Using Concept Maps to Teach and Assess Critical Thinking in IS Education

Full papers

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Abstract

Concept maps have been widely used in education as tools for knowledge representation in both teaching and learning. Built on rigorous learning theories, concept mapping is a technique that is easy to learn and use. Therefore, concept map construction tasks can be incorporated into teaching effectively. By analyzing students' concept maps, we can assess their learning and gain insights into their thinking processes, especially the amount and nature of critical thinking involved. In this study, we explored the feasibility and effectiveness of using concept maps in Information Systems education. Different approaches of using concept maps are experimented and discussed with respect of critical thinking. Questionnaires are designed to gauge students' perception of and attitude toward concept mapping. Moreover, we studied the shift of students' opinion on critical thinking before and after interventions including concept mapping. This study sheds lights on effective teaching methods to teach critical thinking using concept maps.

Keywords

Concept Maps, Critical Thinking, IS Education, Assessment.

Introduction

The globalized and hypercompetitive economy demands future workforce to be critical thinkers (Gibson 1995). Critical thinking (CT) can be defined as "reasonable reflective thinking focused on deciding what to believe or do" (Ennis 1993). To think and reason critically, one should have the mindset to judge the credibility of sources, identify conclusions, reasons, and assumptions, and ask appropriate clarifying questions (Ennis 1987). These pose a challenge to educators at various levels across disciplines—how do we teach our students to learn and practice CT effectively? More specifically, we need to focus on how to: (1) Step away from conventional teaching methods that may hinder CT (Pithers and Soden 2000); (2) Explore new approaches to incorporate CT into existing curricula (Ennis 1989); (3) Devise new mechanisms to teach CT (Cooper 1995; McDade 1995); and (4) Explore how to assess the effectiveness of CT teaching and use the results for continuing improvement in teaching subject matter and CT (Angelo 1995; Cross and Angelo 1988).

We have seen many disciplines strive to teach CT, such as Biology (Bailin 2002), Sociology (Rickles et al. 2013), and Nursing (Paul and Heaslip 1995; Peterson and Bechtel 1999; Yildirim and Ozkahraman 2011). CT has been taught using various methods including cooperative learning (Cooper 1995) and case study pedagogy (Kunselman and Johnson 2004; Mukherjee 2004). In these cases, CT transforms student learning from passive consumption of facts and information to deep learning. In addition, the effectiveness of teaching and learning CT is assessed with different approaches (Angelo and Cross 1993; Rickles et al. 2013), such as Bloom's taxonomy of educational objectives, Collegiate Learning Assessment (CLA), and Structure of the Observed Learning Outcomes (SOLO) taxonomy (Ennis 1993). The assessment may focus on either subject matter or CT (Bissell and Lemons 2006).

The ACM & AIS Curriculum Guidelines for Undergraduate Degree Programs in Information Systems (Topi et al. 2010) lists CT as one of the five foundational knowledge and skills. Information Systems (IS) educators have also attempted to improve learning through embedding CT-promoting class activities into teaching, such as using case study (McDade 1995; Thomas 2011), predefined thinking queries (Wang and Wang 2011), and class exercises (Mukherjee 2004). Bloom's taxonomy was also used to redesign certain IS courses with CT in mind (Eddins 2006). However, teaching CT in IS has a different focus from scientific domains. While most scientific studies focus on learning about "what is true?" computing related subjects such as IS often have emphasis on problem solving, i.e., "what are the processes to devise/find the solution (Zendler et al. 2008; Zendler et al. 2011)?" According to (Zendler et al. 2011), there are two equally important categories of concepts in IS. The first are content concepts such as algorithm, computer, and data. The other are process concepts such as problem solving, problem posing, analyzing, and generalizing. The theoretical components of IS focus on the process concepts and the practical components focus on content concepts. In order to become an effective practitioner in the IS domain, one must practice systems thinking with both types of concepts in mind (Checkland 1999).

Concept Maps (CMs) were introduced by Novak (Novak and Gowin 1984) as graphical tool for representing knowledge structure in a form of a graph. In CMs, a concept is usually a word or a short phrase representing perceived regularity or pattern in events or objects, or records of events or objects. Linking words are used to connect two concepts to indicate relationships. Concepts and the links between them form propositions. CMs allow anyone to express their knowledge in a form that is easily understood by others (Cañas et al. 2005). CMs have been used as an effective tool for teaching and learning (Cañas et al. 2004). Compared to other mapping techniques, CMs have solid underlying theories (Novak and Cañas 2008). In his seminal work on *cognitive learning* (Ausubel 1963), Ausubel identified *meaningful learning* as the most important learning principle. Meaningful learning is signified by integrating new concepts and propositions with existing relevant ideas in some substantive ways, within one's cognitive structure. This is an iterative process in which learners must continue to refine, rectify, rearrange, and reorganize the content and structure of their knowledge so that their cognitive structure can be improved. According to (Mayer 2002), meaningful learning occurs when students build the knowledge and cognitive processes needed for successful problem solving. This makes meaningful learning especially important for students in computing related fields in which "solving problems" is always the focus. Meaningful learning requires CT in this iterative refinement process. The fact that constructing CMs involves meaningful learning indicates that CM is an excellent candidate tool for CT. CMs are also valuable tools to represent, visualize, and monitor one's knowledge structure, which facilitate the assessment of learning. There are various types of CM-based tasks, most of which involve stating an explicit "focus question" to define the context and scope of the CMs. A concept map about basics of CMs and how they can be used are explained succinctly in Figure 1, which is partially adopted from (Novak and Cañas 2008).

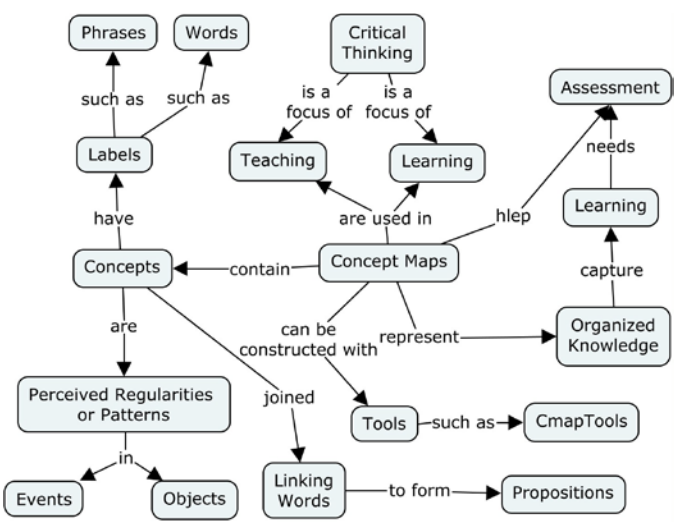


Figure 1 Concept Map about Concept Maps

In this study, we introduce our efforts in utilizing CMs as a tool to teach and assess CT in various courses in the Computer Information Systems (CIS) curriculum at University of Houston-Clear Lake. Series of exploratory studies were carried out and the results were analyzed both qualitatively and quantitatively. We examine the implication of the results and provide insights in terms of how a knowledge representation and visualization tool can facilitate teaching and learning CT in IS curriculum. We believe our findings will benefit IS educators in general, especially those who value CT's role in effective IS education. The rest of the paper is organized as follows. In Related Work, we briefly introduce the underlying theories of our study including CT and CMs, together with prior relevant studies. In section Exploratory Studies, we describe our efforts in teaching and assessing CT using CMs with details. We discuss our major findings and respective implications in Results and Discussion. We then conclude with future research directions.

Related Work

Foundation of Critical Thinking (FCT) is a popular 35 years old non-profit educational organization aiming "to promote essential change in education and society through the cultivation of fair minded critical thinking" (Foundation of Critical Thinking 2016a; Foundation of Critical Thinking 2016b). FCT is the underlying framework of the Applied Critical Thinking (ACT) initiative at University of Houston-Clear Lake. Its model calls for the explicit analysis of thinking using eight *Elements of Thought* (*EoT*): *Purpose, Question at Issue, Information, Interpretation and Inference, Concepts, Assumptions, Implications* and *Consequences, and Point of View* (Paul and Elder 2012; Paul and Elder 2014). Furthermore, FCT promotes the uses of CT standards to gauge the quality of thinking with CT elements. The nine CT *standards* it explicitly advocates are: *Clarity, Accuracy, Precision, Relevance, Depth, Breadth, Logic, Significance, and Fairness*.

Empirical studies by Facione (Facione 2000) suggest that there is no correlation between CT skill and motivation to use CT. Therefore, educators should develop and practice approaches to teach CT, either by explicitly teaching CT as a separate subject, or implicitly teaching CT by immersing it into subject matter. Either way, tools/techniques are needed to convey material, assess and reflect on learning, and visualize the thinking/learning process. In this study, we utilize CMs as a major tool for such purposes. CMs promote meaningful learning by allowing learners to assimilate new concepts and propositions into existing knowledge structure through iterative refined of the CMs. The relative short learning curve of CM makes it possible for the learners to focus more on the thought process. Within the FCT framework, CMs enable us to address and use both EoT and CT standards. To illustrate, CMs make it easier for us to address 'Question at Issue' through focus questions (Novak and Cañas 2008). The flexible structure allows us to incorporate appropriate 'Concepts' from various 'Points of View'. The relationships between concepts can represent 'Assumptions', 'Implications and Consequences', 'Interpretation and Inference', or 'Information'. The efforts on establishing meaningful relationships require the application of CT standards. For example, the relationships have to be 'Relevant'. The label and direction of the relationships have to be 'Clear', 'Precise', 'Accurate', and hopefully with 'Depth'.

As much as CMs are widely adopted in education, their application in computing related domains is rather limited. For example, in (Weideman and Kritzinger 2003), thirteen applications of CMs in education are summarized, none of which is in a domain related to computing. In cases where CMs were used in computing education, the actual focus was not CT. For instance, CMs were adopted to gauge undergraduate students' understanding of content from MIS modules delivered in classroom setting (Gregoriades et al. 2009) in order to test whether significant differences exist between Asian and European student learning styles and outcomes. CMs have also been used to assess students' understanding of IS concepts (Freeman and Urbaczewski 2001). Literature survey has identified the importance of CT in IS domain and we also recognize the value of CMs in supporting CT. Therefore, we propose to introduce CMs as an effective CT tool in IS education. More specifically, the exploratory studies focus on: (1) Various approaches to incorporate CMs into teaching with CT and subject matter in mind, and how to assess their respective effectiveness; (2) Students' perception of, attitude toward, and capability in applying CT and CMs and corresponding implications.

Exploratory Studies

The researchers of this study teach ACT approved courses in the IS curriculum at University of Houston-Clear Lake. We experimented with the teaching and assessment of CT through CMs in four courses. The chosen courses cover two topics—Database Management Systems as the practical component and IS Theories as the theoretical component, at both undergraduate and graduate levels. Several experimental teaching and learning activities were designed and conducted using CMs to either teach or assess CT. Both quantitative and qualitative methods are used to analyze the data collected from the experiments. In this section, we are going to explain our design and present analysis results.

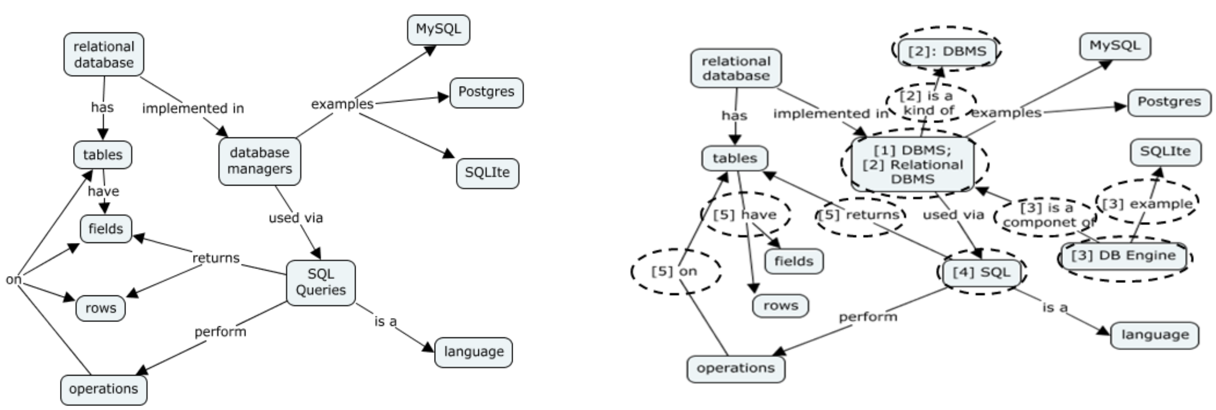
Use Concept Map to Teach Critical Thinking

Effective approaches to teach CT should enable teachers and students to visualize and present the thinking processes. CM is straightforward and fits the requirements to facilitate teaching CT. In our study, CMs are frequently used as a tool to facilitate in-class activities including: (1) Using CMs to organize key knowledge concepts so that students cans see the holistic view of their learning content; (2) Using CMs to demonstrate how EoT and CT standards can be used to iteratively develop and refine knowledge models; (3) Using CMs to guide students' reading and analysis of cases. For the purpose of constructing CMs, we adopted CmapTools (Cañas et al. 2004) developed by Florida Institute for Human and Machine Cognition (IHMC) based on their years of research on knowledge representation. The tool is free for educational use and comes with rich learning materials. We present some examples of our experiments as follows.

Experiment 1. How easy is CM? An important argument of the effectiveness of CMs as a learning tool is its ease of use. To study this, we assigned a classroom quiz asking students to label 10 relationships of a simple CM on subject matter. No prior lecture on CM and very little leading discussion on the subject matter were given. The quiz only contains a brief definition of CM with a small CM sample shown on a similar subject topic. A simple survey was conducted immediately afterward, with 91 responses collected. Only *25.6%* indicated that they have some prior knowledge about CM. On a scale of 1 to 7, with 4 being neutral and 7 denoting strong agreement, respondents agreed with the statement "CM is easy to understand" at a rating of *5.35*. They found the CM quiz to be useful in general at a rating of *5.54*. On average, the students answered the labels of 5.5 relationships correctly. This is reasonably well as the students have very little background on both CM and the subject matter. This experiment provides support on the perceived short learning curve of constructing CMs.

Experiment 2. Apply CT in CMs in Classwork and Classroom Discussion. After a discussion on EoT and CT standards, students were asked to comment on two selected student answers of the CM quiz in Experiment 1. It was then followed by 20 minutes of classroom discussion on iteratively refining the answers with applicable EoT and CT standards illustrated. A survey was conducted, resulting in 70 responses. Again, on a scale of 1 to 7, 4 being neutral, the students found the classwork to be both interesting (at a rating of *6.40*) and useful (*6.20*). They also found the classroom discussion to be interesting (*6.36*) and useful (*6.20*). Their perception on the ease of CM remains largely unchanged (*5.36*) and they viewed CMs as useful (*6.37*). This preliminary result speaks well of CMs as an easy-to-use, interesting, and useful learning tool.

Experiment 3. Integrate CMs in Lectures and Demonstrations. We used CMs in conjunction with CT frequently in our lectures to show how knowledge models are iteratively developed. They may be developed from scratch or from an existing CM. As an illustration, we used a partial CM shown in Figure 2(a), which is adapted from a more complete CM found on the Internet with relational database as the focus. We discussed a number of iterative refinements with the steps and final result shown in Figure 2(b).



(a) **(b)**

Figure 2 Partial CM with DB focus-Before and After CT Refinement

The rationale and the relevant EoT and CT standards discussed in the classroom are summarized in Table 1. The discussion was again followed by a survey to assess students' perception of how useful CMs are in teaching CT. Summary of the survey is as follows—in the format of item surveyed followed by average response on scale from 1 to 7 (n=87): (1) CM is useful in illustrating EoT (*6.01*); (2) CM is useful in illustrating CT standards (*5.80*); (3) CM is useful in illustrating iterative refinement in knowledge modeling

(*6.19*); (4) CM is useful in illustrating relational database concepts as subject matter (*5.91*); (5) CM is easy to understand (*5.91*); (6) CM is useful overall (*6.07*); (7) CM is effective overall (*5.99*). The results indicate that majority students consider CM a useful and easy-to-use tool in helping them understand and apply EoT and CT standards—the two corner stones of our CT teaching efforts, as well as learning the subject matter.

Step	Rationale and notes	EoT	CT Standards
1	"Database managers" may refer to DBMS (software) or Database Administrators (person). Change to DBMS to resolve ambiguity.	Concept Information	Accuracy Precision Clarity
2	The concept "Relational DBMS" is introduced to provide the proper context of the focus question.	Point of View Concept Assumption	Clarity Relevance Precision Fairness
3	DB Engine is distinguished from DBMS to clarify SQLite from other DBMS.	Concept Information Point of View	Clarity Accuracy Precision Depth
4	The concept "SQL Queries" may have several meanings: SQL (which is a language), SQL command (that performs operations), or SQL query (that returns results). The trade-offs for creating three separate concepts are discussed before settling the label to the more inclusive term "SQL".	Concept Purpose Implication	Accuracy Precision Clarity
5	Fix a misconception. Formally, SQL queries return a table.	Concept Information Implication	Accuracy Precision Logic Clarity

Table 1 Applying EoT and CT Standards to Refine CM

These experiments and their preliminary results points to the potential effectiveness of using well-constructed CM classroom activities to teach both CT and subject matters at the same time. Surveys in other CM classroom activities show similar responses. Furthermore, students' perception on the ease of CM is significantly higher after a well-designed iterative CM refinement example (Experiment 3: *5.91*) than after student constructing CM with no prior knowledge in a quiz (Experiment 1: *5.35*). This hints on the efficacy of using CM for demonstrating critical thinking process, which may be further enhanced through well-designed examples.

Use Concept Map to Assess Critical Thinking

Based on our preliminary studies, we are confident about using CMs as an effective tool to teach CT. As follow up, we designed individual assignments to assess student learning of CT and subject matter. The advantage of using CMs for take-home assignment is that it allows students sufficient time to go through the iterative CT process in order to generate CMs of quality. The assignments asked students to construct CMs using CmapTools. In terms of specific methods in constructing CMs, two types of approaches were taken. In both types, a number was given as the minimum number of concepts that the finished CMs must have. The difference is that in Type 1 assignment, students were asked to construct a CM from scratch with a focus question. In Type 2 assignment, given a set of concepts to start with, students were asked to construct a CM. We adopted and modified the CM scoring methods proposed in (McClure and Bell 1990; McClure et al. 1999) to evaluate the quality of students' work. Basically, the instructor created a "master CM", against which student works were compared to obtain Holistic Score, Existential Score, and Relational Score. These three scores were combined in a weighted-manner to compute the overall score. Holistic score was used to assess the overall understanding of the content (i.e., the subject matter) via the lens of CT. For example, the instructor used four CT standards (*Breadth, Depth, Logic, and Relevance*) to judge the overall quality as a whole. Existential score captures the presence or lacking of concepts, weighted by their relative significance in the CMs. Relational score measures the existence and correctness of relationships between concepts, and relationships are also weighted. The overall score is calculated on a 1-10 scale as $Overall = (10 \times {}^{E}/_{E_{max}} + 10 \times {}^{R}/_{R_{max}} + H)/3$, where E and R are the Existential and Relational scores respectively.

E_{max} and R_{max} are calculated using the master map. H is the holistic score on a 1-10 scale. The scoring of CM assignments provided interesting insights in students' capability of applying CT. For Type 1 assignment, students tend to do best in Holistic score and the worst in Relational score, which suggests they may be able to provide a general picture but not adequate details in creating meaningful relationships. Compared to coming up with a set of concepts, connecting those concepts into propositions obviously requires deeper and more challenging CT. In addition, student performance on this assignment positively correlates with their final grades in the course, though weakly (r = *0.37*). However, the correlation becomes moderate between Relational score and the course grade (r = *0.44*). A possible implication of this is that students who are better in applying CT generally perform better than others in this class, where knowing and memorizing facts is not sufficient.

As an example, in a Type 2 CM assignment, undergraduate students were asked to create a CM with focus on "What are the IS-related ethical and social issues?" based on learning content. Students were given 20 concepts to start with and were encouraged to organize all relevant concepts into a CM with minimum 40 concepts. Students were also reminded to apply EoT and CT standards during the creation of the CMs and summarize their CT practice briefly. Prior to this assignment, the nature and amount of CM training received by the students include: (1) About 15 minutes in-class walk-through of what CM is; (2) Some recommended online resources to learn more about CM; (3) A sample CM on a different topic from the instructor. Figure 3 is a partial CM (due to constraint of space) created by a student with total 46 concepts.

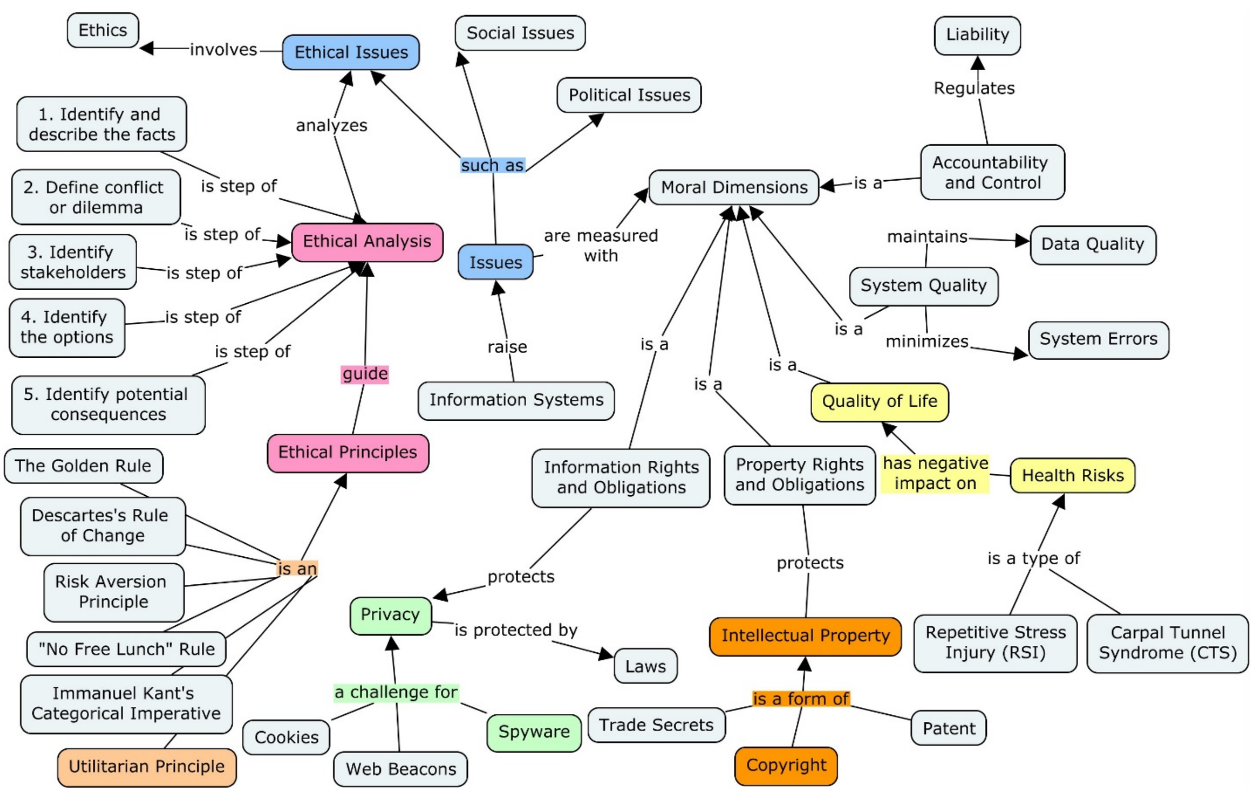


Figure 3 Sample CM by a Student on Ethical and Social Issues with IS

This specific work is a good example of excellent Holistic score in the sense that it offers a very comprehensive coverage of all relevant topics with logic. Multiple EoTs can be identified from the CM, examples of some are discussed as in Table 2 and also highlighted in Figure 3. In addition, the propositions formed in the CM suggest hierarchy, a structure common in good quality CMs (Novak and Cañas 2008). At the leaf node of the hierarchy, instances are used to illustrate or exemplify. For instance, it is suggested that the issues including ethical issues caused by IS usually include 5 moral dimensions. One of the dimensions is Quality of Life, which can be impacted negatively by conditions related to usage of computing devices.

Propositions	Related EoT
"Issues" such as "Ethical issues"	Question at Issue
"Health Risks" has negative impact on "Quality of Life"	Implications and Consequences
"Ethical Principles" guide "Ethical Analysis"	Purpose Concepts
"Utilitarian Principle" is an "Ethical Principles"	Information
"Spyware" (is) a challenge for "Privacy"	Interpretation
"Copyright" is a form of "Intellectual Property"	Concepts

Table 2 Examples of EoT in Sample Student CM

Though some of the relationships can be better labeled, this is a quality work and the student indicated that: (1) Subject matter has to be reviewed thoroughly to get the holistic view of the topic; (2) The class discussion on the topic greatly facilitated her in coming up with the meaningful relationships; (3) Some of the less important concepts/facts are ignored in order to keep the CM cohesive; (4) EoT and CT standards are utilized to guide the thinking process and organize the concepts in the CM.

Results and Discussion

After the exposure to various CM-based activities, students from 3 different classes (n=101) completed a survey on their perception of CM related to CT. 32 items are designed in the survey to measure 6 constructs, each of which has Cronbach's alpha > 0.90 as shown in Table 3. Mean values of each constructs are also given on scale from 1 to 7, with 7 represents Strongly Agree. Distribution of responses to each construct are given in Figure 4. As observed, majority of students consider CM a good tool for CT since constructing CMs makes CT easier and more useful. They also appreciate the value of CMs in improving learning of both CT and subject matter. However, their intention to use CMs is relatively lukewarm. In order to figure out the reason behind relatively low mean on construct "Intend to use CM for CT (*4.36* out of 7), we took a closer look at all survey items and their results. It was discovered that students in general don't intend to use CMs for CT in solving daily problems, which may make sense considering the cognitive burden. The findings also coincide with the study that was previously discussed (Facione 2000). As effective as CMs a tool for CT are, certain intellectual characters need to be cultivated for learners to embrace it. This speaks for the importance of multiple exposures of any tool for students to develop a habit, even if the tool is effective.

Construct	Cronbach's Alpha	Mean
CM makes CT easier	0.9137	5.10
CM makes CT more useful	0.9267	5.19
CM helps to learn CT	0.9322	5.10
CM helps to learn subject matter	0.9300	5.18
Intend to use CM for CT	0.9211	4.36
Intend to use CM for learning	0.9387	4.57

Table 3 CM Survey Results

In addition, among all the students who completed Type2 CM assignments (Students were given a list of concepts to start with), there are significant differences in survey results between the undergraduate (n=28) and graduate (n=19) IS theory classes. In summary, using independent sample and one sided t test, we discovered that graduate students in general think more positively of CMs than undergraduate students. In addition, graduate students are more inclined than undergraduate students to use CMs for CT ($t = 3.749$, $p < 0.001$) and learning of subject matter ($t = 4.371$, $p < 0.001$).

In this study, CMs are just used as a tool to teach CT. The ultimate purpose is to instill CT as a norm, which students will voluntarily apply to learning and other life scenarios. Therefore, it is important for us to understand the changes of their perception of CT after all the intervention. In a CT perception questionnaire, items were designed to investigate whether our efforts in promoting CT through CMs have: (1) Helped students form habit to apply CT; (2) Made students feel CT is easier to do, among others. The items were also implemented in 7-scale Likert-type questions. Students (n = 151) from four classes participated in the experiment. We were able to pool the results because no significant differences were identified between classes.

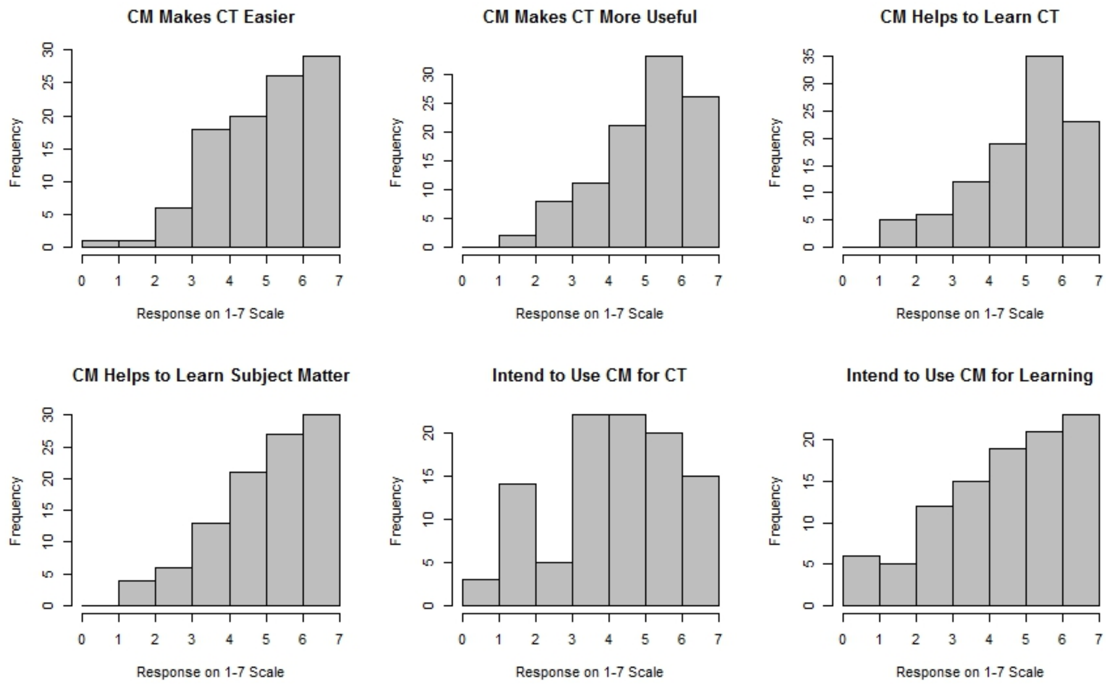


Figure 4 Distribution of Responses to CM Survey by Construct

We conducted pre-test at the very beginning of the semester and a post-test at a later stage of the semester, by then the students have been exposed to many activities designed to promote CT, including using CM. We are interested in finding out if the CT teaching has made a difference in how students perceive CT. One-sided paired t-tests are conducted and with significance level at 0.1. We summarize items that have shown significant differences in Table 4. As the results suggest, being exposed to CT teaching frequently has made an impact on their ways of thinking and problem solving. The fact that they tend to voluntarily utilize CT suggests that they have witnessed the benefits of CT and would like to apply it whenever possible. On the other hand, perceived easiness of learn and use CT has significantly improved thanks to the various resources/tools introduced in CT teaching. The major elements of the resources include EoT, CT standards, and most importantly, CM.

Item	H_0	H_1	t	df	p-value
I have no need to think about applying critical thinking before doing so	$\mu_{pre} \geq \mu_{post}$	$\mu_{pre} < \mu_{post}$	-2.5145	150	<0.01
It makes me feel weird if I do not apply critical thinking	$\mu_{pre} \geq \mu_{post}$	$\mu_{pre} < \mu_{post}$	-1.3477	150	0.0899
It would require effort not to apply critical thinking	$\mu_{pre} \geq \mu_{post}$	$\mu_{pre} < \mu_{post}$	-1.4110	149	0.0802
Critical thinking is easy to learn	$\mu_{pre} \geq \mu_{post}$	$\mu_{pre} < \mu_{post}$	-1.3302	150	0.0927
The resources that help me apply critical thinking are easy to learn	$\mu_{pre} \geq \mu_{post}$	$\mu_{pre} < \mu_{post}$	-2.3687	150	<0.01
The resources that help me apply critical thinking are easy to use	$\mu_{pre} \geq \mu_{post}$	$\mu_{pre} < \mu_{post}$	-1.6453	150	0.0510

Table 4 Hypothesis Testing on Significant Changes in Students' Perception of CT

Conclusion and Future Research

The extreme importance of CT is widely endorsed. Educators at various levels of different domains strive to find effective approaches to cultivate students becoming critical thinkers. In this study, we take advantage of a university-wide initiative to promote CT and weaved CT into conventional teaching of several core requirements in our IS curriculum. CMs are effective in representing knowledge and visualizing thinking. As exploratory study, we utilized CMs as a tool to teach and assess CT. Through various activities, students learned how to construct CMs and started to appreciate its utility in understanding and practicing CT. Well-constructed CM-based quizzes, examples, and activities are found to be cost effective in student learning. Survey results suggest that students consider CMs a useful and accessible tool in CT. In addition, all the CT-promoting teaching changed students' perception of CT—that CT is easy to learn and useful resources have made CT even easier.

This study may be considered as a pilot study that confirms the potential efficacy of applying CMs on teaching CT in IS education. It provides some examples of our experiments on teaching and learning assessment using CMs. Educators in IS may apply similar techniques in their own teaching to promote CT. There are other experiments not reported here because of space, and there are plans for other experiments in the future. We are also working on a systematic framework on how CMs can be best used for varying educational goals in CT. In addition, at University of Houston-Clear Lake, when preliminary results of this study was reported to the university-wide CT initiative, faculty from other disciplines showed great interests and considered it a very useful tool for CT. In the near future, we expect to see wider adoption of CMs in teaching CT at our university.

Acknowledgements

This project is partially supported by UHCL NSF Scholar Program (NSF Grant # 1060039). We thank our students and NSF scholars for their participation and assistance. We also thank the UHCL Quality Enhancement Plan Leadership Team for its support in our investigations on critical thinking.

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