas's (2008) work with concept-maps demonstrates that graphic organisers, created by learners, can be used not only as tools to support learning, but also to assess the quality of learning. Methods to derive objective indicators of learning from graphic organisers, as reported in the literature, are discussed next.

Objective indicators of learning quality

Assurance of learning quality requires the observation of learner-generated artefacts from which objective indicators of learning can be derived. These objective indicators are either encoded in a rubric used by an expert marker (Hay et al, 2008) or are automatically generated.

An automatic scoring tool should provide a result comparable to that of expert markers (Taricani & Clariana, 2006). In the literature, learner-generated graphic organisers have been used to obtain objective indicators that are consistent with expert marker scores. Methods for obtaining the objective indicators typically follow two complementary approaches: one based on physical structure/layout and another that requires a reference (implicit/explicit) for comparison.

Objective indicators from structure

The topography of a concept map reflects the learner's internal knowledge structure. Hay, Kinchin and Lygo-Baker (2008) identify three typologies (typical topologies) that are found in concept maps: chain (reflective of surface learning and propagated by the sequential use of PowerPoint slides), net (complex and reflective of expertise) and spoke (indicates transition). The relative prevalence of each type of sub-graph can be used as an objective indicator. Topological characteristics of the concept map are also plausible objective indicators: namely the graph depth (average or maximum distance of leaf nodes from centre) and graph degree (average or maximum number of edges incident at any node) of the underlying graph, the algebraic connectivity bound (1/nD) where n is the number of graph nodes, and D is the graph diameter for comparison.

Objective indicators relative to reference

The number of key terms used within the concept map reflects the extent of the learner's knowledge. Link-based correlation scores are shown to be predictors of terminology recall, while distance based correlation scores are better predictors of comprehension. Taricani and Clariana (2006) describe marking manual concept-maps using linkage and spatial distance between key concepts to create matrix 'fingerprints', which are compared to the fingerprints of a reference expert concept map to give a similarity measure (intersection total/union total). Clariana, Koul and Salehi (2006) use the same technique with concept maps automatically generated from essays. In the absence of spatial data, they use the number of terms and links shared with an expert reference map. Hay, Kinchin and Lygo-Baker (2008) describe a method based on structural change (none, rote, meaningful) between initial and final maps of a learner rather than an expert map. Johnson and O'Connor (2008) describe an approach to looking at the similarity between individual maps by counting insertion, deletion, substitution operations required to make the maps identical. These methods can also be applied to mind maps.

Background to the research

The BSc. Electrical and Computer Engineering is a three-year undergraduate engineering programme delivered by the Department of Electrical and Computer Engineering at The University of the West Indies, St. Augustine Campus. The delivery and curricular review of courses within the programme is the responsibility of five themed curriculum groups. The Computer Systems Engineering Group is the curriculum group responsible for the delivery of material related to programming, and embedded systems development; namely three courses, and three modules (within other courses) in the first two mandatory years (nominal cohort size 80), as well as several elective courses (average enrolment 10) in the final year.

The campus learning management system (LMS) is a branded version of Moodle (n.d.), a LMS designed to support social constructionism. The LMS is actively used by members of the curriculum group in the delivery of all courses and modules - particularly in the mandatory courses where it is strategically used to manage larger class sizes e.g. online assignment submission, peer- group discussions.

Professional engineering accreditation requirements necessitate curricular review at five - seven year intervals. The BSc. programme is presently accredited by the IET (IET Degree Accreditation Committee, 2006), however in deference to geographical proximity, the department has made a strategic decision to ensure that the accreditation requirements of IEEE (The Joint Task Force on Computing Curricula, 2004) programmes are also met. The Computer Systems Engineering Group originally utilised concept maps to meet the dual demands during the curriculum review and planning process.

The experience with concept maps in curriculum review led the group to consider utilising graphic organisers as a tool for making change in the learner's cognitive model (i.e. learning) visible. The intent was to provide evidence that students' internal cognitive models were of the desired standard and/or had been impacted by the use of constructivist learning practices.

The first matter for consideration was the type of graphic organiser to be used. Students would need to be introduced to the graphic organiser and would not necessarily be using it in other courses. In addition the skills-based curricula emphasised competence and compliance with concepts, rather than relationships between concepts. Curriculum group members felt that the cognitive load associated with specifying the relationship between concepts was not warranted. Hay, Kinchin and Lygo-Baker (2008) identify the spoke concept map as amenable to observing change reflective of constructivist learning. As no relational links were required, the spoke concept map devolved to the topological equivalent of a mind map; mind-maps were chosen for use. The decision to use mind maps has since been supported by Davies' (2011) observation that mind maps and concept maps can be viewed as different options on a spectrum of graphic organisers.

When collectively generated mind maps were first used to assess learning quality in a final-year elective course, the mind maps had a low degree of associativity between concepts, characteristic of surface learning. Further, the use of hand-drawn mind maps, within the relatively small elective class, required significant facilitator effort to capture and analyse. Based on these observations, an action research project (inspired by Hay, Kinchin and Lygo-Baker (2008)) was conceived.

The intent of the action research project was to identify feasible mind map based strategies to deliver content, create and share resources, and document change in student knowledge about course-related concepts and their associations. Strategies needed to complement constructivist learning practices already used by the curriculum group for delivery. Strategies needed to be scalable, in order to be applied to both elective (class size 10) and mandatory (class size 80) courses delivered by the curriculum group; those strategies that could be integrated with the campus LMS were therefore given preference. Specifically, the curriculum group sought to answer the following questions related to existing learning practices:

A1 How should mind maps be integrated into courses delivered using co-operative learning?

A2 How can learning scaffolds, based on expert mind maps, be leveraged?

A3 What display/analysis features are needed to use peer-supported mind-map resources with the campus LMS?

Methodology

Answering the three questions required that mind maps created by students and experts, and their experiences in creating/using mind maps under different circumstances, be collected, reviewed, assessed and compared. Mind maps were used in four course offerings in differing contexts, as outlined in Table 1. Two different final year elective courses with related subject-areas were the subject of the study: ECNG 3016 - digital electronics and ECNG 3006 - computer engineering.

Table 1. Action research context

Offering	Course	Year/Semester	Mind-map Scribe	Mind-Map Content	Creation Time (Semester)
1st	ECNG3006	2009/10 Sem. I	Facilitator, in response to student prompts	Topic	End
2nd	ECNG3016	2009/10 Sem. II	Student, in response to peer prompts	Course	Middle, end
3rd	ECNG3006	2010/11 Sem. I	Facilitator, in response to student prompts, starting from template	Course	End
4th	ECNG3006	2011/12 Sem. I	Multiple students, starting from template	Course	Middle, end

These courses were offered by the authors between Semester I 2009/10 and Semester I 2011/12. Prior to delivery, staff created expert mind maps. During delivery, students were asked to collectively work on mind maps related to course content in small groups. Feedback was collected once during, and/or at the end of, semester by collective construction of a class or small-group mind map. The way in which mind maps were used to support learning practice was varied in the following manner:

> *peer groups/co-operative learning* One of three strategies was used during feedback: facilitator as scribe (offering 1 and 3); student as scribe (offering 2); multiple students as scribes (offering 4).
>
> *scaffolding* Mind maps were either specific to the topic being discussed (offering 1), or reviewed the entire course to date (offerings 2, 3 & 4). The template mind map (used in the third and fourth offering) was a balanced two-level spoke structure extracted from the centre of an expert map. The template is shown in Figure 1.
>
> *peer-supported resource creation* Mind maps were created by either manual (crayon or marker) or electronic (FreeMind, n.d.) means. The resulting scans, photos and XML-based files were shared by facilitators and students on forums/wikis in the campus LMS.

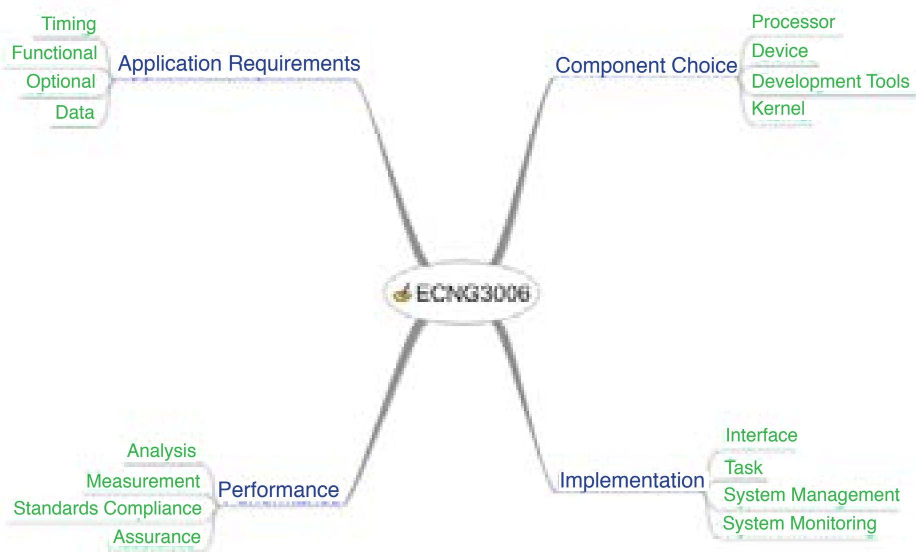

Figure 1. Template mind map

Details for each of the 12 mind maps are shown in Table 2. Although mind maps were created using different paper and electronic media, all mind maps were inputted into FreeMind (n.d.) before analysis to derive objective indicators. Spatial layout, colouring and use of iconic images were retained where possible. A sample mind map derived using the template is shown in Figure 2, and the FreeMind equivalent is shown in Figure 3. The common format was used to prevent human rater bias caused by legibility, or media. In addition the Freemind XML-based format lent itself to automated extraction of objective indicators based on structure, structural change and presence of valid concepts.

Table 2. Mind map media details

ID#	Creation Medium	Creator(s)	Offering	# Colours	Node Format	Creation Time (semester)
1	FreeMind	Group	3rd	2	bubble	end
2	FreeMind	Group	3rd	5	bubble	end
3	WhiteBoard, FreeMind	Class	4th	4	fork	middle
4	Crayon	Group	1st	5	bubble	end
5	Crayon, Post-It	Group	1st	4	bubble	end
6	Marker	Group	3rd	4	fork	end
9	Freemind	Staff	2nd	1	fork	middle
10	WhiteBoard	Class	2nd	1	fork	end
11	FreeMind	Staff	2nd	1	fork	middle
12	FreeMind	Class	2nd	1	fork	middle
13	FreeMind	Staff	2nd	1	fork	end
14	FreeMind	Staff	2nd	1	fork	end

Figure 2. Original whiteboard photo - transcribed using FreeMind (see Figure 1)

Objective indicators were derived from mind maps in three different ways (see Table 3). Firstly, expert raters were asked to produce a score for each mind map using a modified version of the scoresheet from Hay et al. (2008). Scores were averaged across expert raters.

Table 3. Expert rater scores and objective indicators for mind maps

ID#	n	D	degree	chains	spokes	$links_{net}$	depth	%Area	%Term	deg_{avg}	log *conn*	Score
1	106	12	7	9	26	0	6	0.45	0.24	2.00	-3.10	51
2	83	9	8	2	22	0	5	0.45	0.16	2.00	-2.87	49
3	100	10	8	4	21	3	5	0.73	0.31	2.06	-3.00	50
4	42	7	8	1	9	0	4	0.27	0.16	2.00	-2.47	32
5	50	7	7	1	9	0	3	0.64	0.18	2.00	-2.54	22
6	182	15	7	11	58	5	8	0.64	0.45	2.05	-3.44	58
9	261	15	10	11	70	0	8	0.52	0.77	2.00	-3.59	45
10	89	11	10	4	23	0	6	0.52	0.31	2.00	-2.99	38
11	106	12	6	2	32	9	7	0.52	0.41	2.17	-3.10	51
12	47	9	9	2	14	0	6	0.48	0.18	2.00	-2.63	39
13	163	12	8	10	48	12	7	0.67	0.70	2.15	-3.29	46
14	305	14	10	12	69	17	8	0.57	0.90	2.11	-3.63	47

Secondly, the number of valid concepts (terms) appearing in the mind map were counted and expressed as a percentage of valid concepts (terms) appearing in the reference %Area (%Term). For the reference, concepts were extracted by counting terms in the respective course outline(s) and sections from the curriculum documents (IET, 2004). Thirdly, for structural marking, the following statistics were collected for each mind map: number of graph nodes (n), graph diameter (D), maximum degree of graph nodes, number of chain subgraphs, number of spoke nodes, number of extra network links (reflective of network structures), and maximum graph depth. In addition the logarithm of the algebraic connectivity bound (log conn), and average graph degree (degavg) were calculated from the statistics.

In addition to the objective indicators, reflections from facilitators, and student feedback dialogue were reviewed for anecdotal evidence of impact of the technique and student concerns re: workload. Extracts from those items appear in Figure 3.

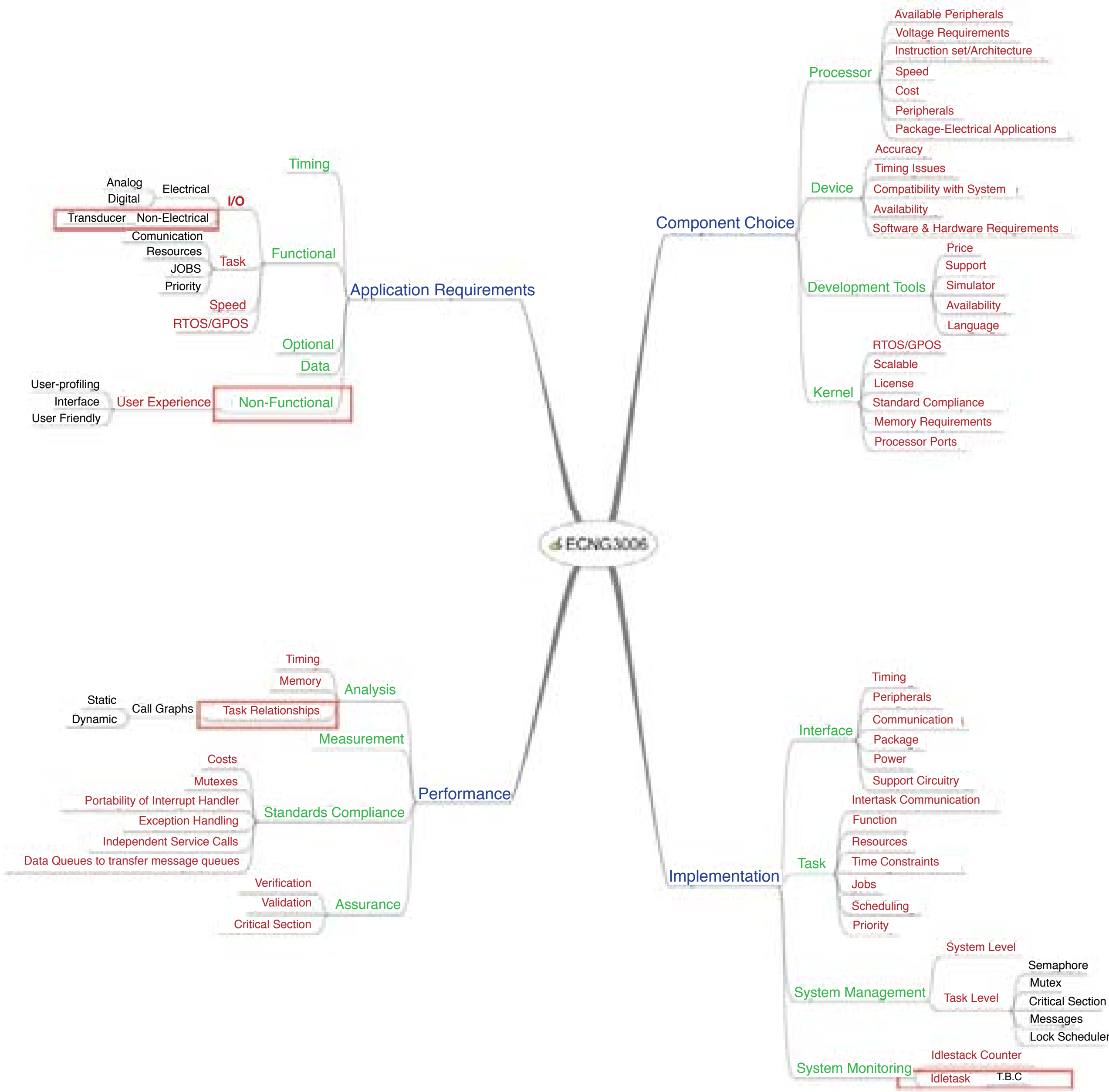

Figure 3. Student-created mind-map - transcribed from photo in Figure 2

Discussion and analysis

Mindmap vs. concept map

An underlying assumption in this action research was that the use of mind maps (as opposed to concept maps) would allow for observation of learning. In the second and fourth offerings, mind maps were examined for structural change from middle to the end of delivery. In both cases, the mind map generated at the end outperforms the map drawn at the middle of delivery in most indicators.

This demonstrates that mind maps can be used to observe change in learner cognitive models as a result of learning practice, consistent with concept map usage by Hay, Kinchin, and Lygo-Baker (2008), and as subsequently predicted by Davies (2011).

Research question A1

The first question considered the most appropriate means to integrate mind maps into the delivery of a course structured for co-operative learning. The course mind maps from the second, third and fourth offerings consistently outperform those from the first offering across indicators. This finding reflects the change in strategy - fully integrated course mind maps were used throughout the course, rather than single topic maps - and is consistent with Novak and Canas (2008).

Similarly, the middle mind map from the fourth offering outperforms the end mind maps from the third offering in some indicators. This reflects greater integration of material produced from a single class map, produced by multiple student scribes, rather than a facilitator scribe. This outcome is consistent with social constructionism theory, in that the students, in interacting with each other to produce the item, thought more deeply about the relations between concepts (see Figure 4 - "if it's overlapping what do we do") earlier in the course offering (middle rather than end). In this case, the student was exhibiting readiness to transition to concept-maps as suggested by Davies (2011).

The findings suggest that in this context, collective construction of a class course mind map by multiple learner scribes is most appropriate to support peer group/co-operative learning.

Research question A2

The second question that was asked was how to leverage scaffolds based on expert maps. In the first and second offerings, students were asked to draw mind maps which were then compared with each other, and with full expert mind maps to identify differences. Repeating the mind map after this exercise did result in improvement, but led to frustration on the part of the students. In the third and fourth offerings, students were given starter template mind maps (derived from an expert map as suggested by Novak & Canas, 2008), which were used to ground in-class discussion. The improvement in the third offering (sustained in the fourth) indicated that the template approach was more effective than referring to the full expert map. It also was a more positive experience for the students, as reflected by the comments regarding initial frustration in the second offering (see Figure 4). This finding, that templates derived from expert maps are more effective scaffolds than use of full expert maps, is consistent with the Zone of Proximal Development.

One unexpected outcome was that the technique impacted the facilitators as well as the students. In creating expert maps prior to delivery, the authors discovered that each had a personal bias towards the course content, and further that some elements of the course outline did not appear in either facilitator's expert map. Re-drawing the expert maps at the end of the course revealed that both facilitator's understanding of the topic had changed, and that the two expert maps have become more similar.

Lecture Transcription for 19-Oct-2011
During construction of group mind-map, after discussion re: issues vs. facts

ECNG3006 2011/12

Student:	"If it's overlapping what do we do?"
Facilitator:	"There will be overlap but that's ok."
	(interruption by another student)
Facilitator:	"There will be overlap but that is ok. That's when we start understanding that you all have been thinking about it - when we start getting a mind-map with criss-cross."
Student:	"Ahh Miss ... if that be the case I understand then."

Critical Incident questionnaire quotes and scores
Two students anonymously reflecting on experience of using mind-map as a cooperative learning tool

ECNG3006 2010/11
"The practical exercise inspired group work and was very interesting" - Score 6
"Well engaged with the mind-map of choosing a processor" - Score 5

Facilitator teaching reflections

ECNG3006 2010/11	"he who hath the pen is extra confident"
ECNG3016 2009/10	"students actually took control of the "pen" and commented that the mind-map could be a useful study aid if annotated with the relevant page numbers. The map they produced showed more depth and structure than the ones of last semester"
ECNG3016 2009/10	"a particular student...who originally has expressed negative feelings, was actually utilizing mind-maps to work on a project...for a competition"

Figure 4. Extracts from lecture transcript, Critical Incident questionnaire, and teaching reflections

Research question A3

The third question that was asked was what display/analysis features would be needed to use peer-supported mind map resources with the campus LMS. In the authors' opinion, a tool, which supports constructivist use of mind maps as explored in this paper, would need to be able to support:

R1 integration with LMS user and grade information
R2 online creation, view, update, and interaction with mind maps
R3 offline creation, view, update, and interaction with mind maps
R4 simultaneous collaborative editing of mind maps
R5 track changed and merged mind maps over time and between individual users
R6 automatic structural analysis, comparison between maps and concept lists
R7 facilitator/peer assessment of mind maps and management of rubrics
R8 linking items in mind maps to related LMS resources
R9 other information submitted by participants using mind maps

Several options for integration of mind maps with the LMS are available. These options fall into four categories: question type, standalone activities, independent files with display filters, and external sites which host mind maps. The authors' preference, based on the comparison of one tool from each category (see Table 4) was for an independent file because this offers the opportunity to use mind maps throughout the site, rather than in a specific activity, and because final year students are already familiar with the processes for uploading and attaching files in the LMS.

Table 4. Comparison of features supported by different options for inclusion of map-type graphic organisers in Moodle LMS

Option	Example	Reference	R1	R2	R3	R4	R5	R6	R7	R8	R9
Question Type	Concept Map	Villalón (n.d.)	Yes	Yes	No	No	No	No	Yes	No	No
Activity	LAMS Lesson	Mindmap Activity (n.d.)	Yes	Yes	No	Yes	?	No	Yes	No	No
File Type	Photo/XML	FreeMind (n.d.)	Yes	?	Yes	?	?	?	Yes	Yes	?
External site	HTML server	OKMindMap (n.d.)	No	Yes	No	Yes	?	No	No	Yes	No

Throughout all course offerings, mind maps have been placed in forum messages, on wiki pages, and as resource links for view/download, by both students and facilitators using either photos, the FreeMind format, or images exported from FreeMind.

Automatic analysis of FreeMind format mind maps was performed in deriving some of the indicators in Table 3. This process highlighted the fact that an automatic assessment tool must be able to cater for synonyms, slang, and spelling errors; each of which required manual intervention during this study. This study examined the inherent assumption of automatic scoring - that all expert rater criteria correlate with automatically extracted indicators. While the data in Table 3 is insufficient to draw meaningful conclusions from an examination of cross-correlation/ANOVA between indicators and expert scores, the relative rankings are consistent across indicators (as observed in examining research question A1). It should be noted that producing some of the indicators might result in undue LMS server workload.

Challenges emerging from the study

One challenge that emerged in this study was the need to discourage students from merely copying an existing mind map. The social constructivist benefits of iterative map creation, as described by Davies (2011) and Hay (2008) will be lost if students merely 'copy' the answers. A tool that supports collaboration in the creation of mind-map resources, should therefore discourage students from using 'cut & paste' as a substitute for engaging in the activity of map construction.

Taricani and Clariana (2006) demonstrated that the spatial layout of mind maps was related to the students' ability to comprehend and recall. In this study, information related to colour and spatial layout, specifically the physical distance between concept nodes, has been sacrificed. The use of an expert template imposes a specific layout structure that is not of the students' own making. Furthermore, the transcription of hand-written maps into FreeMind does not capture the spatial layout of concepts as illustrated in the difference between Figure 1 and Figure 2. These concerns can be addressed by deliberately including spatial information as node/link attributes in FreeMind, as well as by allowing students to re-arrange pre-identified nodes, rather than find nodes to slot into a pre-existing structure.

Opportunities emerging from the study

In addition to potential challenges, there are opportunities for using mind mapping techniques outside of communities of learners, and individual facilitators. During the second offering, two facilitators recognised that individual 'expert' maps could be used to reconcile differences between perceptions of relevant content, and the actual items identified in the course learning outcomes. This function complements the original curriculum determination using concept maps.

Similarly, an individual learner can iteratively construct their own mind map as a reflective exercise (Hay, 2008) as observed with a student who initially resisted using the technique. Johnson and O'Connor (2008) describe combining individual mind maps to extract a shared team mental model. This may be a valid alternate strategy for co-operative learning.

While the students have achieved a particular level of inter-connectedness in their thinking, no consideration was made in this study of their initial mental model(s). In practice, this means that only the sub-graph and interconnectedness of topics introduced within a particular offering should be considered for assessment. An appropriate pruning function should be added to the list of requirements for an appropriate tool that can be integrated with the LMS.

Lastly, graphic organisers may be considered for assessment that affects student grade(s). The use of mind maps as opposed to concept maps in a discipline where the relationship between concepts is key, implies that a separate assessment of the 'correctness' of knowledge would be required.

Conclusion

In this action research study, mind maps created by learners engaged in specific constructivist learning practices have been analysed, both quantitatively and qualitatively, to identify practices that best impacted learning quality. In the initial delivery, the intent was to facilitate sharing amongst the learner community, however the resulting mind maps provided evidence of surface learning. In the second delivery, mind maps were additionally used to document knowledge change. In the third delivery, template mind maps were additionally used as learning scaffolds. The latter seemed to be the best approach and positive outcomes have been replicated (and improved) in a fourth delivery, where the facilitator did not participate in the collaborative mind map creation process.

Results indicate that not only is the mind map technique appropriate for observing learning quality in a technical discipline, but also that the specific practice of collective creation of a course mind map using an initial spoke structure impacts learning quality.

Other notable observations include:

- mind maps can be used as an alternative to content maps in the specified context
- automatically generated indicators are predictive of expert rater scores
- given an initial spoke structure, a community of learners can create expert-comparable mind maps
- map construction was observed stimulating learner transition from associative to relational thought

The work will continue by exploring ways to integrate independent mind map files with the LMS, and subsequently using mind maps via the LMS to support use of constructivist learning practices in larger classes.

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